

UNIVERSITY OF BIRMINGHAM

INFRASTRUCTURE SUSTAINABILITY AND RESILIENCE: A FRAMEWORK FOR ASSESSING CRITICAL OIL AND GAS INFRASTRUCTURES

By

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ABSTRACT

Critical energy infrastructures are pivotal to a well-functioning modern society. Their continuous functions are required to meet energy demands of expanding cities and growing population. Oil and gas remain essential for far-future energy needs, although this requires a sustainable and resilient delivery infrastructure system. Downstream critical oil and gas infrastructures systems (DCOGIs) are vital components of this for domestic and industrial end users. Disruptions to their normal functions have wide-ranging socio-economic and environmental implications. Sustainability and resilience are two concepts commonly used in assessing the quality of a variety of systems. There is growing interest across multiple disciplines that these concepts should be integrated when considering complex systems like DCOGIs, and sustainability alone is considered not enough to assess such systems. To date there is no existing framework(s) to adequately assess both sustainability and resilience of DCOGIs specifically. Within the DCOGI industry it exists measures that are at best reactive, yet in need of a practical and holistic sustainability and resilience (hybrid) framework. The study presented here has developed a novel hybrid framework the 'RESOGI' (REsilient and Sustainable Oil and Gas Infrastructure), composed of 7 headline hybrid indicators and 36 sub-hybrid indicators developed for assessing DCOGIs specifically. In the approach presented the RESOGI is developed using findings from an extensive literature review and empirical data, obtained from a survey involving an array of stakeholders including oil and gas industry professionals. The survey responses also facilitated the development of an accompanying criticality table derived for six identified DCOGI, and the development of weightings for the hybrid indicators using a multi-criteria decision analysis methodology. Cyber security and Noise sub-indicators were found to be the least critical to achieving sustainability and resilience in DCOGIs. Security and Redundancy had the highest weightings (w) with $w = 0.35$ and $w = 0.22$ respectively, implying Security and Redundancy as the most critical to achieving sustainability and resilience in DCOGIs. As a proof of the hybrid concept, the RESOGI is employed for two case study DCOGI systems to assess their sustainability and resilience levels. The results demonstrate that the RESOGI is a suitable framework to provide informed decision-making to DCOGI stakeholders and it can assess the sustainability and resilience levels of DCOGI systems.

DEDICATION

This effort is dedicated to my beloved parents Professor and Mrs Etie Ben Akpan for entrusting me with this opportunity and for their unwavering love, support, and encouragement all through my journey of education. To my lovely wife Dr Mrs Ada Dianabasi and my children Jason, Jamian and Jotham who have been part of this journey, for their unique role during the ups and downs. And to the almighty God, for his grace and divine providence.

"Education must enable one to sift and weigh evidence, to discern the true from the false, the real from the unreal and the facts from the fiction. The function of education, therefore, is to teach one to think intensively and to think critically."
[Martin Luther King Jr]

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TABLE OF ACRONYMS

AHP	Analytical Hierarchy Process
BREEAM	Building Research Establishment Environmental Assessment Methodology
CEEQUAL	Civil Engineering Environmental Quality Assessment & Award Scheme
CSR	Corporate Social Responsibilities
DCOGI	Downstream Critical Oil and Gas Infrastructure
ERM	Effective Regulations and Monitoring
FMS	Facilities Management System
GeoSPeAR®	Geotechnical Sustainable Project Appraisal Routine
GPMP	Guiding Policy for Materials Procurement
GPO	Guiding Policy for Operation
HalSTAR	Halcrow Sustainability Toolkit and Range system
MF/PE	Market Forces and Politics Effect
LEED	Leadership in Energy and Environmental Design
SES	Socio-Ecological System
SPeAR®	Sustainable Project Appraisal Routine

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CHAPTER 1: INTRODUCTION

1.1 Background

Sustainability and resilience have been an essential concept in the field of critical infrastructure systems protection owing to various disruptive events and contentious issues (Labaka et al., 2016; Sterling & Nelson, 2013; Hämmerli & Renda, 2010; Boin & McConnell, 2007; De Bruijne, 2006; De Bruijne and Van Eeten, 2007). To appraise the sustainability and resilience of infrastructure systems, industry experts and practitioners, and civil engineers have employed the use of separate evaluation tools and assessment methodologies related to sustainability and / or resilience. There is growing interest across multiple disciplines that the concepts of sustainability and resilience should be integrated when considering complex systems. Currently very few evaluation tools and assessment frameworks are integrative, and none combines sustainability and resilience assessment available for different infrastructure systems. In many respects this ties in with some of the key debates within the literature review where academics argue on the applicability of the concepts and theories of sustainability and resilience, and whether they should be pursued as single or combined entities. In this research the possibility of the latter is explored, an integrated holistic assessment of sustainability and resilience in one framework. Redman (2014); Ahmad et al., (2016); Roostaie et al., (2019), state that although an integrated assessment may be the best way forward, the hybrid approach has merits. However, care needs to be taken, as there are situations where one approach must be prioritized over the other. And therefore, efforts in this regard need to be tailored appropriately, considering the variable and distinct factors of individual infrastructure systems across different industries. Although the global energy industry has seen progress in renewables, hydroelectric and nuclear power in the past decades, currently oil and gas remain the most used fuel in the world (Zhu et al., 2020; Yuan et al., 2020). Oil alone accounts for 34% of the worlds' total energy supply. Gas is increasingly playing a vital role in economic growth and national security, particularly with the generation of electricity. China for example accounts for 37 per cent of global increase in gas consumption in 2017-2023; and is the world's largest gas importer (Zhu et al., 2020; Yuan et al., 2020). And both oil and gas combined accounts for nearly 60% of the world's primary energy (BP, 2019; BP, 2018; Yuan et al., 2020). The

world's transport sector, electricity generation, and the production of petrochemical products e.g., eyeglasses, clothing, lubricants, asphalt etc. remains heavily reliant on oil and gas. The oil and gas industry impact national security, the global economy and politics (Zhu et al., 2020; Inkpen & Moffett, 2011). It is difficult to substitute oil and gas in the short run, and therefore both oil and gas products are important and valuable to the world today. As such, oil and gas continue to be the most reliable and economically viable source for energy that keeps our modern societies and their supporting economies functioning.

Besides the significance of the oil and gas industry, the sustainability and resilience of its downstream critical oil and gas infrastructure (DCOGI) systems is required as it could provide great potential for continuous delivery of economic competitiveness, environmental sustainability, social benefits, and energy security (Chen et al., 2020); albeit the DCOGI sector is reportedly associated with complex and multidisciplinary problems. As such, the recognition of this necessity implies that it is vital to understand sustainability and resilience as it pertains to DCOGI. Whiles several sustainability and resilience assessment frameworks may exist, it is not clear whether the existing assessment frameworks can apply to DCOGIs, as DCOGIs may have characteristics, dimensions and principles that are different from other critical infrastructure systems. As a sustainability and resilience assessment requires a full impact characterization and examination of the long-term viability, the question of what constitutes sustainability and resilience of DCOGIs needs more conceptualisation. Moreover, the literature review (in chapter 2) of recent studies in the field of sustainability and resilience points to a lack of an integrated assessment framework for DCOGI specifically (Yusuf et al., 2013; Lima et al., 2016; Ahmad et al., 2016, Roostaie et al., 2019). For example, the Department for Business Energy and Industry Strategy in the UK lunched a consultation to stakeholders of the UK downstream oil and gas industry in 2017 on improving downstream oil and gas infrastructure resilience measures. The consultation focused on the three areas of monitor, protect and insure (BEIS Report, 2018). However, this falls short of being comprehensive as it concentrates on only 3 areas that may relate to resilience, without considering an integrated holistic approach currently required in the light of increasing disruptions to DCOGI systems (Roostaie et al., 2019). It is this key driver that set the stage for the work presented in this thesis. In that regard, a DCOGI system that can provide continued functional performance under any presented circumstances is vital to achieving energy security, environmental sustainability and economic competitiveness (Ang. et al, 2015). The overarching benefit of this study is to

develop an integrated sustainability and resilience assessment framework for DCOGI available to governments, oil and gas industry, businesses and pretty much every stakeholder to the DCOGI industry.

1.2 Aim

The principal aim of this research is to develop an integrated holistic, easy to use framework for the assessment of sustainability and resilience of downstream critical oil and gas infrastructure systems. The framework is designed to guide a broad array of stakeholders including NGOs, citizens, and interest groups in decision-making that can improve the sustainability and resilience of the DCOGI systems.

1.3 Objectives

1. To conduct a literature review on the concepts of sustainability and resilience, energy security and the significance of DCOGI.
2. To explore existing sustainability and resilience assessment frameworks and metrices, and their relevance, through a literature review.
3. To investigate, as part of the literature review, what factors constitutes the notion of sustainability and resilience in the context of DCOGIs and factors (natural and human vs. internal and external) that impact them.
4. To develop a conceptual integrated sustainability and resilience (hybrid) assessment framework, composed of hybrid indicators for DCOGI.
5. To carry out stakeholder surveys and consolidate the developed hybrid indicators.
6. To derive the significance of the hybrid indicators and their weightings within the hybrid assessment framework, and to identify and document criticality levels of hybrid indicators across a range of DCOGIs.
7. To road test, on case studies, the derived hybrid assessment framework to demonstrate its practicality and benefits.

1.4 Scope and Structure of The Thesis

The outline of the thesis is summarised in table 1.1.

Table 1.1: Structure of the thesis

Chapters	Title	Content
1	Introduction	This chapter presents the background studies relevant to the research area, aims and objectives, scope and structure of the thesis.
2	Literature Review	The chapter fulfils objectives 1, 2 and 3.
3	Methodology	The chapter presents the methodology of the research.
4	Development of Conceptual Assessment Framework of Hybrid Indicators for DCOGI	The chapter fulfils objective 4.
5	Survey	The chapter fulfils objectives 5 and 6.
6	Case Study - Testing the Framework	The chapter fulfils objective 7.
7	Conclusions	This chapter sums up the conclusions of the research.

1.5 Publication

The publication (both journals and conference papers) achieved as a result of the findings obtained during the research work includes the following:

- Akpan D, Jefferson I, Hunt D. (2017). A Conceptual Hybrid Framework for Long-Term Evaluation of Gas and Oil Energy Infrastructure Systems. International Symposia for Next Generation Infrastructure 2017. Conference proceedings pp. 15 – 27.

Planned Publications:
Following completion and submission of thesis, two peered review journal papers are being prepared for publication in the International Journal of Critical Infrastructure Protection. Proposed titles are:

- A Hybrid Framework for Critical Infrastructures: An Empirical Study in Downstream Oil and Gas Infrastructures.
- Criticality Analysis of Indicators for Sustainability and Resilience of Oil and Gas Infrastructures.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter provides a review of the literature related to sustainability and resilience assessment frameworks including their dimensions and common characteristics by implementing the phases shown in table 2.1 and sought to determine their applicability to DCOGI. The chapter then draws upon the fundamental question of if the assessment of both concepts of sustainability and resilience can be combined in an integrated approach given the complex problems associated with critical infrastructure systems, by further examining the synergies that links both concepts. Following this, the chapter then sets out to determine what factors would constitute the hybrid (sustainability & resilience) indicators for the proposed integrated sustainability and resilience assessment framework, through a review of energy security issues and various crisis associated to sustainability and resilience in the DCOGI sector.

Table 2.1: Literature Review Phases

Phases 1	**Phases** 2	**Phases** 3	**Phases** 4
Historic context, concept of sustainability, existing sustainability assessment indicators and frameworks. Page 6 – 25.	Concept and background context of resilience, existing resilience assessment metrics and frameworks. Page 25 – 37.	Nexus of sustainability Science and resilience theory. Page 37 – 41.	Review of energy security issues and other DCOGI industry related crisis. Pg. 41 – 69.
Findings as applicable to DCOGI	Findings as applicable to DCOGI	Findings as applicable to DCOGI	Findings as applicable to DCOGI

2.2 Concept of Sustainability

The Paris Agreement and the United Nations Sustainable Development Goals are the two major initiatives that drive the need to shift towards a more fully sustainable energy system globally (Meng et al., 2020; United Nations, 2019; Fang et al., 2019). Other initiatives like the Kyoto protocol that came into force in February 2005, World Business Council for Sustainable Development, the Global Reporting Initiative and the organization for economic co-operation and development also committed industrialized nations towards the

adoption of sustainability management and practices (Yusuf et al., 2013; www.unfcc.int; Singh et al., 2012). Industrialized nations continue in efforts to stabilize greenhouse gas (GHC) emissions. China for example, as the largest energy consumer worldwide reports to commit to reduce carbon intensity by 45% in 2021 and further increase the efficiency of its energy industry by 2030 (Yuan et al., 2020; Zhou et al., 2019). There are several definitions of sustainability as well as several frameworks, principles, characteristics, and dimensions that describe the concept in the literature. Despite the Brundtland definition of sustainable development, which is development that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987), the concept of sustainability is still being defined differently and variedly applied. Having taken three years to derive, the Brundtland definition attempted to reach a comprehensive understanding of the existing conflicts between global environmental problems (e.g. Pollution from transportation, industrial processing and human waste) and the needs of less developed nations (Parker, 2004). The definition points to not only considering economic viability alone, but also including environmental sustainability and social justice (Elkington, 1998). Other major events that occurred to mark sustainability journey were the agenda 21 at the UN Earth Summit in 1992, which expressed a more complete and connected vision of the main dimensions of sustainability (UNCOD, 1992); in 1995, the World Summit on Social Development in Copenhagen recognized that people should be at the centre of development; the 2002 World Summit on Sustainable Development held in Johannesburg were social and environmental aspect were deepened along with the discussion of the importance of NGOs to sustainable development (UN, 2002); the 2012 Rio submit generated the agenda of reaffirming the commitment to the Millennium Development Goals and signified an important milestone (UN, 2012) full timeline shown in figure 2.1. Further on, the UN's 17 sustainable development goals (SDGs) were proposed as an important compass for social, economic and ecological systems, seeking the well-being of humanity (UN, 2015, 2018).

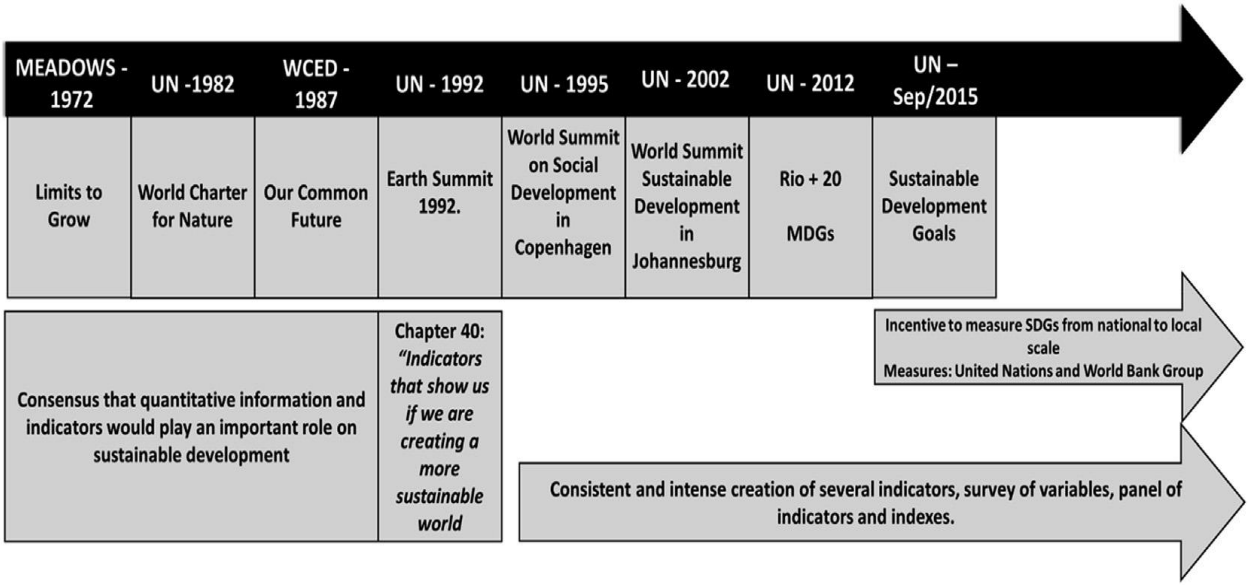


Figure 2.1: Milestones of sustainable development and the evolution of indicators (Eustachio et at. 2019).

The SDGs were developed by working groups in an abstract and intellectual mode relating to their work or practice, rather than by individual leaders or national or regional representatives. Ultimately, SDGs aimed to provide an integrated vision for sustainable development, where member states of UN will adopt the goals jointly (Burford et al., 2016). Eustachio et al. (2019) state that when considering the SDGs in practice, there is still no clear picture of how they could be translated, implemented, or controlled in the context of different industries or countries. Nevertheless, the traditional triple bottom line i.e., economic, social, and environmental shown in figure 2.2 below is still agreed in general.

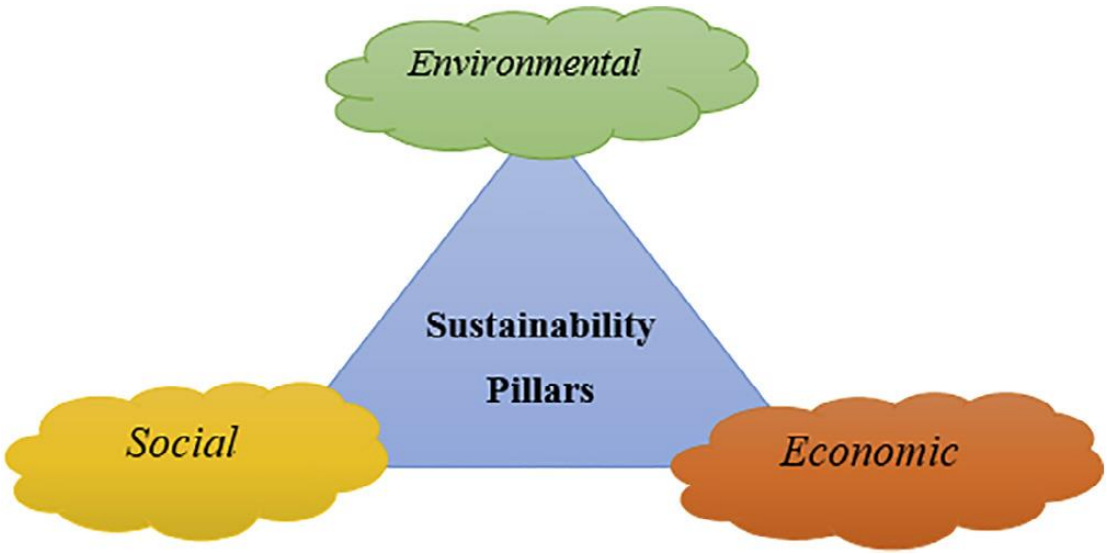


Figure 2.2: Sustainability Dimensions (Saad et al., 2019).

This can be broadly described as follows:

- Social – considers people, skills, health, and broad governance (provision of services, political capacity, law, and justice, political and economic rights of citizens, the right of communities in which resources are located, community culture, socially-conscious corporate governance structures, among others), and the ability facilitating collective actions beneficial to the society (Yusuf et al., 2013; Milward, 2003; Hobbs, 2000).
- Economic – considers employment, income levels, market diversity, tax base, business growth, and internal / external funds, among others. Not limited to economic growth or profitable returns, but also safeguard against environmental and social degradation (Sarkis et al., 2011; Tsai et al., 2009).
- Environmental – pertains to both natural and built environment in the absence of which human cannot exist. Considers air, land, water, food, energy, ecosystem health, facilities, and infrastructure systems, sub-systems, and supporting networks (Yusuf et al., 2013; Goodland, 1995).

Following the evolution of sustainable development, sustainability within a development, industry or organization and research should evaluate the economic, social and environmental pillars of the Triple Bottom Line alongside each other rather than ignoring or preferencing one over another (Wicher et al. 2019; Jefferson et al., 2006, 2007), and possible the other worldview of sustainability in the form of the Sustainable Development Goals to be achieved by 2030 (Opon & Hnery, 2019). Efforts to treat all three dimensions of sustainability with equal importance could be considered an integrative theory of sustainability (Elkington, 1998). Consideration of only one or two components of sustainability without the other two components is deemed inadequate and could bring about negative impact on the two (Parkin et al., 2003; Hunt et al., 2008a; Lombardi et al., 2012), particularly as some aspects of the Triple Bottom Line e.g., environmental stewardship could be easier to quantify making the task of achieving sustainability more difficult. As such, in recent times, there has been the need to move from such fragmented approach to a more holistic, whole systems thinking that account for interrelationships in order to fully address sustainability (Cagno et al., 2019; Trianni et al., 2017; Gimenez et al., 2012). The challenge in seeking and maintaining sustainability lies in the balance between trade-offs among capital and the ultimate risk of exceeding acceptable thresholds for

consumption and degradation, resulting in the possibility of irreversible damage or failure (Botero et al., 2015; Moldan et al., 2012), which is also related to the different decision makers involved (Gong et al., 2018).

An essential part of sustainability is the concept of sustainability assessment, which is continuously recognized as an important pivotal point for decision-making in industries, by government organizations and businesses (Opon et al., 2019; Ameen & Mourshed, 2019; Lee & Hu, 2016; Kates et al., 2001). Assessing and improving sustainability within industries for example, are therefore crucial issues (Howard et al., 2018). The measurement of the actual economic, environmental, and social performance is an essential starting point to understand what, where and how to improve (Wicher et al., 2019; Beske-Janssen et al., 2015). In general sustainability assessment is defined as a "methodology that can help decision makers and policy-makers decide what actions they should take and should not take in an attempt to make society more sustainable" (Sala et al., 2015), this requires understanding and defining the system to be measured, as well as its contributing categories and depends on how sustainable development is conceptualised contextually (Burgass et al., 2017). Ness et al. (2007) states that "the purpose of sustainability assessment is to provide decision-makers with an evaluation of global to local integrated nature-society systems in short- and long-term perspectives in order to assist them to determine which actions should or should not be taken in an attempt to make society sustainable". The definitions stated above does not only highlight the collective efforts required for sustainability assessment, it also implies that sustainability assessment process will vary for different settings and purposes e.g. for different industries, infrastructures, buildings etc. albeit, they could be some transferable similarities. According to Sala et al. (2015), performing a sustainability assessment requires integrating sustainability principles, thresholds, and targets in the evaluation, as well as moving from a mere multidisciplinary to inter and trans disciplinary approaches. Sustainability (or more specifically, sustainable development) can also be viewed as a process, in addition to a normative state, and can require iterative steps of assessment, planning, monitoring, and re-assessment to achieve desired long-term goals linked to system integrity, livelihood sufficiency, opportunity, resource maintenance, and adaptation (Adger & Vincent, 2005; Boyko et al., 2012; Gibson, 2006; Rosales, 2011).

Several sustainability assessment tools and frameworks have been in existence (Wicher et al., 2019; Ness et al., 2007), majority of which are generic e.g. sustainability assessment

tool for evaluating performance of building construction, for civil engineering construction projects, for underground / subsurface utilities etc. but none of them is generally used, and only few existing sustainability assessment tools and frameworks integrate the Triple Bottom Line concept (Sharifi et al., 2021; Wicher et al., 2019; Taticchi et al., 2013; Singh et al., 2012). Existing sustainability tools and framework may not be applicable to DCOGIs; a review of some common ones is presented in the next sections of this thesis that explores their suitability for DCOGIs. However, previous studies suggest there is still no known holistic sustainability assessment framework for DCOGIs (Lima et al., 2016; Yusuf et al., 2013). The DCOGI sector has peculiarities and characteristics, different in other industries (Zhu et al., 2020; Lima et al., 2016;), which could interfere with choice of suitable tools and frameworks to apply to the sustainability assessment. In literature, concerns have been put forward regarding the vagueness of sustainability concept itself, with difficulties defining assessment boundaries and lack of both science-based and policy-based boundaries to define threshold of what contributes to sustainable development or not (EC-JRC, 2012). Nonetheless, as the Triple Bottom Line concept captures the essential elements of sustainability and remains a common authority among evaluation tools, if the absence of a clear perspective on sustainability for DCOGI is confirmed the pillars of sustainability could offer a universal and familiar viewpoint, alongside important features of the sustainable development goals framework as basis for the development of bespoke sustainability assessment framework for DCOGI.

Generally, sustainability assessment tools are either qualitative or quantitative in design, both designs have potential strengths and potential weaknesses. Qualitative tools utilize color-coded charts and figures, and quantitative tools could utilize rating systems or sustainability metrics that are single or multiple criteria based (Basu et al., 2014, Jefferson et al., 2007). Two key methodologies for developing sustainability assessment frameworks are monetary aggregation methods that are mainly used by economists (e.g., natural resource accounting and modelling, sustainable growth modelling) and physical composite indicators that are primarily used by researchers and scientists (Dewan, 2006; Singh et al., 2012). For the purpose of this study sustainability indicators are developed to categorize complex and broad physical and social scientific components into manageable groups of information, which helps a range of stakeholder groups, communicate information for decision-making throughout a DCOGI development process (Jefferson et al., 2007; Holt et al., 2010; Singh et al., 2012; Zargarian et al., 2016).

Increasingly, sustainability indicators are useful tool for policymaking, decision-making and for conveying information on sustainable development performance across multidisciplinary fields of study, countries and industries including infrastructure projects (Singh et al., 2012; Opon & Henry, 2019). Indicators have values that enable ability to summarize, focus and condense complex contextual components into structured amounts of meaningful information by visualizing phenomena and highlighting trends (Godfrey & Todd, 2001; Warhaust, 2002;). The literature states two approaches to sustainability indicators as composite (aggregated) that involves the collective understanding of various indicators at once and could allow for good governance; and detailed indicators that focus on specific problems driven by the commitment to deepen understanding of an issue (Kilkis, 2016). This implies that different stakeholders would seek different indicators depending on their need e.g., scale of application, and their intentions. Indicator development is a fundamental step of an indicator-based sustainability evaluation system as proposed in this study and revolves on the prospect of quantifying and acceptability of the indicators. According to Lundin (2003) & Rametsteiner et al. (2011), sustainability indicators are effective if able to anticipate and assess conditions and trends, provide early warning information to prevent economic, social and environmental damage, formulate strategies and communicate ideas, and support decision-making relevant to sustainable development. The literature constantly highlights the importance that sustainability indicators should communicate efficiently regarding its implementation and adoption, taking into consideration the connections between science, policy, and practice to determine a common understanding of the problems of sustainability contextually. This implies that sustainability could fail, if the communication process of a given indicator is not effective, and the indicator becomes useless. Communication-based indicators make a problem visible, sensitize the decision makers and the public, and expand the basis for decision-making (Janouskova et al., 2018; Eustachio et al., 2019). To this end, it can be stated that the proposal and application of sustainability indicators for this study is necessary and could help DCOGI policymakers and other relevant stakeholders when developing DCOGI systems.

Extant studies on sustainability assessment reveals two main approaches when developing a sustainability assessment framework and selecting sustainability indicators. The top-down approach, were experts and researchers defining the framework and the set of sustainability indicators, also described as an imposition of decisions and actions (Lundin, 2003; Bell &

Morse, 2008). The second is the bottom-up participatory approach where different stakeholders and public opinion are involved in the design of the sustainability assessment framework and sustainability indicators selection process (Lundin, 2003; Opon & Henry, 2019). Other important selection criteria include validity, reliability, comparability, balance between complication and simplicity, data availability, normalizing and weighting, testing of robustness and sensitivity (Singh et al., 2012; ISO 21929-1, 2011). Conceptualisation and operationalisation are two main stages of indicator development to which either approaches typically adheres. Conceptualisation frames what is to be measured by reducing the system into representative priority areas and structuring sub-indicators towards the indicators (Opon & Henry, 2019). As representation of sustainability is difficult to express due to lack of assessment boundaries, the common approach is to individuate sustainability using the triple bottom line to capture the main components for a system (Joung et al., 2012). Operationalisation stage of indicator development covers how to measure the state of a system using indicators and interpreting the meanings of the measurements (Opon & Henry, 2019). These methods can be utilised in this study for conceptualising and operationalising sustainability indicators, for the development of the proposed RESOGI framework. According to Singh et al. (2012), sustainability indicators can be classified and evaluated based on general dimensions of measurement e.g., aspect of sustainability the indicator measures, clarity and simplicity in its content, purpose, method, comparative application, and focus; flexibility in the indicator for allowing change, purpose, method, and comparative application. Indicators are also often based on sub-indicators of which a clear idea is needed of their relevance to the phenomenon to be measured. However, within the literature and in practice it is often argued that use of indicators is too subjective, due to issues of method for including or excluding indicators in a category, normalization scheme, choice of weights and aggregation system; that make the indicator confirmation a formidable task (Saltelli et al., 2008; Singh et al., 2012). Interpretability with indicator sets is also highlighted a key issue, as the complex nature of the interrelationships of indicators could yield conflicting conclusions (Joung et al., 2012). Others argue that a combination of validation, weighting, testing or sensitivity analysis can be used to assess the robustness of the indicator sets (Michael et al., 2014; Opon & Henry, 2019). The literature has continuously highlighted that the evolution of sustainability and indicators require a shift from the traditional scientific view towards a systematic and integrated perspective that enables the understanding of complex systems, this is due to increased awareness of serious consequences of limitations of modern concept of nature from environmental concerns

(Sala et al., 2015; Eustachio et al., 2019). As such, a multi-disciplinary framework with an integrated approach that could call attention to interlinkages in order to achieve sustainability in all dimensions becomes essential (Janouskova et al., 2018). To identify what sustainability assessment frameworks exist for DCOGI, some existing sustainability assessment frameworks are reviewed in the following section.

2.3 Sustainability Frameworks

Sustainability indicators (SI) and decision support tools (DST) have been developed to help with assessing sustainability of various conceptions. In the previous section, indicators were highlighted as the most commonly accepted used for assessing sustainability. The indicators can be interpreted individually or collectively to understand the systemic behaviours. Individual interpretation is useful to get an idea of a specific behaviour. On the other hand, collective analysis summarizes the indicators into a composite value that is easier to communicate such as the Environmental Sustainability Index (ESI) and Environmental Performance Index (EPI), among others (Pakzad and Osmond, 2016; Joung et al., 2013). However, the literature suggests that existing indices and composite indicators are not always utilised due to issues of uncertainty about weights, data normalization, imprecision of data etc. Wicher et al., (2019) & Ozdemir et al., (2011) states that in many disciplines, indicator sets are applied and kept disaggregated, which leads to unsatisfactory, unhandy, and inexpressive results. This has led to the development of normalized and aggregated sustainability assessment approaches e.g., the increasing use of Multi Criteria Decision Methodology (MCDM) for the sustainability performance assessment, which transforms multiple indicator values to a single dimension and can address any possible interaction between different sustainability indicators (Qorri et al., 2018; Wicher et al., 2019; Saad et al., 2019). In the literature, there are many frameworks and tools for sustainability performance assessment. Since the 1990s, many substantial and promising sustainability assessment efforts have been made in different engineering applications such as energy systems, urban planning, building and construction sector, water treatment and mining and mineral industry (Ness et al., 2007; Waas et al., 2014; Singh et al., 2012; Afgan et al., 2000; Afgan and Carvalho, 2008; Begić and Afgan, 2007; Evans et al., 2009; Singh et al., 2016; Pope et al., 2004; Labuschagne et al., 2005; Hacking et al., 2008; Krajnc & Glavic, 2005; Xing et al., 2009; Balkema et al., 2002; Azapagic, 2004; Mateus and Bragança, 2011; Haapio et al., 2008). Despite the efforts, many authors have highlighted the need for further

research around the integrated assessment approaches incorporating the TBL concept and new generation of decision-support tools (Wicher et al., 2019; Reefke and Sundaram, 2017; Beske-Janssen et al., 2015; Taticchi et al., 2015; Morali and Searcy, 2013). In general, the academic productions follow the same trend and necessities for DCOGIs (Lakhal et al., 2007; Yusuf et al., 2013; Lima et al., 2016). Lakhal et al. (2007), Lima et al. (2016) and Wan Ahmed et al. (2016) noted that there is a lack of studies on sustainability in DCOGI industry context. This necessitates the understanding of existing sustainability practices including indicators and metrics adopted in the DCOGI industry, considering that the DCOGI sector is a major contributor to the economy and standard of living. Many of the DCOGI activities also have impacts on the environment and society and would require a comprehensive evaluation of sustainability. As the DCOGI industry sustainability goals may not be stated explicitly, it is argued that DCOGI sustainability issues discussed during materiality studies among stakeholders that are publicly reported by DCOGI companies are valid leads to influence the DCOGI industry priorities and sustainability goals (GRI, 2015). This approach has been adopted in related studies e.g., wan Ahmed et al. (2016) and is considered suitable for this study.

Some sustainability measures used by international oil and gas companies in developing countries e.g., Nigeria, Venezuela, Yemen, Angola, Indonesia, Kazakhstan, Brazil from year 2000 onwards include formulation of local content strategies (Ngoasong, 2014) such as follows:

- ExxonMobil – (Workforce development, strategic community investments, supplier development.)
- Shell – (Capacity development, development of local manufacturing training and support.)
- Chevron – (Preferential selection, capacity development, empowering local competencies, research, and development.)
- BP – (Development of competitive local suppliers, staff capacity development, stakeholder engagement / recognition.)
- Total – (Sustainably enhance local skills, build industrial capacity, stakeholder expectations.)

Out of the 2010 sustainability reports of 12 major oil and gas companies globally (Abu Dhabi National Oil Companies (ADN), Eni (ENI), Hess Corporation (HES), Korean National Oil Corporation (KNO), Mitsubishi Corporation (MIT), Oil & Natural Gas Corporation (ONG), Petroleos Mexicanos (PEM), Petrobras (PET), Rosneft (ROS), Sasol (SAS) and TNK-BP (TNK)) examined by Wan Ahmed et al. (2016), 16 sustainability issues are commonly identified.

There are: Community development; Environmental management; Occupational health and safety; Climate change; Resource efficiency; Transparency; Stakeholder involvement; Employee training and education; Suppliers / contractors management; Air emissions; Energy security; Product responsibility; SHE management systems; Energy transition; Innovations; and Transport safety.

The existing study considers that most of these measures can fit into the social pillar of the sustainability TBL, because they measures are inclined to the organizational microenvironment and some operational issues related to DCOGI sustainability. However, the measures do not address external / macro business environment of the DCOGI industry. The measures are not comprehensive to cover all the pillars of sustainability TBL. Sustainability in supply chains occurs when organizations incorporate explicit and comprehensive economic, environmental, and social goals in the development of their strategic vision and long-term strategic objectives (Carter and Rogers, 2008). Achievement of sustainability goals can be influenced by internal and external environment factors. This underscores the need to identify the factors that can drive or hinder the achievement of the sustainability goals in DCOGIs (explored further from section 2.7 of this chapter), and the need for developing comprehensive measures.

Studies conducted by Lima et al. (2016), which involved an academic review of papers on DCOGI management from year 2000 onwards, reveals contributions on optimization methods (Single MILP formulation), optimization directions (cost minimization and profit maximization), uncertainties (Two-stage stochastic MILP formulation, product demand and market prices), information sharing (Fulfilment of the oil product demand). The study identified gaps in the academic literature, as studies on sustainability and resilience specifically for DCOGIs hardly receive attention. In the UK, Yusuf et al. (2013), reveals

some measures for assessing sustainability adopted by the UK DCOGI industry as, namely: Reducing amount of energy used in the company:

- Waste management e.g., disposal of chemical waste.
- Reduction of amount of resources used e.g., water.
- Sustainable working conditions for staff.
- Sources of raw materials e.g., recycled resources
- Reduction of air pollution.
- And carbon footprint reduction.

While some of the measures are useful and can bring about some positive impacts, the measures generally lack robustness and does not cover all aspects of the traditional triple bottom line for sustainability. The study also reveals that due to the peculiarities in DCOGI industry, a collaborative environment among DCOGIs entities can enhance the operations along entire DCOGIs and improve the overall performance results. Studies by Barbosa-Póvoa (2014) highlights the importance of developing new approaches to enhance the integration among the DCOGI entities. In order to identify if any existing sustainability assessment frameworks can be applicable to DCOGI, the next section presents a synopsis of common sustainability indicators and frameworks that are available. Table 2.2 below shows a summary of sustainability assessment methods that are categorized according to their applicability to project types. There are several assessment tools in the UK ranging from voluntary schemes to public and private sector sustainability toolkits and statutory processes such as sustainability appraisal (Pearce et al., 2012). Most of the tools are either developed with a context in mind which is normally very rigid and consequently, they do not bring much value, or they are too general and do not include all the aspects that are important in any particular perspective. A list of sustainability frameworks for transport and building infrastructure are presented in appendix.

Table 2.2: Sustainability Frameworks

Sustainability Frameworks	Description	Weighting	Result Format
Environmental Geotechnics Indicators (EGI)	A point-based system, EGI comprises a set of 76 generic indicators utilized to evaluate the sustainability of geotechnical project and a set of 32 additional "technology specific" indicators utilized to evaluate the sustainability of specific techniques for treating contaminated land (Jefferson et al., 2007).	Not Weighted	Rose diagram presentation
The "Sustainable Geotechnical Evaluation Model" (S.G.E.M)	A qualitative indicator system that was developed by Jiminez (2004) and is utilized for assessing the sustainability of various material options for slope stabilization.	Not Weighted	Colour code pictorial representation
The Sustainable Project Appraisal Routine (SPeAR®)	Employs a graphic colour coded rose shaped to evaluate a project on account of four principal indicators: social, economic, environmental and natural resources with a subsequent twenty sub-indicators as a sub-text to the principal measures of sustainability (Arup, 2012).	Not Weighted	Circular graph presentation
GeoSPeAR	Substituting 16 indicators from SPeAR with 8 specific geotechnical related indicators. In addition, GeoSPeAR also incorporated the LCA to provide additional data to compliment the colour scale in assessing for sustainability (Holt et al., 2010).	Not Weighted	Circular graph presentation
Halstar	Consist of 840 sub-issues, about 4200 qualitative criteria and 2000 indicators developed for projects. (Pearce et al., 2012)	Can involve assigning of weightings and employment of multi-criteria analysis	Circular graph presentation
Building Research Establishment Environmental Assessment Method (Breeam)	Award based tool, with rating systems for assessing environmental performance of buildings against established benchmarks (Mahmoud et al., 2019).	Weighted	Pass; Good; Very Good; Excellent; Outstanding
LEED	Sustainable sites; Material and resources; Design process; Water efficiency; Energy and atmosphere; Regional priority; Indoor environmental; Quality and Innovation.	Weighted	Certified; Silver; Gold; Platinum
Horizon	Environment; Social and political foundations; Essential needs.	Prioritization with a series of cards	Circular graph presentation
The Civil Engineering Environmental Quality Assessment and Award Scheme (CEEQUAL)	Based on a scoring framework of issues and major design considerations; it has 180 questions related to 12 areas of environmental and social concern (CEEQUAL, 2011).	Weighted	Pass; Good; Very Good; Excellent

2.3.1 Horizon

The Horizon shown in figure 2.3 below has been developed by the Forum for the Future, the Technology Strategy Board and Aviva Investors. Horizon is a continual improvement tool. This Sustainability Framework (SEF) defines a safe environment with social benefits under a sustainable economy (Horizon, 2012). Shown in a circular graph consisting of three layers, the core layer is a sustainable future, the middle layer indicates social and political foundations, and the outer layer is the environment (Horizon, 2012).

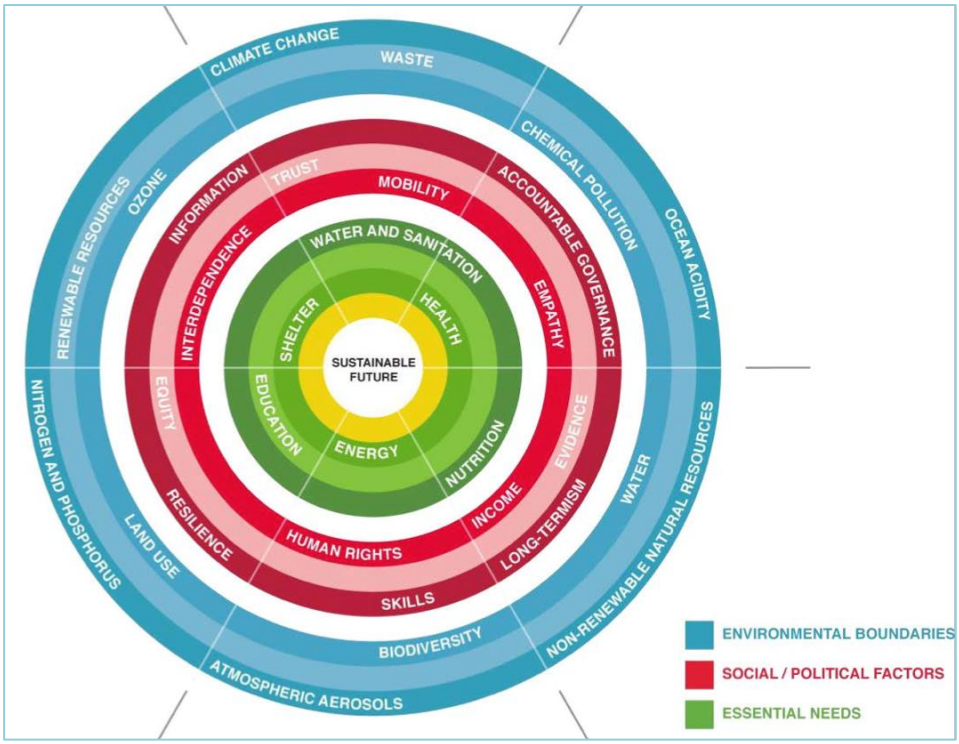


Figure 2.3: A snapshot of Horizon tool (Horizon, 2012)

Although the ultimate sustainability is the goal, it is based on the three pillars of environment, social and essential needs, which differ from what is set out in the previous sections as the tradition TBL of sustainability. Horizon represents each of the categories as a series of cards. There is an option on each card providing an overview of the issue and the reason behind that and presents some suggestions as to how and when to take risk and create opportunities. Generally, it helps an organization evaluate the actions that it should or could take (Horizon, 2012). The Horizon may serve the entity it is designed for. However, due to the limited scope and lack of the full TBL sections, the Horizon may not provide a comprehensive approach for DCOGI assessment.

2.3.2 BREEAM

Building Research Establishment Environmental Assessment Methodology (BREEAM) was developed by Building Research Establishment UK in 1990. BREEAM is an award-based tool that is widely used in the UK. BREEAM is an assessment method and rating system for buildings that is used to measure their environmental performance in terms of energy and water use, health and well-being, pollution, transport, materials, waste, and ecology (Bre, 2021). The method uses recognized measures of performance and compares them against established benchmarks in order to assess a building during design, construction and use. It is of limited use because it assesses buildings and with a focus on environmental performance, it is also criticized for not fit for use globally, as it does not cover other local issues relevant for other countries (Mahmoud et al., 2019).

2.3.3 CEEQUAL

The Civil Engineering Environmental Quality Assessment and Award Scheme (CEEQUAL) is designed as a civil engineering equivalent of BREEAM. A team led by the Institute of Civil Engineers (ICE) UK in 2003 designed CEEQUAL, to demonstrate the commitment of the civil engineering industry to environmental quality and social performance (CEEQUAL, 2021). CEEQUAL is an assessment and awards scheme designed to enhance sustainability in the areas of landscaping and public realm, and applicable to all civil engineering projects unlike BREEAM that is specific to buildings. With CEEQUAL, a project is scored using 9 areas covering a range of environmental and social issues as follows (CEEQUAL, 2021):

- Project / Contract strategy,
- Project / Contract management,
- People and communities,
- Land use and landscape,
- The Historic Environment,
- Ecology and Biodiversity,
- Water environment,
- Physical resources use and management,
- Transport.

The project team is granted an award based on percentage score achieved up to the maximum of 100, once an assessment is carried out. However, given its predominantly environmental focus, it fails to consider other aspects of the TBL and may require DCOGI

specific indicators to be fully useful for DCOGIs. It has been criticized to result in a large number of criteria, because of its focus on different civil engineering projects making the application process too time consuming to use (Hayes et al., 2012).

2.3.4 LEED

The Leadership in Energy and Environmental Design (LEED) framework is also an award-based tool that certifies buildings as silver, gold or platinum. Developed in 1996 by the US Green Building Council, is designed to assess buildings performance through 7 major categories (Wu et al., 2016):

- Sustainable sites,
- Water efficiency,
- Energy and atmosphere,
- Materials and resources,
- Indoor environment quality,
- Innovation and design process,
- Regional priority credits.

LEED is mainly designed to encourage energy efficiency and evaluates the environmental aspects of building performance during their life cycle (Asdrubali et al., 2015). The LEED framework does not constitute holistic components to cover the TBL for sustainability and may not be fully applicable to DCOGI, and it is not designed for DCOGIs sustainability.

2.3.5 HalSTAR

HalSTAR (Halcrow Sustainability Toolkit and Rating System) is a sustainability assessment tool that aims to ensure that sustainability is a source of added value to projects rather than just being an add-on to the development process (Pearce et al., 2012). It is based on a systems model sustainable development, which represents a balance between ranges of needs for a nested system of stakeholders, during the lifetime of a project (figure 2.4). HalSTAR is a continual improvement tool.

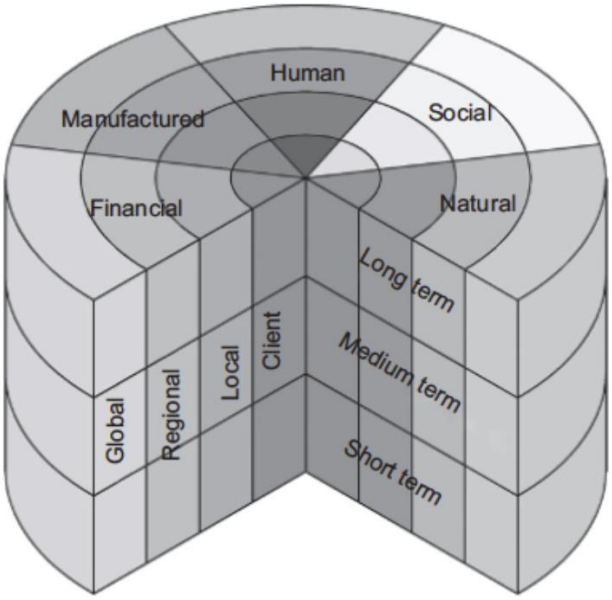


Figure 2.4: HalSTAR system model of sustainability (Pearce at al., 2012)

The HalSTAR sustainability wheel shown in figure 2.5 below represents definitions distilled from over 400 approaches including planning policies, legislation, assessment methods, indicator sets, corporate social responsibility reports, and the needs and requirements of the key stakeholders. The tool consists of a database that includes 840 sub-issues, about 4200 qualitative criteria and 2000 indicators (Pearce at al., 2012).

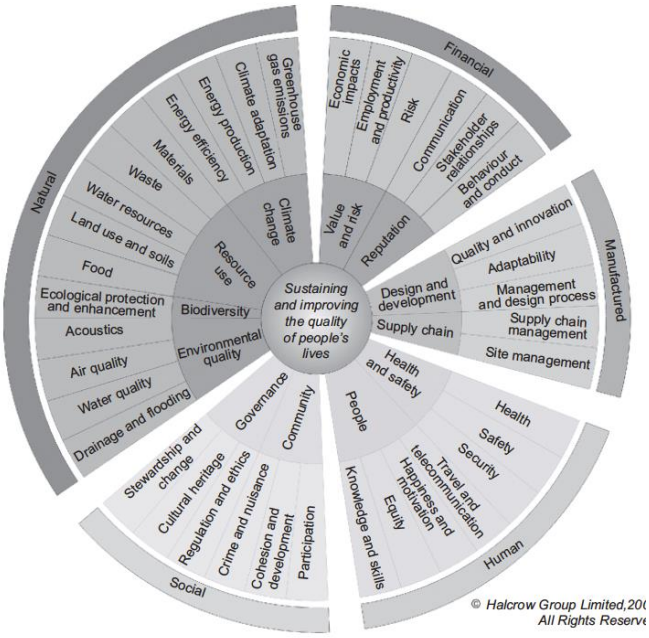


Figure 2.5: HalSTAR sustainability wheel (Pearce at al., 2012)

The HalSTAR tool does cover a range of indicators as shown in the diagrams above. However, it has been criticized as being over complicated and time consuming to use, thus it is tagged a tool fatigue and not user friendly (Holt et al., 2010). The tool is also identified with bias, because it is a stakeholder-focused tool and inclined to stakeholder's priorities. In view of the aims of this study, which includes creating a user friendly and unbiased framework for DCOGI, the HalSTAR may not be suitable for an application to DCOGI

2.3.6 SPeAR®

SPeAR® (Sustainable Project Appraisal Routine) is a sustainability assessment tool that evaluates projects, processes or products using a four-way bottom line approach including economic, social, environmental and natural resources criteria categories as shown in figure 2.6 below. Each category (headline indicator) is composed of sub-indicators. It was developed originally by the international consulting practice Arup in 2001 (Arup, 2014).

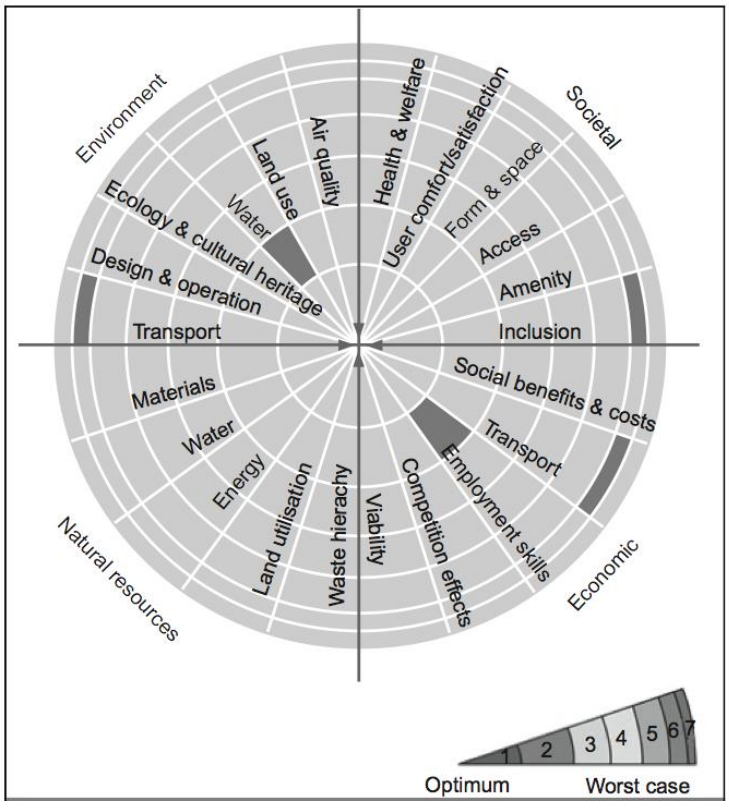


Figure 2.6: SPeAR® diagram template (Braithwaite, 2007)

The SPeAR® development aimed at incorporating a broad range of sustainability issues to cover all projects in the built environment. SPeAR® indicators and sub-indicators have been widely reviewed by a range of professions; the framework is supported by series of detailed

worksheets with 120 indicators covering the TBL for sustainability. SPeAR® is a continuous improvement tool, its assessment is based on the performance of each indicator against a scale of best and worst case (Arup 2012). With SPeAR®, certain projects will need indicators to be modified or new indicator sets to be developed as part of the tool. Nevertheless, it is different from HalSTAR because it has far a smaller number of indicators and should be easier to use, and not prone to fatigue. SPeAR® is generally viewed as not prone to bias when compared to the award-based tools e.g., LEED, BREEAM and CEEQUAL, but it is often criticized for the lack of a weighting system for its indicators (Braithwaite, 2007; Holt et al., 2012). SPeAR® is considered as able to recognize the areas that add real benefits or sustainability improvements to a project. The SPeAR® sustainability assessment tool has also been criticized for being over simplified and therefore easily modifiable (Holt et al., 2010, Donovan et al., 2005), which is evidenced in the various modified versions that has been successfully developed in recent times e.g., GeoSPeAR developed by holt in 2010 for geotechnical projects, and USPeAR developed for underground utility space by Zargarian in 2016. Also, a modified version has also been developed for urban street works social costing. Contrary to the criticism, the modifiable nature of the SPeAR® sustainability assessment tool and the successful development of adaptable versions is considered an advantage for this study.

2.3.7 GeoSPeAR

GeoSPeAR is a tool that was developed for use to identify, assess and address sustainability within geotechnical projects. GeoSPeAR was adapted from the SPeAR® framework, this was possible because the SPeAR® framework is flexible, unbiased, combines social, environmental and economic indicators (plus natural resources) and has a holistic approach making it possible to adapt for different uses. This was done by firstly removing those indicators in SPeAR® that are not relevant to geotechnical engineering and replacing them with relevant indicators. Secondly, quantitative analysis was applied. Numerical calculations were used to complement the colour scale used in SPeAR®, which also removed some of the earlier criticisms of SPeAR® (Holt et al, 2010). GeoSPeAR is beneficial to geotechnical engineers whom through improved sustainability of their own designs can use the framework to encourage clients, suppliers, contractors, and engineers to foster more efficient adoption of sustainability principles. Because specifically designed

and tailored for only geotechnical projects, GeoSPeAR indicators may not be applicable for DCOGIs, but could be modifiable to meet the requirements for DCOGI sustainability.

While the literature reveals several sustainability assessment frameworks, the review finds a general lack of sustainability assessment framework that is able to specifically consider DCOGIs. The existing frameworks are either too generic or designed for specific purposes or do not constitute the dimensions of sustainability that could be applied to DCOGI. Whiles what should constitute a DCOGI sustainability assessment framework is still be considered, the next section will review existing literature on resilience and resilience assessment frameworks.

2.4 Concept of Resilience

Like sustainability, the concept of resilience has increasingly gained attention as an essential concept within industries and in the field of crisis management (Hosseini et al., 2016; Labaka et al., 2016; Roostaie et al., 2019). This is mainly due to its role in reducing the vulnerability of systems, risks associated with the inevitable disruption of systems and critical infrastructure protection (Hosseini et al., 2016; Labaka et al., 2016; Arup, 2019). The word resilience has been originally originated from the Latin word “resiliere,” which means to “bounce back” (Petersen et al., 2020). In academia, its origin is mainly associated with Hollings (1973) and Pimm’s (1984) study on ecological resilience illustrated using mathematical approach (Webb, 2007). As with sustainability, there are several definitions in the literature regarding the concept of resilience, but no single definition of resilience in the literature is universally accepted (Manyena, 2006; Moteff, 2012; Labaka et al., 2016; Petersen et al., 2020). Different disciplines take different views about resilience, which has impeded progress made towards a common understanding and application of resilience concept (Brand & Jax, 2007). The literature highlights many of the views about resilience as similar, and the core principles as transferable; though many of the views overlap with a number of already existing concepts such as robustness, fault-tolerance, flexibility (Redundancy), survivability (Resourcefulness), agility (Rapidity), vulnerability, adaptive capacity, diversity, foresight capacity, interdependence (and independence) and creativity, among others (Bruneau et al., 2003; MCEER, 2008; Zobel, 2010; Francis & Bekera, 2014; Hosseini et al., 2016; Arup, 2019).

The literature offers some general definitions of resilience across multiple disciplines. For example, Vugrin et al. (2010) defines system resilience as: “given the occurrence of a particular disruptive event (or set of events), the resilience of a system to that event (or events) is that system's ability to reduce efficiently both the magnitude and duration of deviation from targeted system performance levels.” The National Infrastructure Advisory Council (NIAC, 2009) defined the resilience of infrastructure systems as “their ability to predict, absorb, adapt, and / or quickly recover from a disruptive event such as natural disasters”. Resilience in an energy system has been define as “its ability to reduce the impact of the shocks and stresses, including the capacity to anticipate, absorb, adapt to, and rapidly recover from such events and to transform where necessary” (Arup 2019). Haimes (2009) defined the resilience as the “ability of system to withstand a major disruption within acceptable degradation parameters and to recover with a suitable time and reasonable costs and risks.” Pregenzer (2011) defined resilience as the “measure of a system's ability to absorb continuous and unpredictable change and still maintain its vital functions.” However, like many other supply chain systems globally, it is not clear how these definitions imply to DCOGIs without an explicit evaluation of DCOGIs specific issues. In general, a secure and resilient supply chain is a system enabled with security processes and procedures including redundancy, while it is capable to proactively respond to diverse disruptions and restore its original operations (Lima et al., 2016). However, Cardoso et al. (2015) states that there exists a trade-off between the cost of developing supply chain systems and its benefits to the network. Consequently, the concept of resilience must be taken into account when designing and planning a supply chain including DCOGI, to improve the capability to respond rapidly and cost-effectively to unpredictable events.

The concept of resilience has been broken down into four application domains and dimensions as engineering or technical, organizational, economic and social resilience (Hosseini et al., 2016; Labaka et al., 2016). Engineering or technical resilience refers to the function of the reliability rate (Survivability) and restoration rate (Proactive) of an organization’s physical systems when subject to a crisis (Youn et al., 2011). This domain covers systems that interact with humans and physical systems. Supply chain infrastructure systems such as DCOGIs, water distribution systems, nuclear plants, transportation systems, and locks and dams, among others, can be considered as subdomain of the engineering domain as their construction and restoration require engineering knowledge. Literature points out that for this these systems; it is vital to understand the normal functions and

causes of failures in order to implement resilience engineering (Hollnagel & Prologue, 2010). Organizational resilience refers to 'the capacity of crisis managers to make decisions and take actions that allow normal operations to continue or recover a steady state after a disruption (Sheffi, 2006). Resilience in this domain emerged to tackle the need for business management to respond to a rapidly changing operations environment. Economic resilience refers to the ability and adaptive response of firms, industries, institutions etc. to face the extra costs that arise from a crisis (Rose & Liao, 2005). Social resilience refers to the ability of society to lessen the impact of crisis in the face of political, social and environmental change (Adger, 2000). Resilience in this domain covers individual groups, communities, environment, and the ability to predict or prevent risk. Critical energy infrastructures are also considered as subdomain of social domain in which the lack of their resilience can lead to adverse impacts on communities. Social resilience usually entails collaboration between the entities and also covers the subdomains of ecology, psychology and sociology, where resilience is also defined respectively. In ecology, resilience is defined as the capacity of an ecosystem to tolerate disturbance without collapsing into a qualitatively different state, controlled by a different set of processes (Carpenter et al., 2001; Webb, 2007; Kerkhoff & Enquist, 2007). In psychology resilience is defined as the capability to survive a trauma successfully (Bonanno et al., 2007; Barata-Salgueiro & Erkip, 2014). As extant literature reveals that the concept of resilience varies in practical application, much is to do with 'ability to bounce back' in the face of expected and unexpected occurrence and therefore definitions are (and must be) contextually and temporally specific. This affirms the assertion by Ungar (2011), that findings on resilience may not (and should not) be generalized, although the general approach to assessing resilience may be transferable.

In the literature, several authors argue that the aforementioned dimensions do not consider their interrelationship, because there are often studied separately (Ramussen, 1997; Leveson, 2004; Labaka et al., 2016; Hosseini et al., 2016; Gillespie-Marthaler et al., 2018; Arup, 2019). Critical infrastructure systems including DCOGIs have strong links to the environment, the economy, the society, and livelihood in addition to the technical, strategic and tactic linkages. Critical infrastructure systems can greatly improve the economic efficiency of a country (Percoco, 2004). This highlights the importance of an integrated approach with consideration of interdependencies. Disruptions of critical infrastructure systems could originate from lack of integration of dimensions of resilience, or if resilience dimensions are analysed independently (Leveson, 2004; Labaka et al., 2015; Arup, 2019).

For example, a valve could be the right one, but operators might not have the required training for its proper use, political and community instability could disrupt operations in a supply chain, among others. As a result of this gap, there are continuous calls in the literature for efforts to develop approaches that incorporate technical aspects and the broader stakeholders that may be involved in crisis management such as government agencies, communities, NGOs, legislators, insurance companies, system operators, top managers etc. for example a model of accident causation (STAMP) based on system theory has been proposed. STAMP integrates resilience dimensions including organizational, social, economic and technical aspects. The model is defined based on a systemic view where components are interrelated and continuously adapted to react to changes within the system or in its environment with the aim at ensuring safety (Hosseini et al., 2016).

For critical energy systems, models have been proposed to incorporate all internal and external factors linked to critical infrastructures; Arup has suggested three-dimension approaches for energy systems resilience as leadership and strategy, economy and society, infrastructure, and ecosystems (Labaka et al., 2016; Arup, 2019). In generally, the literature also highlights the lack of empirical studies for the application of integrated resilience approach to critical infrastructure systems. The literature review so far reveals that the lack of an integrated and generally accepted approach for resilience is in some ways similar to the lack of integrated and generally acceptable approach for sustainability. Notable, the call for an integration of the dimensions of resilience could yield an overlap with the components of the TBL of sustainability i.e., Social, economy and environment. It is suggested that resilience is generally viewed as a prerequisite i.e., component of, or contributor to achieve sustainability where robust ability to resist disruption is required (Fiksel, 2003; Mayer, 2008). Redman (2014) in their study of sustainability and resilient pursuits suggests that for systems to be sustainable, they must be resilient. This also highlights the link between the concept of sustainability and the concept of resilience, to which this study seeks to develop a hybrid approach (sustainability and resilience) applicable to DCOGIs. To this end, in line with the aim of this study the following sections of this study will explore existing resilience assessment frameworks for and applicability to DCOGIs. By looking at pre-existing frameworks, the study can begin to establish what exists and what shortfalls there are therein. Subsequent sections will review the prospects of an integrated approach for assessing DCOGIs and factors related to the DCOGI sector that

require consideration when constituting a holistic assessment framework for DCOGIs specifically.

2.5 Resilience Frameworks

In the literature on resilience, various resilience assessment frameworks have been presented. Approaches to assessing the resilience of infrastructure depend on distinct parameters, and may vary for different infrastructures, different geographical locations around the world, and different scales. Table 2.3 summarizes the approaches to resilience assessment. It can be deduced from previous section that the causes of disruptions that may interrupt normal functionality of infrastructure systems do vary; they are either known or unknown. In cases where risks or uncertainties are known, deterministic approach are adopted; otherwise, what is termed a probabilistic performance assessment of a system may be adopted (Ouyang, 2014). Risk management approaches and ability to determine the vulnerability of infrastructure systems are current prerequisites to building in resilience into infrastructure systems. Vulnerability of infrastructure systems refers to the "manifestation of the inherent states of the system that can be exploited by an adversary to harm or damage the system" (Haimes and Horowitz, 2004).

Table 2.3: Resilience assessment approaches

Qualitative Assessment	Quantitative assessment	
Conceptual frameworks	General measures	Probabilistic approaches Deterministic approaches
Semi-quantitative indices	Structured-based models	Optimization models Simulation models Fuzzy logic models

Some frameworks presented include resilience framework by Reed et al. (2009), which suggested a resilience assessment methodology for subsystems of a multi-system networked infrastructure for extreme natural hazard events. In their proposed method, they combined the resilience measure from previous work by Bruneau et al. (2003), which used input-output models, and structural fragilities, and used available data for Hurricane Katrina lifeline damage to illustrate the application of their method. Cimellaro et al. (2014), also extended the resilience assessment framework proposed by Bruneau et al. (2003), and

unambiguously defined resilience as the area beneath the performance curve for a given time / period and demonstrated its application for seismic resilience using a network of hospitals in Tennessee and Memphis in the USA. Ouyang and Dueñas-Osorio (2012), in their publication (a three-stage resilience analysis framework for urban infrastructure systems) introduced a resilience assessment framework that is adequate for both single and multiple hazards and computed the expected annual resilience of the power transmission grid in Harris County, Texas under random hazards and hurricane hazards. Ouyang (2014), in his most recent publication has provided an extensive review of modelling and simulation approaches of critical interdependent infrastructure systems and compared these methodologies from the overarching perspective of resilience.

Chang and Shinozuka (2004) proposed the probabilistic method that quantifies resilience as the probability of meeting pre-defined robustness and rapidity standards. Seismic assessment framework has also been proposed, here seismic resilience is defined by the multidisciplinary centre for earthquake engineering research (MCEER) as "the ability of both physical and social systems to withstand earthquake-generated forces and demands and to cope with earthquake impacts through situation assessment, rapid response, and effective recovery strategies," and is composed of four dimensions: robustness, redundancy, resourcefulness, and rapidity (MCEER, 2008). Various studies have implemented such frameworks to quantify the resilience of various infrastructure systems against natural hazards or the intelligent actions of adversaries, but this only limited to earthquake prone areas of the world.

Zhang and Ramirez (2013) proposed a resilience framework for intentional attacks on critical infrastructure (CI). This approach models CI as networks and the development of network protection strategies is modelled as a two-stage game between a protector and an attacker with incomplete information. However, due to the complexity of critical infrastructures and the need for large number of combinations of potential protection and attack strategies, led to a computational challenge to find the Pareto equilibrium solutions for the proposed game. Another resilience framework for CI systems is that proposed by Francis and Bakera (2014), the framework consists of system identification, resilience objective setting, vulnerability analysis, and stakeholder engagement. The implementation of this framework is focused on the achievement of three resilience capacities: adaptive capacity, absorptive capacity, and recoverability. The framework has been criticized

because the processes, the order, and transformations required to create resilience-building activities are not specified.

Shah et al. (2014) proposed a geotechnical infrastructure assets resilience assessment framework, which is a decision support framework designed for geotechnical asset owners to help in decision making and identify solutions and test the resilience of geotechnical design solutions in the light of changing socio-economic, technological, environmental, and political conditions in the future. However, this framework is not applicable to DCOGIs as it falls short of addressing the broader factors peculiar to DCOGIs. The literature in social science-oriented environmental research that deals with analysing human nature interactions in socio-ecological systems, presents several frameworks for ecosystem and social-ecological resilience (Holling, 1973; Carpenter et al., 2001; Folke et al., 2002; Berkes et al., 2002). Table 2.4 below is a summary of the frameworks for analysing socio-ecological systems, their origin and applicability. Their core principles and conceptual approaches to developing these frameworks may be transferable. However, the frameworks are not developed to comprehensively assess resilience of DCOGIs.

Table 2.4: Frameworks for Analysing Social-Ecological Systems

FRAMEWORK / ACRONYM USED	DISCIPLINARY ORIGIN	THEORETICAL ORIGIN	FIELDS APPLIED	PURPOSE	SCALE
Human-Environment System framework HES. (Scholz & Binder 2004; Scholz et al., 2011a)	Environmental decision making and psychology	System science, sustainability science, game theory, decision theory	It can be applied to any research area in which human-environmental interactions play a role: e.g., energy, water, wastes.	Provide a methodological guide or template for analyzing the structure of social-ecological systems and understanding the processes and dynamics between the social and ecological systems as well as within different scales of the social system.	Applicable in any spatial scale (favors regional and national scale).
The Material and Energy Flow Analysis framework MEFA. (Ayres, 1978; Baccini & Bader, 1996; Haberl et al., 2004; Brunner & Rechberger, 2005)	Engineering (natural science)	System science	All problem fields that have to deal with the analysis of human impact on the ecological system and can be related to material and energy flows, such as resource management, pollution control, etc.	Analyze the metabolic profiles of societies. Analyze the material and energy flows as representing the metabolism of a society, region, or nation.	Applicable in any spatial scale (favors regional and national scale).
Turners Vulnerability framework TVUL. (Turner et al., 2003a, b)	Social and natural science	Risk-hazard (RH) and pressure-and-release (PAR) models, climate impact research, and resilience research.	Widely applied.	Analyzes who and what are vulnerable to multiple environmental and human changes, and what can be done to reduce these vulnerabilities.	Local scale.
The Management and Transition Framework MTF. (Pahl-Wostl, 2009; Knieper et al., 2010; Pahl-Wostl & Kranz, 2010)	Social science	Complex system science	Risk governance and integrated landscape management. Can be tailored.	Support the understanding of water systems, management regimes, and transition processes toward more adaptive management; enable comparative analyses of a wide range of diverse case studies; and facilitate the development of simulation models based on empirical evidence.	Applicable in any spatial scale (favors regional and national scale).
The Social-Ecological Systems framework SESF. (Ostrom, 2007; Ostrom, 2009)	Political science	Collective choice, common-pool resources, and natural resource management	Management of forests, pastures, fisheries, and water	Provide a common language for case comparison for organizing the many variables relevant in the analysis of SES into a multitier hierarchy that can be unfolded when needed, and for facilitating the	Applicable in Local and regional scale.

				selection of variables in a case study.	
The Driver, Pressure, State, Impact, Response framework DPSIR. (Eurostat, 1999; Carr et al., 2007; Svarstad et al., 2008)	Natural science	System science	Integrated environmental assessment. e.g., coastal zones, water, transport, pollution control.	Develop an improved understanding of, indicators for, and appropriate responses to impacts of human activities on the environment along the causal chain-drivers-pressure-state-impact-responses.	Applicable in any spatial scale.
The Natural Step framework TNS. (Burns & Katz 1997; Robert, 2000; Upham, 2000; Missimer et al., 2010)	Economics	Systems science and management theories	Businesses and regions	Provide a framework for planning toward sustainability based on: constitutional principles (how the system is constituted); outcome (principles for sustainability); and process to reach this outcome (principles for sustainable development).	Businesses and regions.
The Ecosystem Services framework ES. (Costanza et al., 1997; Daily, 1997; De Groot et al., 2002; Limburg et al., 2002)	Natural science, social science	System science	Integrated management of the linkages between environment and human well being, e.g., the Convention on Biological Diversity (United Nations 1992) and the Millennium Ecosystem Assessment (MA).	Analyze the integral, dynamic, and complex interactions of biotic and abiotic components of an ecosystem in relation to the supply of services this system provides to support life on Earth.	Applicable in any spatial scale (favors regional and national scale).
The Sustainable Livelihood Approach SLA. (Ashley & Carney, 1999; Scoones, 1998)	Social science	Capability / entitlement approach	Development research / assistance	Analyze which combinations of livelihood assets enable the following of what combination of livelihood strategies with sustainable outcomes.	Applicable in local and regional scale.
The Earth Systems Analysis ESA. (Schellnhuber 1998, 1999; Schellnhuber et al., 2005)	Physics (natural science)	System sciences	International Geosphere Biosphere Programme.	Understand the global interactions in and dynamics of the earth system as well as its sustainable evolutions.	Global scale.

Speranza et al. (2014) developed a notional framework for analysing resilience of livelihoods, or the "resources that people have and the strategies they adopt to make a living." The framework provides a few attributes of three dimension of resilience: buffer capacity (the amount of change that a system can undergo), self-organization (the emergence of society through inherent social structure), and capacity for learning (an ability to adapt). Labaka et al. (2015) proposed a holistic resilience framework that has been defined in close collaboration with general management. Their proposed framework consists of two resilience types: internal resilience and external resilience with resilience policies and resilience sub-policies. The framework is too generic and does not provide

specific considerations for DCOGIs. Several qualitative resilience studies have addressed critical infrastructure applications. Sterbenz et al. (2011) presented a framework for resilience and survivability of communication networks and a survey that includes the resilience disciplines. The results of their study indicate that six factors of defend, detect, diagnose, remediate, refine, and recover contribute to designing resilient networks that can be extended to other domains. This framework provides only a conceptual insight and does not quantify system resilience. Other authors (Cutter et al., 2010; Cohen et al., 2013) define a set of indicators to evaluate disaster resilience levels and in turn evaluate the efficiency of the established policies that support the resilience level. However, these policies focus on social resilience and do not provide specific policies for CI operators. Furthermore, little is stated about how to improve these indicators. Sharifi and Yamagata (2014) proposed a framework for assessing the resilience of urban energy systems. The framework itself constitutes components of availability, accessibility, affordability and acceptability (the 4 A's); however, the framework is very generic and simply may not address characteristics that are specific to DCOGI. Other approaches suggested by Russo (2014), American Gas Association (2014) and Johnson (2014) emphasize either cyber security or physical oil and gas infrastructure protection as a strategy to build resilience. For the UK downstream oil and gas sector, government is working on maintaining capability to make fuel deliveries in the event of a serious disruption as a strategy to build resilience (BEIS, 2018). These strategies do not provide an integrative approach to achieving sustainability and resilience for DCOGI.

In general, the literature reveals several individual resilience metrics currently identified for oil and gas systems in studies from 1997 to date, covering published reports and peer-reviewed journal articles. They metrics as presented in table 2.5 are identified in piece meal for specific purposes and there is no evidence the resilience metrics are utilised comprehensively for DCOGIs assessment. Metrics are used to monitor or assess set goals, track progress, and determine if goals have been successfully achieved (Willis & Loa, 2015). For clarity of purpose and ease of understanding i.e., carrying out assessments and interpretations of outcomes, metrics are better presented within a consistent framework like the logic models (Greenfield et al., 2006).

Table 2.5: Resilience Metrics for Oil and Gas Systems at Facility, Region and Nation Level

Energy Resilience Block	Resilience Metrics
Inputs	**Diversity of import fuels**. (Gnansounou, 2008). **Gas strategic reserve.** (Ellison et al., 2006). **Primary energy supply** – Includes the systems and processes used to supply a primary energy resource to its point of conversion into the final energy product of interest. (McCarthy et al., 2007). **Storage facilities, nodes and intermediate storage** – Elements of the network that can receive gas from storage facilities, pipeline interconnections of production areas. (Vugrin & Turnquist, 2012; Ellison et al., 2013, Anderson, 2001). **Natural gas strategic reserve**. (Ellison et al., 2006). **Hubs and links -** Nodes with the most interconnected links, links flows between nodes e.g., roads, oil or gas mains, transmission lines. (Nadeau, 2007; Vugrin & Turnquist, 2012; Ellison et al., 2013).
Capabilities	**Ability to expand facilities -** The degree to which the system can be easily, and cost effectively expanded. (McCarthy et al., 2007). **Restorative Capacity -** Ability of a system to be repaired easily these repairs are considered to be dynamic. (Vugrin et al., 2011). **Total recovery effort -** Efficiency with which the system recovers from a disruption, measured by analyzing the amount of resources expended during the recovery process. (Vugrin et al., 2011). **Emergency procedures and emergency shutdown system.** (Hsu et al., 2010). **Sector coordination -** The degree to which coordination between stakeholders within the sector results in an effective exchange of information alerting stakeholders of emerging threats and mitigation strategies. (McCarthy et al., 2007). **Maximum and minimum flow**. (Ellison et al., 2013). **Adaptive Capacity -** Degree to which the system is capable of self-organization for recovery of system performance levels. (Vugrin et al., 2011). **Interdependencies -** The degree to which the system relies on other infrastructure for its reliable operation and is vulnerable to that infrastructures disruption. (McCarthy et al., 2007). **Pipeline capacity used and Network Resiliency -** Ability to keep supplying and distributing natural gas despite damage to pipelines, terminals, storage and other gas sources**.** (Nadeau, 2007). **Physical and Information security -** The degree to which physical and information assets in the system are secure against threats. (McCarthy at al., 2007). **Economic, Environmental & Health Impact -** The degree to which a disruption in the system might feasibly cause economic damage to industry, stakeholders, government or the public; cause environmental damage; harm the health of employees or the public. (McCarthy at al., 2007).
Capacities	**Import levels -** The degree to which primary energy supply relies on resources originating from outside of the country. (McCarthy et al., 2007). **Import capacity, dependency and vulnerability -** Divided into source dependence, transit dependence and facility dependence proportional to the reliance on imported gas from countries in geopolitical conflict. (Reymond, 2007; Ellison et al., 2013)

They identified resilience metrics for oil and gas systems are considered suitable for operational and strategic decision-making. Using the building blocks of resilience in energy systems that are Input, Capacity, Capability, (Willis & Loa, 2015), the resilience metrics as presented in table 2.5 can enable the identification of suitable aspects of an energy system to apply the metrics. The Inputs block categorize resources that are available to support resilience e.g. budgets, number of spare parts, number of generators, number of personnel to support recovery operations; the Capacity block categorizes the resources to resource owners and into relevant frameworks within which inputs are organized to support resilience e.g. response teams for repairing equipment, disaster recovery plans, aid agreements, smart-grid technology for power reroute and reconstituting portions of a grid; and the Capability block categorizes expected performance levels that will support resilience e.g. restoring power outage, repairing damaged power lines or pipelines, detect leaks or outages.

The resilience frameworks and metrics discussed are not developed for DCOGI context, they are rarely integrative, and their approach do not cover all dimensions of resilience that may be transferable to DCOGIs. Most of the frameworks only focus on developing the resilience level of their entities or even only on improving organizational microenvironment and operational aspect of resilience which neglects the role of the external stakeholders such as first responders, government, and society, of which their importance to attaining resilience in critical infrastructure systems are recognized. See for example Yusuf et al., 2013; Ngoasong, 2014; Tesfay, 2014; Abdul Rahman et al., 2015; Ahmad et al., 2016. Furthermore, due to the theoretical nature of some of the frameworks, the literature lacks much on the way of empirical research and case studies that address operationalization of their resilience principles. This would present difficulties when attempting to adapt and implement these frameworks in practice. The complex nature of problems associated with the oil and gas industry and DCOGIs sector specifically, would require to be dealt with in an integrative, interdisciplinary way, taking explicit consideration of all the dimensions of resilience as well as all dimensions of sustainability holistically; in other to meet the desired outcomes and for all stakeholders. See for example studies by Redman, 2014; Lima et al., 2016; Labaka et al., 2016; Roostaie et al., 2019 supports the integration of sustainability and resilience concepts in DCOGI context. With the absence of such a comprehensive assessment framework, a nexus of sustainability and resilience dimensions for DCOGIs

specifically is a required approach to address the shortfall. As a necessity, the following sections of the thesis would begin to address this.

2.6 The Nexus of Sustainability Science and Resilience Theory

There may be an argument that sustainability criteria can be used as proxy for the assessment of resilience, however by virtue of the presence of varying characteristics and dimensions this may not always be possible (Brand & Jax, 2007; Binder et al., 2013; Redman, 2014; Roostaie et al., 2019). Other views suggest resilience as a prerequisite for attaining sustainability, but sustainability alone does necessarily achieve resilience (Marchese et al., 2018). It can be asserted that approaches to assessing the resilience of infrastructure depend on distinct parameters, and may vary for different infrastructures, different geographical locations around the world, and different scales (Lew et al., 2016). In many respects this ties in with some of the key debates within literature where academics argue on the applicability of the concepts and theories of sustainability and resilience, and whether they should be pursued as single or combined entities (Redman, 2014). This section explores this, for the purpose of the research aim.

Based on the context of application of the framework proposed in this study i.e., sustainability and resilience assessment framework for DCOGIs, it is vital to consider if the concepts of sustainability and resilience can be viewed as inversely related, interdependent, or intersecting. While sustainability is viewed as the long-term ability to operate without failure through balanced management of critical social, economic, and environmental capital; resilience is generally viewed as the ability to resist disruption, recover, adapt, and / or transform given a hazardous event in order to maintain desired system performance (Gillespie-Marthaler et al., 2018). It is sometimes said that improving resilience will improve the sustainability and vice versa, this is not always the case (Redman, 2014; Ahmad et al., 2016). Gillespie-Marthaler et al., (2018), suggest that both concepts have differences in scale and perspective that produce pros and cons. This should necessitate further studies into areas of strengths and weaknesses. The approach to implementing both concepts if not properly done can lead to inappropriate considerations of related concepts and a failure to examine trade-offs, resulting in seemingly competing and unsustainable outcomes (Mori & Yamashita, 2015). Table 2.6 below presents the strengths and weaknesses of the individual concepts as applicable to complex systems.

Table 2.6: Strengths and Weakness (GAPS) of Individual Concept Application in Complex Systems Assessment. (Adapted from Gillespie-Marthaler Et al., 2018)

	Strength of Individual Concept	Weaknesses (Gaps) in Current Application
Sustainability	• Deficiencies and/or opportunities • Long-term system-wide viability and wellbeing	• Consideration of critical system and sub-system/component properties given hazardous event scenarios • Consideration of dynamic system changes over time, including the impact of adaptation or transformation strategies
Resilience	• Performance related risks • Plans for reduction of harmful impact and severity • Recovery and adaptation strategies • Transformation needs associated with system operations	• Balance across social-environmental components • Consideration of sub-system/component level variations and their impact on system-wide performance and quality over time • Consideration of impacts on sustainability capital resulting from implementation of adaptation or transformation strategies and resulting changes in adaptive capacity

Where sustainability assessment aims to minimize resource consumption in the development and operation of a system, it is possible to undermine essential components of robustness and redundancy that are critical to resilience. It is important to improve understanding of the nature of linkages and interactions to enable strategic integration of concepts, rather than a simple combination of terms. Basic understanding of the interactions between concepts can show areas where a strategic approach to balanced integration and alignment of resilience, and sustainability goals may improve method for assessing the performance of any complex system, as well as improved ability to strategically build adaptive capacity, thereby strengthening long-term sustainability and resilience (Leslie et al., 2018). Five critical areas where conceptual interactions exist between assessment types for sustainability and resilience are goals, focal lens, scale (spatial and temporal), and key measurement and practice terms as presented in table 2.7. It can be seen below that

economic considerations (cost, effectiveness, efficiency) are common across sustainability and resilience concepts. From the areas of divergence and potential linkages across concepts as shown in Table 2.7, specific areas are identified where strategic integration of both concepts can be expected to result in greater understanding of system quality or value added over time. The following table 2.8 presents a summary of areas of value-added through focused integration of concepts, timescales, systems, and resources.

Table 2.7: Sustainability and Resilience Assessment: Conceptual Linkages and Interactions.

(Adapted from Gillespie-Marthaler Et al., 2018)

	Focal Lenses	Goals	Spatial and Temporal Scale	Conceptual Definition Terminology	Key Measurement and Practice Terms
Sustainability	How will the system impact its surrounding environment (across social, economic, and environmental systems and sub-systems)? Will impacts to critical resources modify system viability?	Identify and manage impacts to connected resource systems and sustainability capital to maintain indefinite system viability and wellbeing.	Spatial: Meso (system) with macro (beyond system boundaries) connectivity. Temporal: Long-term or strategic (lifetime and beyond).	- Equity - Long term resource availability (in terms of social, economic, and environmental capital). - Resource quality and quantity	Access Cost Diversity Effectiveness Efficiency Redundancy Reliability Resources Demand & Supply
Resilience	How did the system respond? How will the system recover?	Maintain system performance and functionality in the presence of change, minimize periods of disruption, and recover as well as adapt or transform.	Spatial: Meso (system-wide). Temporal: Mid-term (operational lifetime).	- Absorb / Resist / Cope - Recover - Adapt - Transform	Cost Effectiveness Efficiency Exposure Rapidity Threshold Redundancy Robustness

Table 2.8: Areas of Added Value Through Focus Integration of Concepts, Timescales, Systems and Resources

	Gaps	Value-Added through Integration to Address Gaps
Sustainability	Consideration of critical system and sub-system/component properties given hazardous event scenarios. Consideration of dynamic system changes over time, including the impact of adaptation or transformation strategies.	Improved identification of adaptation and/or transformation strategies that can be effectively implemented . Improved consideration of effects on system sustainability capital in order to maintain long-term system viability . Greater consideration of changes in the availability of sustainability capital . Improved consideration of effect of sustainability capital on adaptive capacity.
Resilience	Balance between social-environmental components. Consideration of sub-system/component level variations and their impact on system-wide performance and quality over time. Consideration of impacts on sustainability capital resulting from implementation of adaptation or transformation strategies and resulting changes in adaptive capacity	Improved consideration of impacts to system sustainability capital . Greater consideration of socio-economic and socio-political effects . Improved understanding of how to reduce severity of harmful impacts . Improved identification and consideration of sub-systems/ components critical to maintenance of system-wide performance.

A detailed conceptualised framework to assess sustainability and resilience in an integrated manner for DCOGI specifically that can be operationalised is yet to be described in the literature. The section surmises the essence of integrating the concepts of sustainability and resilience by looking into aspects of linkages and interactions, albeit the practical application would depend on the applicable entity in view. This would also require that both concepts compliment areas it would naturally not address respectively. The nexus of sustainability and resilience assessment approach is consistent with the need for an integrated assessment of critical infrastructure systems, as mandated by the complex nature of problems associated with critical infrastructure systems. For the development of an integrated approach for DCOGIs, the study considers it necessary to first determine what would constitute an integrated sustainability and resilience assessment framework for DCOGIs. As such, the following sections will focus on sustainability and resilience related

subjects and problems associated with the DCOGI sector. It was deemed that this could be achieved through the lenses of energy security, and through a review of activities related to the DCOGI sector globally.

2.7 Energy security (Oil and Gas)

In the last decade, an increasing number of studies on energy security have continuously been reported (Cherp & Jewell, 2014). As a result, numerous definitions of energy security have been suggested, there is also been increased emphasis and interest on how energy security should be measured. Energy security issues are becoming a concern to various stakeholders particularly as most of what is done today within a well- functioning modern society and its supporting economy is dependent in one way or another on the availability of energy and also because of various threats from climate change and human induced effects. Some of the stakeholders include governments / policy makers, oil and gas industry, businesses (including major energy consumers), and the wider community whose wellbeing may depend on continuous use of energy resources. However, the meaning of energy security differs amongst the various stakeholders because their energy needs vary. According to Ang. et al (2015), energy security for the various stakeholders could depend on:

- Special circumstances of a country,
- Level of economic development,
- Risk's perception,
- The robustness of its energy system,
- Prevailing geopolitical issues etc.

This implies that the term energy security is contextual, due its dynamic and multidimensional nature and the lexical ambiguity that exist in various literatures on energy security (Ang. et al., 2015). Following on from the above, recent studies have describe energy security differently e.g. (1) From supply security aspect e.g., energy availability and prices (Jamasb and Pollitt, 2008), (2) From an overarching view to include supply chain e.g., downstream distribution effects such as impacts on socio-economic welfare (Vivoda V., 2010).

The concept of "Energy Trilemma" as presented in Figure 2.7 highlights the need to make a holistic pursuit of energy goals, by tackling and balancing the trade-offs between the three

main energy issues: Energy Security, Economic Competitiveness, and Environmental Sustainability; rather than dealing with energy security in isolation (WEC, 2012). By extension, the aforementioned approach could potentially aid to tackle the broader sustainability issue, as well as considerations for integrating resilience when taking such holistic endeavours. With sustainability and resilience at the heart of every task of evaluating energy goals and policies.

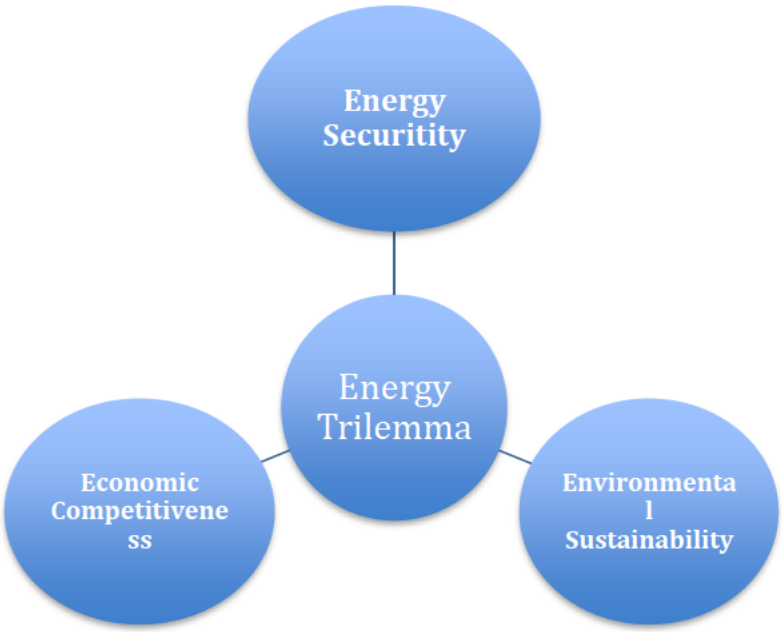


Figure 2.7: Energy security and the energy trilemma (Adapted from Ang. Et al, 2015)

The oil and gas supply chain are inserted in an unstable context, influenced by geopolitical unrest, global competition and price volatility, where the business focuses on margins and the savings are carried out through improved forecasts and schedules with shorter planning horizon (Zhu et al., 2020). This highlights the need for designing and implementing new tools that aim to establish an integrated and adaptive supply chain to improve the decision-making process, reduce costs, decrease inventories and enhance margins (Capgemini, 2008; Lima et al., 2016). Also, as resilient oil and gas supply chains with higher capacity of mitigating risks are sought by the oil and gas industries, where the resilience could be improved by different ways, e.g., through flexibility, redundancy etc. (Deloitte, 2010). It is vital to develop policies and assessment tools that can support oil and gas supply chain systems to proactively respond to diverse disruptions and restore its original operations (Martîsauskas et al., 2018). As previously mentioned, energy security is a highly contextual

dependent concept. For the purpose of this research, the following key energy security themes relating to oil and gas that steered the focus of the research are discussed below.

2.7.1 Energy availability

The oil and gas availability are paramount to various stakeholders, particularly as it is the most reliable and economically viable source for energy (Chen et al., 2020). Albeit it could pose some environmental consequences during exploration and usage, compared with renewable and environmentally friendly alternatives. Demand for oil and gas for energy security is still on the high, a trend that is likely to continue for the next 40 years (IEA, 2017). To ensure continuous energy availability, countries continue to seek diverse means for oil and gas. E.g., the discovery of gas in northern Egypt by the Egyptian government in August 2015; oil gas discovery in Lincolnshire UK in 2015; Russia taking advantage of impact of climate change in the Arctic to access the purported quarter of the world's gas reserves (Chazan, 2006; Devyatkin, 2018; CEIP, 2021). Numerous factors could determine oil and gas availability e.g., geopolitical factors (destabilized regimes, war outbreaks, regional tensions, activist protest, and youth restive), diversification (redundancies, alternative distribution facilities), which can lead to oil and gas supply disruptions (MartîSauskas et al., 2018).

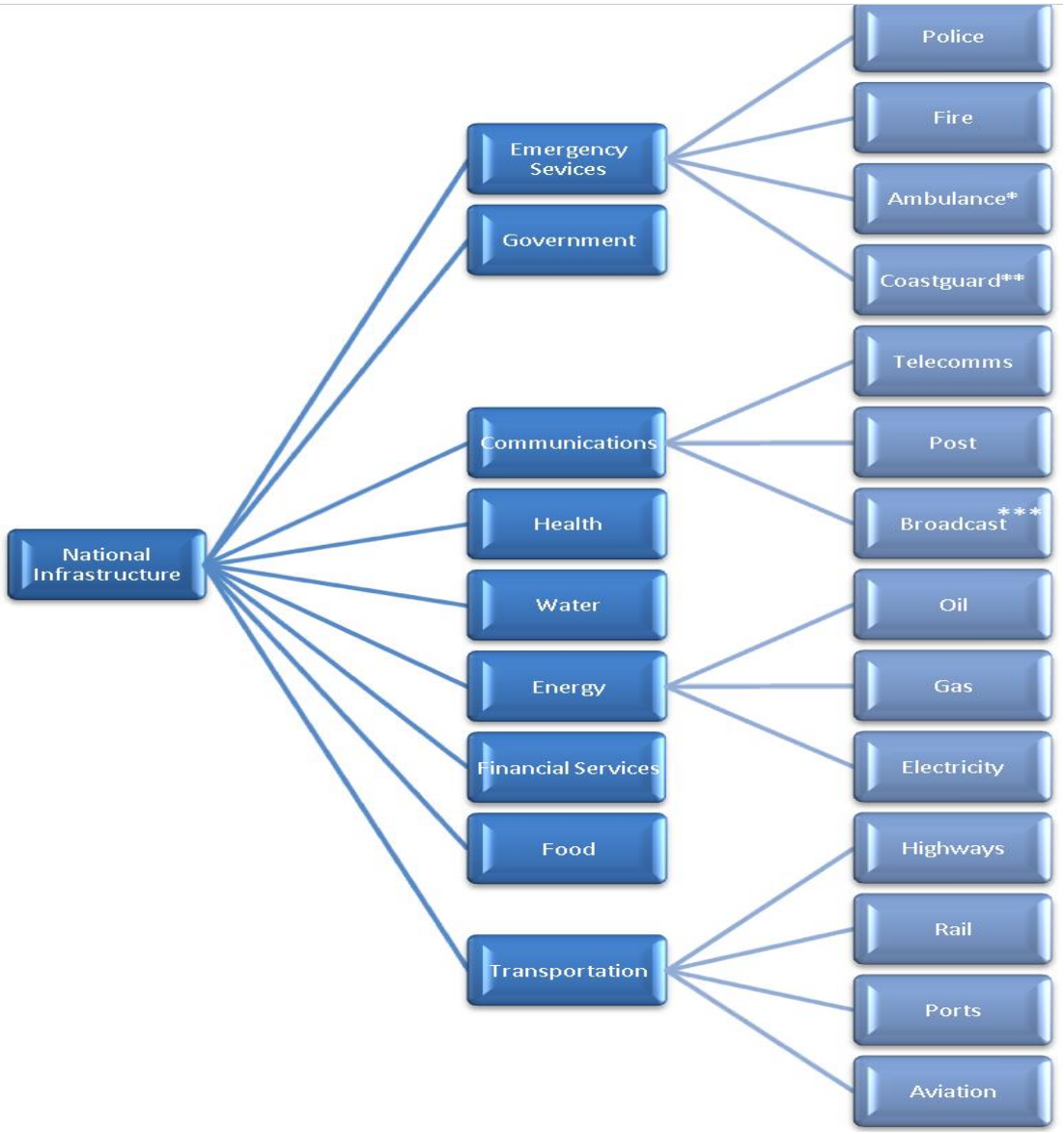
2.7.2 Critical National Infrastructures and Assets Management – The case for DCOGI

Facilities, systems, sites and networks necessary for the functioning of society and the delivery of essential services on which daily life depends are called critical infrastructures (Rogers et al., 2012). Infrastructure assets that are fundamental to the continuous delivery and integrity of the essential services on which a country relies, of which their loss or disruption of its normal functions would lead to negative impacts on the country's economy, environment and human well-being are termed critical infrastructures (Rogers et al., 2012). Critical infrastructures have however been defined in various ways. Bosher et al. (2007), define critical infrastructures as physical and cyber-based systems that are essential to the key operations of the economy and government. Their failure or destruction would have a debilitating effect on the defence, economic security and health of local or national administrations and populations. Montoya (2010) defines critical infrastructures as those

physical and cyber-based systems essential to the minimum operations of the economy and government. The US government defines critical infrastructure as “systems and assets, whether physical or virtual, so vital to the United States that the incapacity or destruction of such systems and assets would have a debilitating impact on security, national economic security, national public health or safety, or any combination of those matters” (Rinaldi et al., 2001). Critical infrastructure systems provide the essential physical basis for modern societies and have a multi-dimensional impact on public safety and economic prosperity at regional and national levels (Shafieezadeh & Burden, 2014). Other approaches refer to critical infrastructure as a term used by governments to describe assets that are essential for the functioning of a society and economy.

The definitions above suggest that critical infrastructure in generally are of both local and national importance because they relate to our everyday living and the economy of our societies; their continued effective performance is capable of creating a national sense of confidence, identity, and purpose (Bosher et al., 2007). Some facilities identified as critical infrastructures are: Electricity generation and transmission infrastructure, gas production, transport and distribution, oil production facilities, transport and distribution, storage, telecommunication infrastructures, water supply and discharge, drainage facilities, public health infrastructures (hospitals, ambulances), transportation systems (fuel supply, railway network, airports, harbours, inland shipping) (Bosher et al., 2007). Also, security services facilities (police, military) and financial services facilities (banking, clearing).

In the UK, the Cabinet office published sector plans for the resilience of critical infrastructure systems in March 2010 and categorized national infrastructure into 9 sector and 16 sub-sectors as shown in figure 2.8 (CO, 2011). Oil and gas sub-sector have been categorized under energy sector. In 2014, the sectors were updated with addition 4 sectors that are chemical industry, civil nuclear industry, defence, and space (CPNI, 2019). Critical national infrastructures vary for different countries, particularly between developed and developing countries.



*Ambulance sub-sector is managed as part of the health sector **Coastguard sub-sector is managed as part of the transport sector *** Broadcast included in 2011/12 Plan

Figure 2.8: UK National Infrastructure Sectors and Subsectors (Cabinet Office, 2011)

Critical oil and gas distribution infrastructures are integral in providing constant supply of oil and gas towards ensuring energy security and requires well-established logistics assets (Shaikh et al., 2017; Grasso, 2019; Chen et al., 2020). Therefore, oil and gas distribution infrastructure sustainability and resilience are of importance to stakeholders in all fronts including investors and host communities. Oil and gas distribution infrastructures include pipelines, storage facilities, transport vehicles and tankers or trucks, rail, barge etc. (Fernandes et al., 2013; Shaikh et al., 2017; Grasso, 2019). Distribution infrastructures of oil and gas are generally categorized under the downstream sector of the oil and gas

industry, others being the midstream and upstream sectors as shown in figures 2.9 and 2.10. Although midstream operations e.g., refinery and petrochemical plants are often included in the downstream category and considered to be a part of the downstream sector in certain cases (Sahebi, 2013; Grasso, 2019).

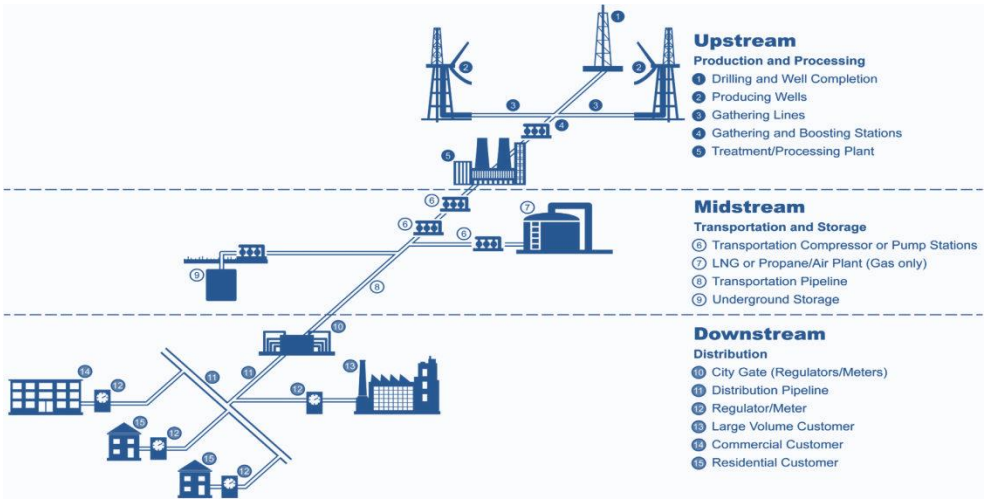


Figure 2.9: Conceptual diagram of sectors of the oil and gas industry (Adapted from Anifowose 2015)

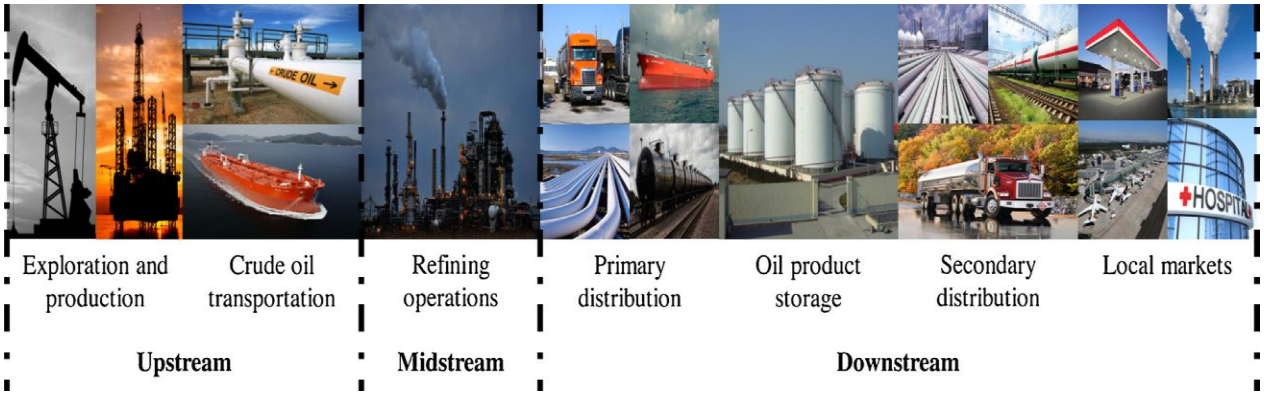


Figure 2.10: The oil supply chain (Adapted from Lima et al., 2016)

The other segment of the downstream is marketing, which implies the selling of oil and gas products to direct wholesale customers e.g., petrochemicals, power plants, aviation, marine etc. and retail customers e.g., users for transportation, warehouses, supermarkets, domestic heating and so forth (Galp, 2014). The literature reveals they are some peculiarities with DCOGIs different from other infrastructure systems that highlight the complexities of DCOGIs. As such some typical tools e.g., stock keeping units (SKU), radio frequency

identification (RFID) and bar codes (IBM, 2005) are not applicable to oil and gas products. Other specific challenges within DCOGI sector include limited visibility in the movement of truck transportation, requirements of optimized schedules of road and railroad transportation, low asset utilization of maritime transportation, ad-hoc mode, and carrier selection also in the maritime transportation and necessity of visibility in the inventory management at storage facilities (IBM, 2003; Capgemini, 2008; British Petroleum, 2015). Although some mathematical modelling approaches and optimization techniques from other supply chains can be adapted to DCOGIs in certain isolated issues, there still remains the need of holistic considerations for integrative assessment and linkages; to cover the triple bottom line and sustainable development goals; as well as the considerations for resilience (Lima et al., 2016).

Apart from the vital process of production, transportation and storage of oil and gas infrastructures, some countries' economies are mainly reliant on their oil and gas industry. Shafieezadeh & Burden (2014) states that such industries are exposed to various natural and manmade hazards. As such, the reliability of these facilities is crucial to prevent disruptions, shortages or blackouts etc. Disruption to their operation may cause human casualties and disrupt the normal day-to-day life in the society. These disruptions may also impose significant direct and secondary economic losses due to business interruption that may not ever fully recover, also debilitating impact on public health and safety of a nation (Cheatle, 2006; Min et al., 2007). Many countries usually adopt asset management measures for managing critical national infrastructures. For countries where a critical national asset is a lifeline, such asset's upkeep and effective management should be and will continue to be of paramount interest (Lima et al., 2016). Like other critical national assets, oil and gas distribution systems are national assets particularly for countries whose economies are reliant on the oil industry. For example, they are essential to exports, distribution within the country and energy security. Oil and gas distribution infrastructures are often vulnerable to disasters and disruptions because of their interdependencies within its sector and across other infrastructure sectors (MartîSauskas et al., 2018; Arup, 2019). Due to the critical nature of such national assets, there is dire need to invest sensibly and ensure adequate management. According to Ramirez-Marquez et al. (2009) and Zhang et al. (2011), there is need to research intelligent cost-effective approaches for their protection. Also, adequate

fiscal investments in these assets could ensure that sufficient energy is available in the short and long terms.

Developed countries like the USA are taking measures to manage their national assets by attempting to tackle current challenges, particularly as the assets are ageing. Several best practice guidance on asset management exists. In the UK several guidance notes for the development and implementation of an asset management system exist e.g., guidance document published by OECD (2001), ISO 55000, ICE Manual of Asset Management (2011), County Surveyors Society (2004) etc. Similarly, in other countries around the world, several organizations and government agencies produce guidance procedures for infrastructure asset management. According to Shah et al., (2014), asset management does not only consider a specific infrastructure, but also takes into consideration impacts of interdependent infrastructure assets. However, Bouch et al. (2015), argues that considerations for infrastructure interdependence should incorporate the end value for it end users and not limited to the infrastructures alone. It can be deduced that an integrated and comprehensive approach is required when considering infrastructure interdependence. For DCOGI systems, there may be a need to adopt bespoke management guidance, taking into consideration interdependencies. Also protecting the investment, minimizing cost and ensuring service delivery; alongside the need to consider future uncertainties, and energy security challenges. The overall goal should take a holistic and robust approach to ensure sustainability and resilience of infrastructure assets towards achieving sustainable development. The next sections attempt to broaden the understanding of interdependence in critical infrastructure systems.

2.7.3 Interdependency and Interconnectedness

This is the reliance of oil and gas infrastructure systems upon another, mutual reliance, also reliance of other socio and geopolitical factors on oil and gas, particularly in systems where feedback loops exist. Societies today are dependent on critical infrastructure systems to provide essential services that support economic prosperity, governance, and quality of life (Ouyang, 2014). Critical infrastructure systems are not isolated but highly interconnected and mutually interdependent at multiple levels to enhance their overall performance. For instance, oil and gas distribution systems will need steady supply of electric energy, various telecommunication services etc. for continuous operation. Water and telecommunication

systems need steady supply of electric energy to maintain their normal operations. Electric power systems require the provision of water and various telecommunication services for power generation and delivery. According to Erenoglu & Erenoglu (2014) transportation networks, water delivery, oil, power, and other related systems are essentials of modern infrastructure. Damage because of natural disasters in one system may cause disruption in other critical infrastructure. As these infrastructure systems are crucial to all social, economic, and living activity in societies, there is need for governments and societies to be aware about potential disasters; thereby ensure preparedness either through strategic planning or pre-evaluation of financial risk (Erenoglu & Erenoglu, 2014).

Interdependence and interconnectedness can either yield positively or negatively. Interdependencies and interconnectedness can improve infrastructure operational efficiency but can be a means to disrupting normal operations or eliminating the functioning of infrastructure systems (Rinaldi, 2001). Recent worldwide events such as the 9/11 terrorist attack, Gulf Coast hurricanes, the 2010 Chile, 2011 Japanese, and 2014 Nepal earthquakes, 1998 storm in Canada, the 2003 North American blackout, the 2004 hurricane season in Florida, the 2007 UK floods, heat waves, among others (Ouyang, 2014); have highlighted that interdependencies among critical infrastructure systems can potentially spread failures and increase the effect of both large and small scale initial failures into events of catastrophic magnitudes throughout regional or national scales. As populations and demands are increasingly rising, infrastructures are becoming more pressured increasing their vulnerability to operational failure. Consequently, increased vulnerability of single infrastructure can be easily amplified due to the interdependencies.

To build in resilience into infrastructure systems there is every need to assess and understand interdependence and interconnectedness that exist with the system. In relation to this research, the proposed sustainability and resilience assessment framework for DCOGI should consider an assessment of all Interdependent and Interconnected infrastructures, both internal and external to the systems. According to Hay (2014), in a preliminary investigation of a community characteristics study, a trend suggested a far greater relationship between infrastructure, organization and people as they together enable an operation within a complex risk context. In the relationship, each as an enabling component of the operation cannot alone deliver resilience, but rather, it needs to be balanced across all three. This balance of components and interconnection demands a degree of synergy that

can only come about if the relationship between operations, organizations and communities are strategically defined. Where this synergy between components and between communities is absent, there is the risk of one high-dependency community drawing down excessively on its neighbours and impeding the city's ability to respond and recover (Cohen et al., 2013; Hay, 2014). Some examples of events resulting from interdependencies include (Ouyang, 2014):

- Outages in power systems led to price changes of food and fuels.
- Disruptions on communication services affected the situational awareness and control of electric power (or water) systems and caused their partial failures due to lack of monitoring.
- Outages in power systems caused the failures of traffic signals, water supply pumping stations, and automated teller machines as well as the closure of businesses.
- Electricity loss led to the interruption of communication services (e.g., mobile phone services), which further affected emergency communication and restoration coordination of power systems etc.

Interdependencies and dependencies of critical infrastructures exist in multiple ways. Interdependency refers to bidirectional interaction and dependency is unidirectional relationship. Dependencies could be considered as interdependencies except they are specially referred (Ouyang, 2014). Table 2.9 presents a summary of interdependency types described by various scholars.

Table 2.9: Types of Interdependencies and their definitions

TYPES OF INTERDEPENDENCY	DEFINITIONS
Physical	The state of one infrastructure system is dependent on the material output(s) of another infrastructure system. There are direct linkages between infrastructure systems from a supply - consumption - production relationship. Infrastructure systems are coupled through shared physical attributes, so that a strong linkage exists when infrastructure systems share flow right of way, leading to joint capacity constraints. (Rinalidi et al., 2001).
Spatial	Spatial refers to proximity between infrastructure systems. (Zimmerman, 2001).
Logical	The state of one infrastructure system depends on the state of others via a mechanism that is not a physical, cyber, or geographic. (Rinalidi et al., 2001).
Functional	The operation of one infrastructure system is necessary for the operation of another infrastructure system. The functioning of one system requires inputs from another system, or can be substituted, to a certain extent, by the other system. (Zang & peeta, 2011).
Market and economy	Infrastructure systems interact with each other in the same economic system or serve the same end users who determine the final demand for each commodity/service subject to budget constraints or are in the shared regulatory environment where the government agencies may control and impact the individual systems through policy, legislation, or financial means such as taxation or investment. (Zang & peeta, 2011).
Budgetary	Infrastructure systems involve some level of public financing, especially under a centrally controlled economy or during disaster recovery. (Zang & peeta, 2011).
Geographic	A local environmental event can create state changes in two or more infrastructure systems. (Dudenhoeffer, 2006).
Geospatial	There is co-location of infrastructure components within the same footprint. (Dedenhoeffer, 2006)
Co-located	Components of two or more systems are situated within a prescribed geographical region. (Wallace et al, 2003)
Mutual	At least one of the activities of each infrastructure system is dependent upon each of the other infrastructure systems. (Wallace et al., 2003)
Exclusive	Only one of two or more services can be provided by an infrastructure system, where disruption can occur within a single infrastructure system or among two or more systems. (Wallace et al., 2003)
Shared	Some physical components or activities of the infrastructure systems used in providing the services are shared with one or more other infrastructure systems. (Wallace et al., 2003)

The DCOGI industry has strong backward and forward linkage with other sector of the economy due to its multidisciplinary nature. By implication, the development in the oil and gas sector plays an important role in the growth of other sectors (IEA, 2017). The growth in oil and gas sector generates the demand for the output of associated sectors like the heavy machinery and equipment's and different kinds of chemical that are used in oil and gas industry received from the manufacturing sector. The construction industry facilitates it by constructing and building platforms. Similarly, the output of the oil and gas sector are consumed as input in the manufacturing, construction, and other sectors of the economy such as diesel fuel, motor oil, kerosene, jet fuel, asphalt, paraffin wax, gasoline and many other commodities (IEA, 2017).

2.7.4 Redundancy

Establishing redundancy is another crucial approach to ensure oil and gas energy security. This approach builds on the concept of planning for expected failures and disruptions by building spare capacity or duplicated infrastructure within a system; examples could include having multiple distribution routes reducing reliance, creating pockets of independent systems and thereby reducing the risks and impacts of disruptions. Systems with redundancy can normally tolerate some infrastructure failures without it affecting their overall function. This may include interconnection to external systems or duplication of assets (Arup, 2019).

In addition to redundancy, Arup has added 6 new recommendations as dimensions that should be consider for energy systems. There are (Arup, 2019): Reflective – ability to understand the impact of internal and external conditions on assets, supply chain and consumption patterns by learning from past experiences through monitoring.

Flexibility – ability to adapt to changing circumstances, as well as deliver energy to end-users through various pathways. E.g., multi-vector energy systems or decentralized and modular approaches to infrastructure like microgrids.

Integration – aligning different energy vectors, exchanging information and energy among different energy vectors. This is essential for optimizing the efficiency and performance of multi-vector energy systems.

Resourcefulness – the possession of range of energy resources and infrastructure at the disposal of planners and operators, to meet demand in times of shock or stress. This may

also include the ability to mobilize and coordinate wider human, financial, and physical resources to respond rapidly. E.g., back-up generators.

Robust – building well-designed energy systems in anticipation of potential failures of infrastructure in the energy supply chain and adopting design thresholds to minimize the risk of infrastructure collapsing catastrophically.

Inclusion – creating a sense of shared ownership and joint vision to build energy system resilience, through broad consultation and engagement of energy users including vulnerable users in fuel poverty.

The following section discusses further, the link between events in the DCOGI industry to their sustainability and resilience.

2.7.5 Governance

Government's role in policymaking, regulatory process, diplomacy, and information collection is vital to ensuring energy security through guaranteed oil and gas distribution (DECC, 2006; Watson, 2015; BEIS, 2018). This will ensure oil and gas are available for use, as sound government policies help circumvent and mitigate energy disruptions in the short-term and can be made elaborate to cater for long term energy disruptions. Projected global demands for oil and gas require forward-looking governments to support the effective planning for and protecting infrastructure to ensure long-term energy security (Goldthau & Sovacool, 2012). Governance and decision-making processes should have an important place in the discussion of frameworks (Allen et al., 2017; Bartniczak & Raszkowski, 2019; Eustachio et al., 2019). Following the sustainable development agenda of 2015, the importance of integrating governance is a focus for sustainability indicator development (Müller et al., 2015). Pupphachai & Zuidema (2017), states that governance should embody Sustainability Indicators in order to generate adaptive and learning processes for sustainability transitions. Having a well-defined and updated regulation and legislation results in infrastructures that are safer and better prepared to prevent a crisis occurrence and that are to better able to handle one when it does occur (Labaka et al., 2016). Recent accidents in the oil and gas industry for example the Deepwater horizon accident, has exposed the lack of regulatory pressure on safety, health, and environment protection (Lin-Hi & Blumberg, 2011). Anejionu et al. (2015) in their study, also reveals that oil and gas companies has exploited the lapses in Nigeria's petroleum laws to gain economic advantages that negatively affect local communities and environment. Evidence

in literature indicates that regulatory pressure can enable oil and gas distribution companies adopt sustainable practices, albeit there may be a risk of creating a barrier to innovations and lowering competitive value (Seuring & Muller, 2008a; Wu et al., 2012; Zhu et al., 2007; Grekova et al., 2014). In many circumstances, oil and gas companies face different regulatory requirements across several countries they operate in. This could be overlapping and can attract cost implications and delays (Wagner & Armstrong, 2010). A review of UK and EU legislation as regards the oil and gas industry is presented next.

2.7.5.1 Planning and Legislative Frameworks for Oil and Gas Infrastructure Development

In times of security of supply concerns and emergency situations, against the backdrop of disruptions to supply e.g., political tensions, natural disasters or human induced events, tight markets; effective planning and regulatory frameworks are mechanisms used to enhance robustness of security of oil and gas supply (IEA, 2017). However, current regulatory frameworks for oil and gas are widely considered as inappropriate and too reactive for example in the UK and Nigeria (BEIS, 2017, NNPC, 2017). The dynamic nature of disruptive event to DCOGI would require that updates and adjustments to existing policy frameworks should be carried out to ensure they are compatible with relevant characteristics of a country or region e.g., to diversify supply source and means of transport that can change over time (OECD / IEA, 2017).

2.7.5.2 UK Current legislation and controls

Government's powers to monitor sector risks, support industry in improving fuel supply resilience and protect fuel supply are currently limited in scope (for example, under the Offshore Safety Act 1992) or, more often, are only available for use during an emergency or crisis. In many cases, powers to direct do not allow Government to act in advance to prevent a problem occurring. Existing powers are outlined below:

- Energy Act 1976: Government has wide powers to regulate or prohibit the production, supply, acquisition or use of petroleum products, fuel, or electricity where: "there exists or is imminent an actual or threatened emergency affecting fuel or electricity supplies".

- Offshore Safety Act 1992: powers that allow directions to be given: "for preserving security of petroleum and petroleum products". The power of direction is limited to security purposes, and can only be used in relation to refineries, or terminals that receive crude oil directly or indirectly from a UK offshore installation.
- Civil Contingencies Act 2004: powers for government to make emergency regulations to deal with actual or threatened emergencies where, for example, there is a serious threat to human welfare arising from disruption to the supply of money, food, water, energy or fuel, or a threat to communication or transport systems.
- Enterprise Act 2002: power for Government to intervene in relevant mergers on national security (which can include security of supply), financial stability or media plurality grounds. To be able to intervene, turnover or share of supply tests must be met.

In the last decade, the UK government as continually recognized the role of oil and gas towards meeting the countries future energy needs. Gas, most notable, has been described as the fuel of the future (Watson, 2011), because gas is considered as the cleanest of the fossil fuels, available in abundance and cheap. Albeit there are ambivalent views on concerns regarding available technology to capture and store gas that has made vital contributions to the UK energy supply, as of 2011 gas contributed 29 per cent of the energy consumed in the UK second only to petroleum products. Over 40 per cent of the country's electricity comes from gas-fired power plants and over 20 million households rely on gas for their heating and hot water. Irrespective of differing views, significant oil and gas is certain to be with us for a long time. Therefore, governments and DCOGI owners as well as other stakeholders are paying more attention to oil and gas security; alongside inherent difficulty of predicting which threats to energy security will suffice. In the UK, 3 planning strategies proposed to strengthen the resilience of oil and gas infrastructures to disruptions that could impact on price and availability; Increasing energy efficiency, diversify sources of supply routes, storage sites and guard against over dependence on a single source, and plans to build more storage facilities. It is also recommended that plans for energy security generally should not be left for investors and operators alone, government should actively be involved (Watson 2015, BEIS, 2018).

2.7.5.3 European Union Regulatory Framework

The EU regulation 994/2010 is the principal legislation with respect to oil and gas security of supply. The regulation establishes a framework to co-ordinate security of supply issues between natural gas transmission system operators, EU member states (and their competent authorities) and the European Commission. Two main indicators are established. To ensure that member states proves that it can satisfy total product demand in case the single largest element of its product infrastructure is not available (infrastructure standard) and that relevant natural gas system operators can supply protected customers even under severe weather conditions (supply standard). Crisis management and information exchange are structured based on three crisis levels that includes the role of European Commission and member states in an emergency declaration as follows: Phase 1 (Early warning) – Defines a situation where an event may occur that is likely to result in significant deterioration of the supply situation. Phase 2 (Alert) – Triggered when a supply disruption or exceptionally high gas demand occurs and results in significant deterioration of the supply situation. However, the market is still able to manage the disruption or demand without the need to resort to non-market measures. Phase 3 (Emergency) - Declared where there is a significant supply disruption, exceptionally high gas demand or other significant deterioration of the supply situation. All relevant market measures have already been implemented, but the supply of gas is still insufficient to meet the remaining gas demand, so non-market measures have to be introduced specially to safeguard gas supply to protected customers (European Council, 2017).

2.7.6 Environment

The European commission emphasizes the significance of environmental concerns and sustainability in energy security (EC, 2001), just as Pasqualetti and Sovacool (2012) highlights the importance of provision of environmentally benign energy services for energy security. Environmental issues are closely related with oil and gas due to carbon and other emissions that contribute to global warming and air pollution, others include oil and gas leaks oil spills during oil and gas transportation. Most oil and gas companies operate in politically unstable countries; conflicts resulting from the instability could lead to adverse events that can cause ecological disasters with wide ranging implications e.g., economic / financial loses, can affect employments and means of livelihood (Urciuoli et al., 2014). Environmental impacts from oil and gas operations potentially invokes stakeholder pressure

(Ahmad et al., 2016), this necessitates that the companies should become more proactive towards the impacts of its activities on the environment. Oil and gas distribution systems, just like most other distribution systems globally are complex, physical, chemical, biological and socio-ecological systems that can contaminate elements they interact with including the environment (Husband & Boxall, 2016).

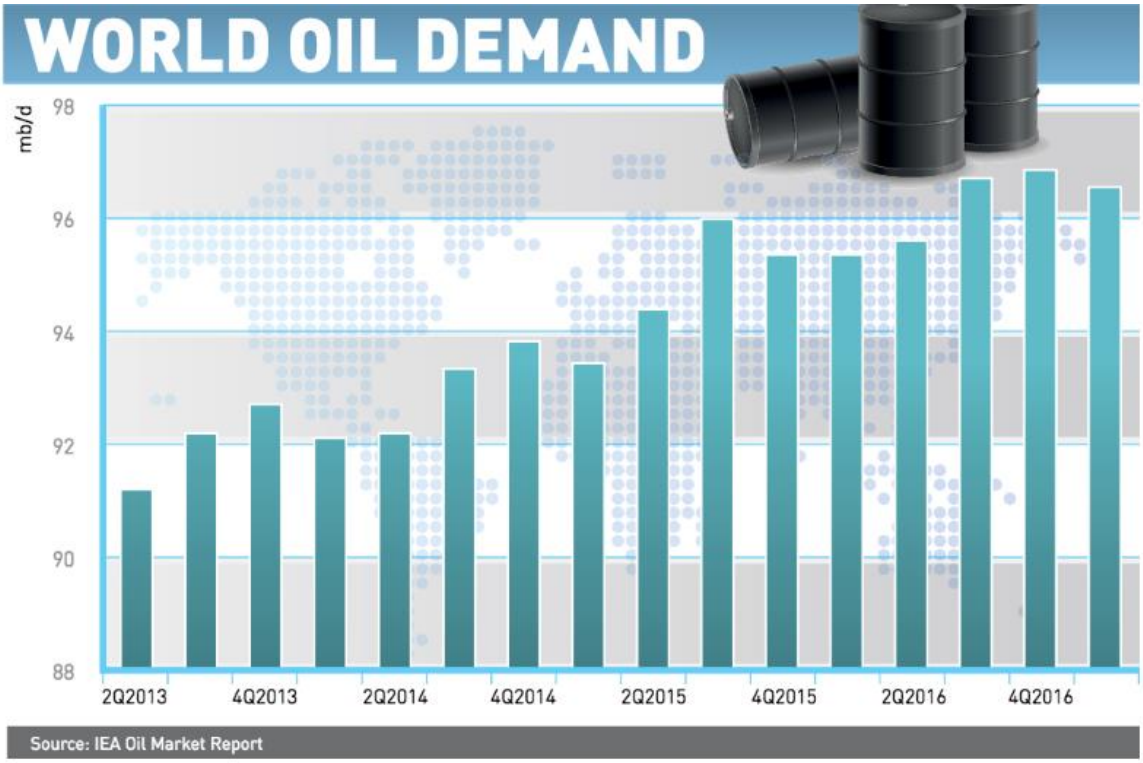
2.7.7 Societal Effects

Oil and gas distribution infrastructures are mainly routed through cities, local communities, and along roads where citizens dwell and ply respectively, therefore the effects and interactions these infrastructures have on citizens should be of concern. Also, to ensure good level of social and economic welfare of citizens through uninterrupted access to oil and gas products, it is vital to ensure that oil and gas distribution facilities are resilient to various disruptive elements. This is consistent with the Centre for Energy Economics emphasis that energy security should ensure that "the economic and social development of the host country is not materially constrained" (CEE, 2008), and the UK DECC's (now BEIS) emphasis on the social aspect of energy security. The literature reveals that increasingly more oil and gas companies are involved in cooperate social responsibilities (CSR) practices, in some cases necessitated by stakeholder concerns and society pressure (Hilson, 2012; Ahmad et al., 2016). However, it is not clear how effective the practices are in the long term. Current oil and gas companies CSR practices have been criticized, they are considered to only provide short term impacts and somewhat philanthropic in nature (Frynas, 2005). A major flaw identified thus far is that the development program for the CSR does not involve key stakeholders and beneficiaries e.g., the local communities, hence current CSR are largely not sustainable (Frynas, 2005, Ahmad et al., 2016).

2.7.7.1 Role of Oil and Gas in Societal Wellbeing (Global & Local)

Oil and gas availability continue to be the most reliable and economically viable source for energy that keeps our modern societies and their supporting economies functioning. Thereby contributing largely to the global primary energy consumption (Dudley, 2019; Chen et al., 2020). The global demand for oil and gas has continued to soar as shown in figure 2.11, a trend that is likely to continue without decline for the next 40 years, with China and India accounting for the most demand growth in 2019 (Chen et al., 2020; IEA, 2020). Gas is increasingly playing a vital role in economic growth and national security, particularly with the generation of electricity. Globally, oil continues to account for the

largest source of liquid fuels and expected to still account for about 90% by 2030 and beyond (Grasso, 2019). China for example is accounting for 37 per cent of global increase in gas consumption in 2017-2023; in 2019 China was expected to be the world's largest gas importer (IEA, 2018). To ensure continuous energy availability and economic growth,



Vertical axis shows quantity in million barrels per day – Horizontal axis shows 2nd and 4th quarter of the years

Figure 2.11: Global Oil Demand (IEA 2018)

countries have continued to find new site(s) for exploration and develop new techniques (e.g., fracking, also see section 2.7.1) by which to extract further deposits of oil and gas. The oil and gas industry touches everyone's live and will continue to play an important role in the global energy system by 2040 and beyond (F. Hedenus et al., 2010; IEA, 2018; BP, 2019;). Countries are largely economically dependent on their oil and gas industry as a major contributor to their Gross Domestic Product (GDP). For example, UAE; Qatar; Nigeria; Saudi Arabia; Libya; Russia and India (Anifowose B. & Odubela M., 2015). Therein oil and gas continue to serve as a traditional source of energy for many industries (e.g., chemical, metal, paper, plastics and oil refining industry). In addition, oil and gas products (e.g., diesel fuel, motor oil, kerosene, jet fuel, asphalt, paraffin wax, gasoline and many other commodities) are equally important for: operating vehicles; home appliances; industrial processes; manufacturing; construction and other sectors of the economy. The

distribution infrastructures for the oil and gas products are as vital, without which it may be difficult to access the products (Lima et al., 2016).

Oil and gas activities also have negative impacts on society for e.g., pollution. Impacts of oil pollution on the environment and societal wellbeing can be grouped into three interrelated impacts:

1. Adverse Impacts on Biodiversity: The most profound and adverse impact of oil pollution has been the total loss of biodiversity and destruction of habitats largely due to soil degradation. The result of unchecked oil pollution has led to complete destruction of ecosystems (Anifowose & Odubela, 2015).
2. Socio-Economic Impacts: Socio-economic impacts of oil pollution result in changes in nutritional styles and food shortage, which also leads to job loss, as the local economic support system of fishing, and farming is no longer sustainable. Migration of people from oil spill communities due to the in conducive environment has had adverse impacts on cultural values and social harmony (Anifowose & Odubela, 2015).
3. Physico-Health Impacts: Oil pollution has led to the rise in occurrence of certain ailments previously unknown in the area such as respiratory problems, skin ailments like rash and dermatitis, eye problems, gastro-intestinal disorders, water borne diseases and nutritional problems associated with poor diet. Furthermore, when oil spills occur, it seeps the oil into the ground and becomes mixed in the underground water system. This underground water moves into streams and wells, which are the main source of local water supply in some community, resulting in the rise of water borne diseases (Pyagbara, 2007).

2.8 Activities and Accidents in the DCOGI Industry – Relation to Sustainability and Resilience

The concept of sustainability has been very much around, although not much within the confines of DCOGI; resilience as a concept has only been talked about much recently within the policy and infrastructure sphere (Anderies et al., 2013; Lew et al., 2016; Martîsauskas et al., 2018; Chen et al., 2020). For example, resilience entered the US national policy vocabulary in April 2015 when the first US quadrennial energy review

identified deficiencies in oil, gas, and electricity transportation, storage, and distribution systems that emerged in Hurricane Katrina's wake nearly 10 years earlier (BEIS, 2018). Following this, not many could have anticipated that an even more violent storm would put the same systems to a fresh test in late August 2017. As identified, it is now being thought that for such critical national infrastructures to continue to provide essential services, there is a need to put in place resilience policies to ensure these infrastructure systems are continuing to function or recover swiftly despite such events (O&G Journal, 2018). Following the growing trend of disruptions in the DCOGI industry, Lew et al., (2016) suggest sustainability alone is not sufficient response. In this regard, Binder et al., 2013; Redman, 2014; Zhao et al., 2015; Champagne & Aktas, 2016; Lima et al., 2016; Gillespie-Marthaler et al. 2018; Roostaie et al., 2019 propose the integration of sustainability and resilience or balancing both concepts to attain a comprehensive and effective response. A review of disruptive events to the DCOGI systems is being done in the remainder of this section.

There are several inherent disruptive events to the DCOGI that can be viewed from a historic perspective, human induced events, and nature-induced events. These events include malicious attacks, accidents, severe weather, and even industrial actions (BEIS, 2018). Disruptions in the DCOGI industry are reported to have increased in recent times (Chen et al., 2020); particular in the wake of recent intentional attacks on DCOGI that has shocked the world. Disruptions to the DCOGI have been reported to have long-term effect on societal wellbeing and economic impacts. For example, table 2.10 presents the economic impacts of disruptions to two DCOGI systems in the UK. More examples of impacts to DCOGI systems are listed next:

Table 2.10: Potential Economic Impact of DCOGI Disruptions (£M in 2015 prices, using Oil Intensity Ratio in 2019) (Source: BEIS, 2017)

(£M)	3-day disruption (£M)	6-day disruption (£M)	10-day disruption (£M)
Refinery or large terminal	100 - 500	200 - 950	350 - 1600
Smaller Terminal or Jetty	50 - 200	100 - 450	150 - 750

On August 27, 2018, 22% of the oil distribution and 27.5% of the gas distribution in the US gulf coast was off-line (US DEIER, 2018). Most US Gulf Coast refineries also had to be shut down; it continued to affect retail gas station as outages were reported in the impacted region. Valero Energy Corporation closed its refineries at Corpus Christi and Three Rivers on August 25, 2018 and reported 2 days later that neither was damaged substantially (BEIS, 2018). Between 1993 and 2008, a total of 15,718 intentional attacks on DCOGIs occurred in Nigeria (Anifowose et al., 2012).

On 14th September 2019, the Abqaiq oil plant in Saudi Arabia was attacked using drones. This impacted the distribution of oil by 50% and an increase in price of oil in Abqaiq (Chen at al., 2020). The incident highlighted the vulnerability of DCOGIs to intention attacks and the importance of safety and security in the DCOGI industry. On 22nd November 2013, oil storage facility in Qingdao China had fire explosions from a leakage point ignited during leak repair operation (Zhu et al., 2015), causing fatalities, injuries, damages and impact of suspending service operations. The Shamoon cyber-attack on Aramco in 2012, the Saudi Arabian Oil Company and cyber-attack on RasGas natural gas firm in Qatar in 2012, aimed at causing disruptions to physical energy supply chain. Signifying the inception of new form of attacks on DCOGIs (Onyeji et al., 2014).

The explosion in Buncefield oil storage depot (Hemel Hempstead, Hertfordshire. UK) in December 2005 (See Figure 2.12), caused a fire that destroyed the site. The event caused an immediate shortage on fuel supply, forcing the long-term systematic rationing of products e.g., aviation fuels with severe impacts on long-distance carriers; increased supply by other suppliers to meet demand, impacts on road fuels that caused a shock to users, airlines using Heathrow resorted to carrying extra supplies of fuel on inbound flights (BEIS, 2017). As currently practiced in the DCOGI industry, suppliers made a reactive response to quickly put alternative routes in place. This single event cost the aviation industry alone over £250 million (BEIS, 2017).

In 2007, Petroplus purchased the Coryton Insolvency refinery, situated on the Thames Estuary in Essex, UK. They eventually went into bankruptcy in 2012, and later converted to an import terminal in 2013 (BEIS, 2017). The closure had implications on logistics capacity

affecting the immediate and wider regions, also reduction in storage capacity affecting assets across the South East. There was a four-year interruption following the closure.



Figure 2.12: Buncefield Oil Fire Explosion on Sunday 11 December 2005 (Image Source: Robert Stainforth, 2005).

Between January 2015 and January 2016, the Nigerian National Petroleum Corporation (NNPC) recorded loses of N57.71b due to vandalism from 2,832 vandalized pipeline points and 400 in February 2016 alone (Tubotein, 2016). It was report that unless the Government took drastic measures to eliminate acts of pipeline vandalism, it may be virtually impossible to operate its refineries crude oil and products pipelines nationwide profitably and meet supply obligations to customers (Tubotein, 2016). Security challenges have been a major cause of disruption in addition to aged infrastructure and the corporation has reported dilapidating pipelines. Figures 2.13, 2.14, 2.15, 2.16 are more evidence of intentional attacks on DCOGI and impacts. Table 2.11 and 2.12 presents a summary of disruptive events in the DCOGI industry and factors that affects DCOGI sustainability and resilience respectively. Arup (2019) identifies the following as capable of causing risk of shocks and stresses in the DCOGI industry: ageing and deteriorating assets, extreme weather events and climate change, natural hazards e.g., earthquakes and volcanoes, geopolitical uncertainty, population growth, increasingly interconnected and interdependent systems,

new disruptive technologies, human error, physical and cyber security threats, and changing consumer expectations.



Figure 2.13: NNPC gas distribution pipeline repairs (Image Source: Tubotein, 2016).



Figure 2.14: NNPC gas distribution pipeline after an intentional explosion (Image Source: Tubotein, 2016).



Figure 2.15: Poorly Maintained Oil Distribution Pipeline Spewing products (Image Source: Author)



Figure 2.16: Vandalized oil distribution pipeline (Image Source: Tubotein, 2016).

Table 2.11: Causes of Accidents in DCOGI Industry (Adapted from Fabiano & Curro, 2012).

Source	Cause
Plant / process	
	Failure or damage to reactors, vessels and equipment.
	Components failure / malfunction.
	Loss of process control.
	Corrosion, fatigue, wears.
	Failure/malfunction of equipment and control system.
	Piping loss of containment.
	Unexpected / uncontrolled reaction or transition phase.
	Plant block
	Electrostatic charge.
	Loading and unloading operations of road tankers/barge.
Environment	
	Natural event.
	Domino effect from other events.
	Transport accident.
	Hit by objects / fall of objects.
	Building / facility failure.
	Security lack.
Organization	
	Inappropriate management / planning policy.
	Absent, inadequate, unclear procedures.
	Absent, inadequate job / safety training.
	Absent, inadequate supervision.
	Absent, inadequate staffing.
	Incorrect process analysis.
	Inappropriate / inadequate plant design.
	Equipment and instruments non user-friendly.
	Unsuitability of manufacturing / construction.
	Inappropriate / inadequate installation.
	Insufficient isolation of equipment.
	Lack of maintenance.
	No inspections.
	Worker error.
	Worker health.
	Non-observation of procedures and rules.
	Intentional act / attack.

Table 2.12: Summary of Factors that hinder the Sustainability and Resilience of DCOGIs.

Factors	Events	Impacts
External	Political instability and societal unrest, economic instability, stakeholder pressure, stakeholder dissatisfaction, Competition (Wan Ahmad et al., 2016). Terrorist Attacks, Intentional attacks, theft, earthquakes, floods, lighting, accidents, (Zhu et al., 2015; Sharifi & Yamagata, 2016; Razazadeh et al., 2019; Chen et al., 2020). Attacks on physical DCOGI (Sharifi & Yamagata, 2016), Vandalism, facility interdictions, intentional attacks (Anifowose et al., 2012).	Reduction in demand, loss of revenue, public unrest, civil war, industry protest, insecurity, industrial accidents, supply delays, and competitive disadvantage. Economic losses, casualties, environmental pollution, sustainability of infrastructure, resilience, impact on population, impact on the industry activity, injuries, loss of life, public panic, disruption and precarious oil and gas supply, rippling impact on and failure of interdependent infrastructure systems and allied industry operations. Sustainability and resilience of systems, loss of revenue, disruptions in supply operations, product scarcity, impact on support business and allied industry, increased transportation prices, increased prices of goods.
Internal	Lack of local content policies, positive contributions to economic development, corporate social responsibility gaps, inadequate management directives and guidelines, non-compliance to government regulations (Ngoasong, 2014). Lack of intelligent technologies and digitization (Lu et al., 2019). Cybercrime and attacks, IT security issues, insider sabotage (Onyeji et al., 2014; Corallo et al., 2020;). Lack of energy transition strategies, regulations, health management system, safety management system, and safety culture. Fire incident, explosions, knowledge management and communication, safety, toxic release in environment, human error, corrosion risk, obsolete infrastructure, no facilities management systems, maintenance culture, noncompliance to policies and regulations, obsolete infrastructure systems (Anifowose et al., 2012; Wan Ahmad et al., 2016; Zhu et al., 2015; Sharifi & Yamagata, 2016; Razazadeh et al., 2019; Chen et al., 2020). Preparedness for risk, organizational innovation, environment's preparedness for disaster, personnel preparedness for disasters, disaster contingency plans, risk and safety management and standards, flexibility of systems, personnel knowledge-skills-attitude development (Rehak, 2020).	Commercial implications, public policy repercussions, social unrest, disruptions to operations, competitiveness. Disruptions to vital energy supply / availability of energy, disabling monitoring and security equipment, causing physical damage on DCOGI systems, operational disruptions, theft of information and competitiveness. Efficiency and optimized operations, systems reliability, facilities security, Disruptions of operations, sustainability and resilience, impact on DCOGI systems, personnel risk.

2.9 Cyber Security

Today's changing world presents a mix of new concerns across the DCOGI industry, from physical threats to compromised information technology (Russo, 2014; Corallo et al., 2020). The threat from all forms of cyber disruption has grown continually over the last decade, and shows no sign of abating, rather the rate of increase in the threat grows in both number of incidents, and sophistication (Onyeji et al., 2014; Pipeline magazine, 2017). And so cyber security across the DCOGI industry has become one of the highest priorities for governments and asset owners due to the increasing susceptibility to cyber-attacks (Onyeji et al., 2014). Currently, there is a shift from the traditional separation between information technology and operational technology in the DCOGI industry, to an integrated approach. IT is now integrated into virtually every aspect of OT. Although this has created new opportunities towards cyber resilience, it also presents some complexities, and new vulnerabilities (IEA, 2018; Estay et al., 2020; Corallo et al., 2020). In many countries today, there are increased spending for abating cyber security challenges (Onyeji et al., 2014). The UK government has recently put in place a national cyber security center and strategy 2016-2021 supported by a £1.9bn transformational investment, with a vision of ensuring its national assets are secure and resilient to cyber threats (Source: Sky news UK, May 2018). In the Middle East, spending on protecting against cyber-attacks on energy and critical infrastructures was forecasted to be a market worth USD$8.2bn by 2020 (IEA, 2018). The increased focus on cyber security in recent times makes it a key indicator for ensuring security as it relates to DCOGI systems.

2.10 Health and Safety

Health and safety are an important part of any industry, but particularly so in the downstream oil and gas sector (Chen et al., 2020), which is classed as a major hazards industry. Reducing the number of dangerous occurrences, injuries and carbon footprints should remain a top priority and a key focus of the industry's absolute commitment to continually improve process safety standards. The industry is expected to continuously put more effort into improving its safety performance through leadership, communication, and co-operation (IEA, 2018). Transparent reporting of safety performance and learning from accidents and incidents is achieved through information sharing at many industry safety forums. The DCOGI industry should continue to recognize the importance of joined up working and engage the workforce and trade unions through safety committees and industry wide networks.

2.11 Summary and Knowledge Gaps: Remarks on the State-of-the-Art

A review of the literature on relevant research studies pertaining to sustainability and sustainability assessment frameworks, resilience, and resilience assessment frameworks, DCOGI industry, and disruptions that impact DCOGI sustainability and resilience has been provided for the purpose of drawing out current approaches and practices applicable to DCOGI specifically. The literature denotes sustainability and resilience as pliable concepts and accentuates the importance of their integration, in the light of increasing hazards, disruptions to critical infrastructures, and efforts to attain sustainable development goals. Although the core principles of both concepts are transferable, existing studies suggest a context specific definition of both concepts is more meaningful. From the literature review of DCOGI industry activities, the sustainability and resilience in DCOGI context can be broadly surmised into the following four characters: 1. Longevity and flexibility of DCOGI physical structures; 2. Uninterrupted delivery of oil or gas and their products; 3. Adequate DCOGI organizational and management system; 4. Economic Competitiveness of DCOGI systems.

Following the literature review, not all the knowledge gaps identified may be relevant to the aim of this study. As such, statements to that effect will be limited to those that impact the aim of this study. The identified knowledge gaps are presented as follows: Although the sustainability assessment frameworks reviewed serve the entities they were developed for, none of these assessment frameworks considers sustainability for DCOGI conceptually and operationally. Some of the sustainability assessment frameworks and approaches reviewed have a range of sustainability indicators but are too generic e.g., SPeAR®, time consuming to use e.g., HalSTAR, and not user-friendly, while others do not cover the triple bottom line of sustainability (i.e., economic, social, and environmental considerations). Therefore, they do not meet the requirements for the purpose of this study. Additionally, the literature identifies that there is lack of empirical studies on sustainability assessment for DCOGI specifically (Lima et al., 2016, pg89). This is a significant shortfall for all stakeholders to the DCOGI industry.

The resilience assessment frameworks reviewed may serve the entities they are developed for. However, the literature review reveals that none of these assessment frameworks has considerations for DCOGI conceptually and operationally. Although they are generic resilience metrics and assessment frameworks for critical infrastructures, none of them is

comprehensive (i.e., encompassing all the dimensions of resilience) for assessing the resilience of DCOGI. The study by Labaka et al. (2016) specifically recommends the need to develop resilience assessment frameworks for individual infrastructure systems, taking full consideration of infrastructure specific requirements. In general, the literature identifies that there is a lack of empirical studies on resilience assessment for DCOGI specifically (Lima et al., 2016, pg89). This is a substantial knowledge gap identified within the literature.

A further knowledge gap worthy of note is that none of the current assessment frameworks offers guidance on an integrated sustainability and resilience assessment. The need for an integrated assessment of critical systems is consistently emphasized in the literature, where synergies, linkages, interdependence, and interconnectedness within the domains of sustainability and resilience are fully considered. Binder et al., (2013); Redman, (2014); Zhao et al., (2015); Champagne & Aktas, (2016); Lima et al., (2016); Gillespie-Marthaler et al. (2018); Roostaie et al., (2019), specifically identifies the need to develop conceptual frameworks to assess sustainability and resilience in an integrated manner and ultimately operationalise.

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter presents the general methodology for the study following the gaps in knowledge demonstrated in the literature review chapter. The literature revealed the rather fragmented and non-integrative indicators, and no comprehensive framework for assessing sustainability and resilience in the context of DCOGI. To address this shortfall, this chapter describes the philosophical phases of the research and the related methods used to develop the bespoke sustainability and resilience assessment framework for assessing DCOGI system. The theoretical narrative of and justification for each method used for this study is detailed in the following sections of the chapter. Figure 3.1 represents the phases undertaken to achieve the overall aim of this research. In summary, the phases are as follows:

Phase 1. Theoretical Investigation: A systematic literature review was conducted to have a clear understanding of concepts of sustainability and concepts of resilience, existing sustainability, and resilience assessment frameworks to identify existing sustainability indicators and resilience metrics if applicable to DCOGIs, and justification of the combine (hybrid) approach for both sustainability and resilience assessments. This included the review of DCOGI industry related crisis through the lenses of energy security, to understand all the internal and external factors that impact DCOGI sustainability and resilience. This enabled the identification of gaps in literature, identification of research methods, identifying the most appropriate tool within the literature to meet the requirement of the research, selection of indicators to reflect the objectives of the research, and the development of a conceptual sustainability and resilience assessment framework for DCOGIs.

Phase 2. Empirical Investigation: A survey involving a range of DCOGI stakeholders was utilised to obtain information necessary for the development of the proposed RESOGI assessment framework, comprising of sets of qualitative and quantitative questions to which respondents provide their views with respect to sustainability and resilience of DCOGIs, ranking each of

the identified indicators, measures necessary for developing weightings of identified indicators, and rating impact levels of the identified indicators on a range of DCOGI. As a necessary component of this study, the survey results facilitate some key achievements. To match theoretical findings from extant literature on sustainability and resilience assessment with actual practice, their implication to DCOGIs, and to identify indicators applicable to DCOGIs. To gain in-depth empirical understanding from the identified stakeholder's standpoint on extant industry practices, suggestions for improvement, and modalities for measurement. And enabled the development of beta version of the proposed RESOGI assessment framework, incorporating the survey responses to the identified indicators and the development of an implementation and rating system.

Phase 3. Demonstration and application of the RESOGI assessment framework: to demonstrate the application of the developed RESOGI assessment framework, two case study assessments were carried out. Both case studies DCOGI are in Nigeria, West Africa. This enabled the road testing of the RESOGI assessment framework; prove of the hybrid concept and deriving the Gemma version of the RESOGI.

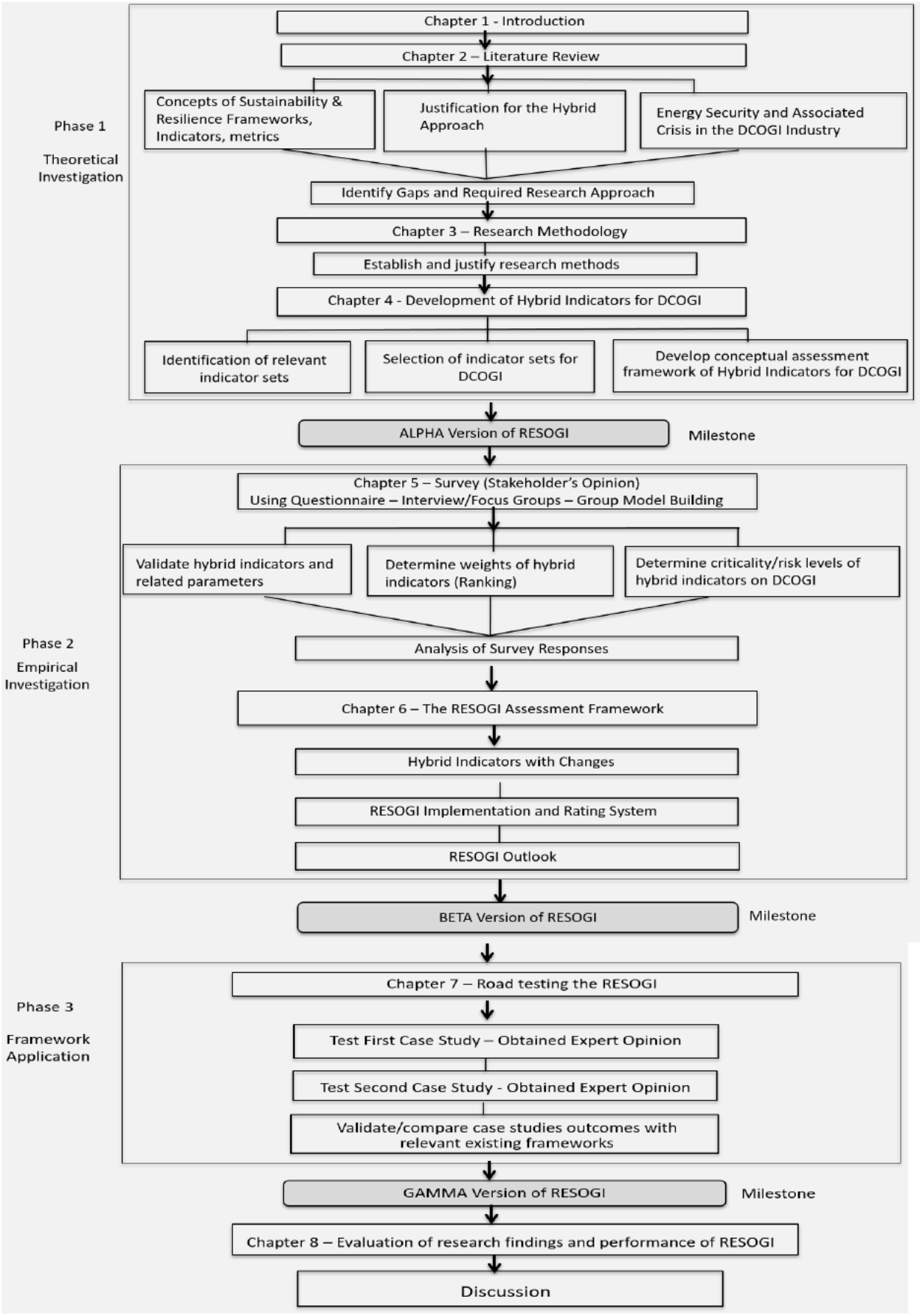


Figure 3.1: Philosophical Phases Of Investigation

3.2 Research Phase 1

In this section of the chapter, the step-by-step methods undertaken to carry out literature review and to develop a conceptual framework for sustainability and resilience assessment of DCOGI is explained.

3.2.1 Literature Review

The review of literature is an important process in acquiring knowledge of a research subject area and constitutes an integral part of an academic development (Bell, 2010; Estay et al., 2020). Integral to specific justification and methodological approach for the review of the literature is also the need to answer specific research questions, identify gaps in theory as regards the research subject area, as well as justify the need for this research and benefit of this research. A systematic gathering of extant scientific work, and the use of direct or meta-analysis of explicit or tacit information synthesis have been documented to be effective approach for literature review (Schryen et al., 2015; Estay et al., 2020). For this research a systematic literature review process (SLR) is adapted, using documented guidelines as outlined by Durach et al. (2017). The SLR is originally common in medical research, but it is increasingly in use for supply chain management (SCM) research despite the challenges posed by the ontological and epistemological idiosyncrasies of SCM research. Durach's guidelines build on the frameworks by Mulrow (1987) for the medical field and it's adaption by Tranfield et al. (2003) to the management field. The SLR is considered as comprehensive, explicit, and reproducible method to provide evidence of identification and selection of relevant literature for this research. The literature review protocol followed in this research is presented in table 3.1.

Table 3.1: SLR Protocol Used for This Research (Adapted from Durach et al., 2017)

SLR Parameter	Description
Context of research	Sustainability and resilience assessment framework for DCOGIs; The strategic importance of a comprehensive and integrative framework for developing, managing and rehabilitating DCOGI systems to prevent or limit the consequences of operational disruptions and meet stakeholder needs; Energy security from oil and gas; justifies the effort of summarizing what has been published through a structured, reproducible process.
SLR relevance	The review of existing literature about sustainability and resilience frameworks for DCOGIs can highlight shortfalls in the research subject area, highlight aspects for future research and provide guide to develop the proposed RESOGI assessment framework.
Unit of Analysis	Published articles in peer-reviewed journals, oil - gas - energy policy reports.
Research questions	What are the sustainability and resilience assessment frameworks for DCOGIs published in literature.
Sources of data	Search engines on the science direct (Elsevier) database with no time restrictions. Also, Google Scholar / Google search.
Search strategy	a.- Used the search engines with the title keyword combinations to obtain a wide set of relevant literature. b.- Filtered the initial set of literature by using the Exclusion Criteria and Inclusion Criteria to obtain literature more relevant to the research subject area. c.- Downloaded and reviewed full text format of the literature, manually search their reference list for more relevant literature using the keywords.
Title keyword (search) combinations	sustainability AND resilience AND framework OR methodology AND assessment AND oil and gas AND critical infrastructure AND indicators OR metrics.
Exclusion Criteria	a.- Only scientific articles, b.- Written and published in English language, c.- Has an abstract.
Inclusion Criteria	Title or abstract contains "Framework" OR "Methods" OR "Indicators" OR "Metrics" AND "Sustainability" AND "Resilience" and are related to oil and gas and DCOGIs.

Using the SLR protocol in table 3.1, the review of peer-reviewed journal articles, oil and gas industry reports and government energy policy reports was conducted, that focus on concepts of sustainability, resilience and the DCOGI industry activities. The process involved exploring what has already been done in the research area of sustainability and resilience applicable to DCOGIs, how it has been researched, identifying existing indicators or metrics, current industry practices and policy, key issues associated to the DCOGI sector; in general gathering information relevant to the research aim and establishing the theoretical

basis for the intended research. This resulted in showing an understanding of the main theories in the subject area and how they have been applied and developed, including the main criticisms that have been made. Given the broad nature of the sustainability and resilience subject area, the literature review was structured in three phases.

Firstly, the literature review of existing sustainability and resilience assessment frameworks, here the literature review explores sustainability science and resilience theory, by examining the various definitions, and the frameworks and indicators or metrics for assessing sustainability and resilience. This was necessary in giving insight on established tools and indicators for assessing sustainability and resilience concepts in different context. It was possible to identify adaptable sustainability and resilience indicators and frameworks, for developing the proposed RESOGI. Secondly, an integrative approach is proposed due to the nature of the study (i.e., combine assessment of sustainability and resilience), this necessitated the review of academic literature on the hybrid approach. It is expected that the review would reveal the benefits and pitfalls for the hybrid approach and to examine existing efforts to this regard. Thirdly, the review of literature on energy security factors associated with sustainability and resilience of DCOGI industry. It was necessary to review this aspect of literature as it relates to this study, to identify sustainability and resilience indicators or metrics useful for the development of the proposed REOSGI assessment framework. It was deemed necessary to examine the role of oil and gas in societies, economies, governance framework, operational complexities and external factors affecting the DCOGI sector.

Ultimately, using the SLR protocol and structure discussed, it was possible to establish relevant information that exists in the literature and shortfalls that significantly contribute to shape the remaining phases of the research. There is the possibility or risks of not capturing all information (e.g., disruptions, vulnerabilities, existing indicators and mitigation measures etc.) from the literature review and secondary data sources used. However, it is expected that further information obtained in the empirical phase (surveys with DCOGI stakeholders) of the research would capture more contributions from actual experience, alongside validating information obtained from the literature and ensure robustness of the research.

3.2.2 Indicator Selection and Development of Conceptual Framework

Prior to the development of the conceptual framework of hybrid indicators for DCOGI, literature review on various sustainability and resilience assessment frameworks was carried out in chapter 2. It is worth noting that at this stage of the research, the term "hybrid indicator" refers to sustainability and resilience indicators derived specifically for DCOGI. The literature review covered current sustainability and resilience frameworks and indicators applicable to allied infrastructure sectors, and deductions from emerging issues in the literature on global causes of disruptions to DCOGI operations. From the frameworks reviewed, the Arup SPeAR® sustainability assessment framework was selected as the most appropriate tool to be used as a base tool for indicator selection and development of conceptual sustainability and resilience assessment framework for DCOGI. The Arup SPeAR® is widely known for its flexibility, holistic considerations, and ease of usage across numerous projects, SPeAR® indicators can be removed or modified (Venables et al., 2005; Braithwaite, 2007; Holt et al., 2010; Singh et al., 2012; Zargarian et al., 2016). The literature review revealed various disruptive (including anthropogenic and natural) events affecting DCOGIs operations, and a summary of impacts. Thus, it was postulated that the following themes affect the sustainability and resilience of DCOGIs: Vulnerabilities, Interdependencies, Cost, Scale, Policy, Governance, Redundancies, Risk management, and Alternatives.

Using the SPeAR® framework and the themes identified from the literature, sustainability and resilience indicators and sub-indicators deemed suitable for DCOGI were selected by undergoing a sifting process, and new sets of hybrid indicators were developed specifically for DCOGI. It is considered best practice that any such selection or removal process should be done by professionals e.g., with the SPeAR® selection process. The selection process was done and reviewed at the Centre for Resilience Research and Education, University of Birmingham with a sustainability engineer and former member of Arup involved in the development of SPeAR® (Mr. Peter Braithwaite) who as an expert has experience in the subject area. A qualitative selection and review process were done in the form of yes / no answer with respect to suitability of SPeAR® indicators and the above themes to DCOGIs. As such, some postulates were affirmed as true to consolidate the proposed hybrid model theory. Following this, it was possible to conceptualise an integrated assessment framework of hybrid indicators for DCOGIs. The conceptual hybrid assessment framework

incorporates all the fundamental dimensions of sustainability and resilience (i.e., Social, Environmental, Economic, Technical, Organizational dimensions) as well as internal and external factors relating to the DCOGI industry are also embedded into the framework. The detailed narratives of each of the indicators are presented in chapter four. To validate the developed framework, the hybrid indicators and sub-indicators were presented to stakeholders of the DCOGI industry during a survey including industry practitioners, to further assess their suitability and make useful contributions. Apart from being a milestone towards achieving the aim of the research, this conceptual framework also served as the foundation for the next philosophical phase of the research.

3.3 Research Phase 2

This phase involved the survey process undertaken, the response analysis and use of survey outcomes to develop the beta version of the proposed RESOGI is explained.

3.3.1 Survey with Stakeholders

Due to the ambition of this study and proposed area of applicability, it was necessary to obtain baseline information from the various stakeholders. It was determined that to obtain insights into the understanding of the subject of resilience and sustainability in the context of DCOGIs and to gather information about the current assessment methods and mitigation strategies (if any), it was imperative to canvass the opinions of all the relevant stakeholders by conducting a survey including the use of questionnaires, one to one interview, and focus groups. And ultimately develop a one stop, holistic and easy to use decision-making framework that is free of bias. The surveys were a necessary component of this research for two main reasons:

- To validate findings from the literature review on sustainability and resilience assessment, the indicators applicable to downstream oil and gas distribution systems.
- To gain some understanding from the identified stakeholder's standpoint on existing practices and suggestions for improvement, and modalities for measurement.

This research employed an empirical approach by conducting surveys, therefore the framework development was centred on the juxtaposition of data from extant literature on sustainability and resilience study (Theoretical findings), and survey responses obtained

from a range of stakeholders to DCOGI industry including NGOs and interest groups, Government agencies, oil and gas industry practitioners (both those at strategic levels and field engineers), prominent community indigenes, academics and civil engineers, and construction contractors. The surveys were conducted in Nigeria and the UK to capture the 'developing and developed country' context for the proposed framework, because the framework is designed for global (anyone) application.

3.3.2 Questionnaire

According to Bell (2010), use of questionnaires enables a logical technique of collecting data from respondents. Naoum (2001) describes questionnaires as the most suited for surveys, widely adopted for analytical and descriptive surveys when seeking to enquire about facts as well as authenticate data. Through the literature review, some issues that are particularly relevant to sustainability and resilience of DCOGI have been identified, which in turn constitute aspects to be further investigated. The use of questionnaire for this research is considered adequate for collecting more data required to achieve the aim of the research, and to validate initiate findings from the first phase of the research. In addition to several other themes mentioned in the literature, the following themes obtained from the literature review constituted the foundation for the survey questions.

- How sustainability and resilience are understood by all stakeholders and the implication for end-users: To understand how both concepts are interpreted in DCOGI context
- Existing assessment frameworks: To understand current industry practice and improvements required.
- Existing mitigation strategies: To understand existing mitigation approaches.
- Measurability / applicability: To understand efficacy of current and proposed methods.
- Impacts and relative weight: To understand risks levels and priorities for DCOGI systems.
- Stakeholder communication and interconnection: To understand efficacy of current practices and barriers.

The questionnaire used for the survey was designed and structured, incorporating the themes mentioned above. Following this, piloting of the questionnaire was initially done to determine the time required for survey participant to answer the questions before

commencing the distribution of questionnaire to survey participants. Questionnaires were distributed mainly electronically including by emails to specific respondents identified in conferences and related events and those contacted solely for the study. Respondents were recruited through their organizations, community heads, local government councillors, and relevant government agencies. A total of 176 questionnaires were administered during the survey. 155 were administered to industry practitioners and other experts, and 21 were administered to community indigenes and Non-Governmental Organizations (NGOs). Of the 155 administered to industry practitioners and other experts, 106 were returned and only 85 were deemed valid after the initial sorting of questionnaire responses.

3.3.2.1 Design and Structure

Due to the varying array of stakeholders to DCOGIs, two sets of questionnaires were designed. The first questionnaire had 20 semi structured (open and close) questions (see appendix), designed for the community indigenes and NGOs, an idiot proved version that excluded technical terminologies and focused on social-economic, environmental, and organisational aspects of the research. Section A was based on the respondent's biodata, section B consisted of general issues about the development and operations of DCOGI in communities, issues about disputes and communications, collaborations between infrastructure owners – government – locals, their understanding of the DCOGI activities in the community, the benefits, and negative effects of DCOGI activities on wellbeing if any e.g., environment, the local economy and social equity etc.

The second questionnaire was designed for industry practitioners and other experts; the questionnaire consists of five sections of semi structured (open and close) questions, and few multiple-choice answers (see appendix). Section one of the second questionnaire cover the respondents' biodata. Section two is designed to capture the general opinions of sustainability and resilience relating to DCOGIs specifically including current industry practices. In section three of the questionnaire, respondents are asked to primarily identify the indicators suitable for the hybrid assessment and rank the significance of each indicator on achieving sustainability and resilience. In the fourth section of the questionnaire, respondents are prompted to carry out pair-wise comparison, for determining priority weightings of each indicator. Section five consisted of six DCOGI prompting respondents to identify risks and impacts of the hybrid indicators on achieving sustainability and

resilience of each of the listed DCOGI. Table 3.2 summarizes the structure of the second questionnaire, comprising aspects of the research philosophy, aspects of the literature where questions are derived from and the developed questions. The need for more information on specifics, particularly from industry practitioners and other experts necessitated the conduct of the surveys.

Table 3.2: Structure of Questionnaire for Industry Practitioners and other Experts

Aspects of the research	Sections derived from literature review	Questions developed from the sections from conclusions made in literature review
Theoretical	Interpretation of resilience in practice, definition and understanding.	Are you familiar with the concept of resilience in the context of downstream critical oil and gas distribution systems?
		Do you think resilience is a familiar concept in the planning, design, development and operation of downstream critical oil and gas infrastructures?
		Do you think resilience and sustainability are related issues?
		Which of the following do you think describes the current notion of resilience for downstream critical oil and gas infrastructures?
	Implementation	Does achieving sustainability and resilience of downstream critical oil and gas infrastructures require the collaboration of every stakeholder including end users and host community indigenes?
		Briefly state the role host communities can play to ensure oil and gas infrastructure safety and energy security?
	Barriers	In your view, what factors are most capable of disrupting the operations of downstream critical oil and gas infrastructure systems?
		Based on your experience, please state potential vulnerable components/factors that are capable of causing disruptions to the operation of downstream oil and gas distribution systems.
		In your view, do you think cost considerations by infrastructure owners can influence the achievability of sustainability goals or resilience of downstream critical oil and gas infrastructures?
	Scale / Boundary	Do you think the nature of resilience changes depending on the scale of infrastructure?

		depending on the scale of infrastructure?
Empirical	Applicability / measurability of sustainability and resilience in the study context.	Please state, if any, known ways of assessing sustainability and resilience of downstream critical oil and gas distribution systems.
		How would you rate the current methods of assessing sustainability and resilience of downstream oil and gas distribution systems?
		Do you think resilience could (and should) be integrated into assessment tools as an indicator or rating codes?
		In your view, is the application of a set of principles or guidelines useful in achieving long-term effectiveness of sustainability and resilience that can inform the operation of oil/gas infrastructures?
		In your view, do you think a value based/quantitative approach (e.g. establishing performances of the infrastructure that should be sustained over the life time of the service delivery), is rather useful in achieving the long-term effectiveness of sustainability and resilience.
		In your view, what measures can be put in place to prevent disruptions of downstream critical oil and gas infrastructures?
		Based on your answer above, please state how disruptions of critical oil and gas distribution infrastructures are currently prevented and mitigation strategies if any.

3.3.3 Interviews

Questionnaire two was used in conducting the one-to-one interviews. From the interviews, it was possible to capture specific information that may not have been captured in questionnaire two distributed to respondents. Interviewees included practitioners in the oil and gas industry (those at strategic levels and field engineers), enlightened community indigenes, interest groups and Non-governmental organizations as well as government agencies. The stakeholders that were interviewed were sampled based on the following criteria:

- Oil and gas industry experts with many years of experience in project management, infrastructure management, operation/equipment maintenance, product sales / distribution.
- Prominent community indigenes that have residence for many years (mainly all their life's), highly educated and involved in the management of community affairs.
- Experienced government agency personnel who are involved in policy making for oil and gas distribution, monitoring, and compliance.
- Active non-governmental organizations and interest groups regularly involved with the activities of the oil and gas industry.

These criteria ensured that the interviewees selected were well informed of current professional discussions in the research area. Most of the interviewees are considered as experts in their professional domain, consequently their opinions are deemed practical and consolidate findings from the literature review. It was also expected that their contribution would inform the development of the proposed RESOGI assessment framework, to achieve the overarching aim of this research.

The interviewees were invited by emails and by face-to-face request. Not all invitations were honoured, in all it was possible to conduct 35 face-to-face interviews with interviews comprising industry practitioners and other experts. Following the invitations and acceptance by interviewees, the interview dates, times, and means were agreed. It was possible to conduct the interviews face-to-face and by phone. However, it was determined that focus group interviews would be more suitable for community indigenes (locales), NGOs and interest groups. The interviews were done using an audio recording device (apple laptop) with a battery life of up to seven hours, 64-gigabyte storage memory, capable of start-pause-stop functions. A second device (Blackberry passport) was held on standby during the interviews, with full battery life and similar storage memory capacity as contingency in case of any unexpected disruption with the first device. The interview time was set for one hour, they were occasions interview discussions extended and the maximum time was three hours and thirty minutes. The interviewees were interviewed using the questionnaires starting from sections one to the last section, allowing for elaborate responses to all questions including the closed (yes / no) answers.

3.3.3.1 Focus Groups

Focus group interviews were conducted with 21 community indigenes (locals) using questionnaire one. The focus group interview is deemed necessary where interviewees are more comfortable with block interviewing mainly in the communities, and where it was adjudged that more reliable and honest responses was tenable e.g., the government institutions, community indigenes (locales) and NGOs. It was possible to recruit the community indigenes (locals) through the auspices of Spaces for Change / Friends of the Earth as part of a community sensitization event held in Port Harcourt, Rivers State Nigeria. Participants were mainly from different communities with DCOGI industry activities in the Niger Delta. Twenty-one participants took part. Using the first survey questionnaire described in section 3.3.2.1, participants were asked questions from one to twenty and were able to elaborate responses with further explanations and examples. Similar devices were used as in section 3.3.3 above.

3.3.3.2 Group Model Building

A collaborative method called the Group Model Building (GMB) was used to obtain input from industry experts and academics, to provide more confidence in the list of indicators initially developed. GMB facilitates the integration of disintegrated knowledge, which originally exists in the minds of different agents, into grouped models (Richardson and Andersen, 1995). Two workshops were attended, one in Abuja, Nigeria (Organized by the Ministry of Petroleum - Gas Infrastructure Technical Team) and one in York, UK (organized by ARCC - EPSRC), both in the context of energy security and stakeholder engagement. Academic researchers attended the workshop in York from Universities of Manchester, Plymouth, Newcastle, and Glasgow; oil and gas industry experts in Nigeria attended the workshop in Abuja. The workshops provided an opportunity to obtain information from various perspectives on challenges and prospects in the DCOGI industry and list of factors that impact on the sustainability and resilience of DCOGI systems. This helped in consolidating the preliminary indicators developed. Workshop participants were also asked to identify the DCOGI development stages, applicable to the list of proposed hybrid indicators.

3.3.4 Survey Analysis

The responses from the distributed questionnaires (Used in sections 5.5 and 5.6 of the thesis), focus group interviews (Presented in table 5.2), one-to-one interviews (Presented in table 5.3) and GMD (Presented in table 5.4) were collated over a four-month period. Following this, an analysis of the various sections of the questionnaires were done using descriptive statistics, Excel software and content analysis. Content analysis is a textual investigation method that allows a researcher to determine or interpret a set of survey responses (Bell, 2010). In this study, it was used to gain insights on and ascertain the views of various stakeholders / respondents. It is adequate to allow different researchers attain the same result when the same body of responses is assessed (Bell, 2010). It consists of the sampling of text or interview responses, to identify respondents' views emerging from the survey responses to reach the same conclusions. It was possible to take the survey responses at face value without the use of coding or themed grouping. The group of interviewees sampled, and the evaluation of the interview responses led to the materialisation of respondent's views on the concept of sustainability and resilience of DCOGI and the expert's acceptable approach to embed both concepts into practice. Such views were sufficiently clear and did not need to be interpreted and classified under codes. The process delivered what it was primarily intended, i.e., a set of meanings that could approve or challenge the initial conception of sustainability and resilience in DCOGI context conceived from literature review. Ultimately, the results from analysis of responses were utilised for validation (confirming) of theoretical findings required for the development of the RESOGI framework.

3.3.4.1 Validating Indicators

Following the survey responses (i.e., the distributed questionnaire) to section three of the second questionnaires, respondents were asked to primarily identify and validate the indicators suitable for the hybrid assessment and rank the significance of each indicator on achieving sustainability and resilience. The results were used to demonstrate that the indicators were valid and significant, described in detail in Chapter five.

3.3.4.2 Weighting Determination

The literature highlights the importance of weightings; it is adjudged that the developed framework would benefit from a set of weightings. The weightings are general, and not project specific. Weighting plays a role to indicate the relative importance of each indicator in a quantitative manner. Two key approaches to obtaining weightings are the objective method that determines the numerical value of each indicator e.g., Factor analysis method etc., the subjective method that is opinion based and the decision maker can judge the relative importance of the indicators by their personal professional judgment e.g., Delphi, Analytical Hierarchy Process (AHP) etc. (Yang et al., 2009; Yu et al., 2015; Mikulic et al., 2015). In this research, two opinion-based method has been adopted in a quasi-triangulation of methods, using survey respondents to determine the hybrid indicator weightings. There are the Weighted Average Methodology (WAM) and the Analytical Hierarchy Process (AHP).

3.3.4.2.1 The Weighted Average Methodology

The results from section three of the second questionnaire were analysed using the Weighted Average Methodology, as described in detail in Chapter five.

3.3.4.2.2 The Analytical Hierarchy Process as Part of the Hybrid Model Development

The AHP process was adopted when developing the survey questionnaires, the process was deemed necessary for obtaining weighting for the hybrid indicators. It was considered that expert views would suffice as accurate, thereby giving credibility to the part of this study. The AHP is a multi-criteria decision analysis methodology developed by Saaty (2008) to solve decision problems and is based on expression of preference when different alternatives are available. It is a subjective tool that is widely used for weighting determination, easy to use, scalable, easily adjustable to fit many size problems and not data intensive (Zhao et al., 2016; Saad et al., 2019). The AHP uses relative comparisons from multiple combinations of criteria and alternatives, drawing from what is known as AHP hierarchy. The AHP can engage a mathematical approach of multiple subjective and unquantifiable factors into decision-making processes (Koo et al., 2009). It decomposes complex problems in the

form of hierarchy, descending from overall goal to criteria, sub-criteria or alternatives. The process involves developing questions and comparing criteria against each other. However, the process is being criticized for being only applicable to project with few indicators, and difficulty to understand the results of AHP. Velasquez & Hester (2013) states that the AHP does not consider interdependence among criteria and alternatives in the same hierarchy level and can lead to inconsistencies between judgment and rankings. The process is being elicited in this study using expert judgment from experienced academics and DCOGI industry practitioners.

3.3.4.2.3 AHP-Pairwise Comparison for Weighting Indicators

In the fourth section of the questionnaires, respondents were prompted to carry out pair-wise comparison, an analytical hierarchy method for determining priority weightings that aids in decision making, by rating the relative importance of each headline indicators with others. The AHP process and the final weightings derived are presented in detail in Chapter five.

3.3.4.2.4 Criticality Ranking and Risk Levels for DCOGIs

Section five of the second questionnaire consisted of six DCOGI prompting respondents to carry out risk identification and impacts of the hybrid indicators on achieving sustainability and resilience of each of the listed DCOGI. This process was deemed useful considering identifying associated risk is requirement and building block for achieving sustainability and resilience. It was expected that the results could further validate and give more confident to the hybrid indicators developed for DCOGIs. Additionally, the results provide risk data for individual DCOGI and are utilised as a supporting guide for developed RESOGI end users. They result are presented in Chapter five.

3.4 Research Phase 3

In the final phase of the research the application of the developed RESOGI assessment framework to two case studies DCOGI undertaken, the validation of the performance of the RESOGI and use of case study application outcomes to develop the final version of the proposed RESOGI is explained.

3.4.1 Case Study Application

The development of case studies is functional to validate findings from the literature as well as testing the framework developed. Case study is vital to evaluate and compare findings to ascertain communalities and divergences as well as the general validity and efficacy of the analysis method (Bell, 2010). The number of case studies (2) was considered in line with the given timeframe for the research, a larger number of case studies could provide a stronger evidence base for drawing conclusions. The case studies were initially sought from the UK and Nigeria constituting of newly proposed DCOGI development projects particularly with sustainability and resilience claims. Obtaining case study information was quite an ordeal and deemed as the most challenging part of the entire study, it was only possible to utilize case studies from Nigeria due to available data. The perceived cagey or highly confidential requirement of DCOGI operations made it extremely difficult to access data e.g., as DCOGI matters relate to national security. Nevertheless, the convergence of findings of the identified case studies will constitute sufficient proof of robustness. Full account of the case studies application is given in the case study chapter of this thesis. The focus of the analysis is therefore on ascertaining conditions for sustainability and resilience performance of the case studies over their lifetime.

3.4.2 Framework Validation

Subsequent to the development of the RESOGI assessment framework and road testing the framework in an application to two case studies, the next task is to assess the case studies using two existing frameworks. One is the SPeAR® framework developed for sustainability assessment, the second is the Resilience Assessment Framework developed for resilience assessment. The validation results are explained in Chapter 7.

3.5 Statements on the Methods and Philosophy

The study is inter-disciplinary because it draws from diverse discipline specific sources and methodologies due to the intricacy of the research subject area. The study sets out to explore the complexity of critical oil and gas infrastructure delivery and energy security, viewed through the lenses of sustainability and resilience, embracing impacts on individual and societal wellbeing and the natural environment. The

research encompasses indicators for social, environmental, natural resources and economic implications of resilience including other necessary resilience factors identified during the study. It is expected that the use of quantitative and qualitative methods to collect primary data based on the research questions i.e., questionnaires and interviews, and to analyze data obtained yields two folds. First validates data on the research subject area obtained from review of the literature, secondly it informed the composition, and the development of the proposed RESOGI assessment framework. Analysis of data obtained entailed the application of methodologies used in social sciences alongside statistical analysis e.g., content analysis. Noticeably, this approach comes with the inherent difficulties of drawing together diverse methods of investigation in a logical fashion and interpreting and understanding knowledge that does not strictly belong to the field of studies to which this thesis pertains. It is therefore important to note that since this attempt is to an extent experimental, it is possible to apply methodologies in an unorthodox fashion, or even hybridized. Nevertheless, the proposed methodology is consistent with methodologies presented in the literature for development of sustainability and resilience frameworks generally. It was expected that the results obtained will bring about conclusions that are consistent and supported by evidence, then validated through triangulation of methodologies e.g., use of WAM and AHP to determine RESOGI indicator weights.

It was the target of this research to apply a hybrid approach (i.e., both sustainability and resilience) and other innovative approaches in developing an integrative assessment framework for DCOGI. Whereas, in the literature there are arguments that sustainability criteria can be used as proxy for the assessment of resilience. It is asserted that due to the presence of varying characteristics and dimensions this may not always be possible. It is assertive that approaches to assessing the sustainability and resilience of critical infrastructure systems depend on distinct parameters, and may vary for different infrastructures, different geographical locations around the world, and different scales. By looking at pre-existing frameworks in the literature review (chapter 2) it was possible to establish what exists and what shortfalls there are therein. Moreover, academic debates within the literature highlighting the benefits of combine assessment of sustainability and resilience for complex systems supports the need of a hybrid concept. The core of this study is the attempt to explore the possibility of a hybrid model; an integrated assessment of sustainability and resilience

in one framework as depicted in Figure 3.2.

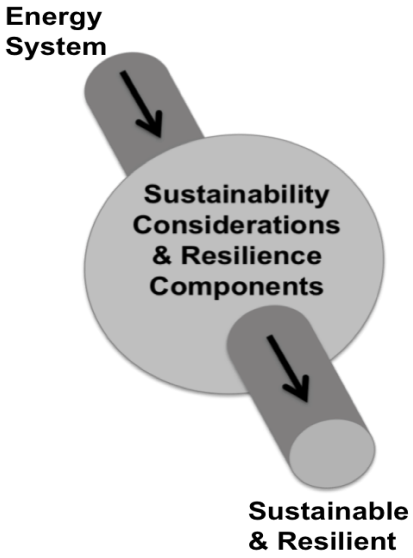


Figure 3.2: The Hybrid Model

Most recent debates in literature argue the applicability of the concepts and theories of sustainability and resilience, if both should be pursued as single entities i.e., distinctively or as a combination of both sustainability and resilience incorporating requirements for both, for example Folke (2006); Ostrom (2007, 2009a); Folke et al. (2010); Binder et al. (2013); Redman (2014). Similarly, there is on-going debate if sustainability and resilience should be measured quantitatively or qualitatively. Binder et al. (2013), suggest the hybrid concept as an overarching or encompassing approach that applies the concept of resilience to coupled social-ecological systems such as for supply of food, energy, and drinking water. The hybrid concept emphasizes the need to consider human systems alongside environmental systems (which includes the built environment) when proffering solutions. Berkes et al. (2002); Adger et al. (2005); Redman, 2014; Makana et al. (2017), suggest that the hybrid approach is based on the theory that sustainability can be achieved through resilience. However, Redman (2014) states that although combining both approaches may be the best, both approaches have merits, but there are situations where researchers must prioritize one approach and focus their energies appropriately. In general, the increasing emphasis in academia on the need for a hybrid approach is part of recent efforts to change the trend of engaging sustainability science in isolation (Roostaie et al., 2019), albeit in practice the hybrid approach is still in an exploratory stage. Given the hybrid concept fundamentally supports the nexus of sustainability

science and resilience theory, the hybrid concept approach is considered naturally suitable for this study based on the aim of this study. This research contributes to the on-going academic debate; the research has provided a conceptual framework of hybrid indicators for assessing DCOGIs specifically. This has enabled the development of the RESOGI framework and the operationalization on DCOGI systems. To this end, it is assertive that the hybrid approach is achievable.

3.6 Summary

The chapter has presented the methodology undertaken to conduct the research. The RESOGI framework has been developed for assessment of DCOGI specifically, by implementing the philosophical phases and methods presented in this chapter. This comprised of the theoretical phase, the empirical phase, and the framework application phase. The theoretical phase shows how the gaps in knowledge were established and the steps taken to derive the initial conceptual hybrid framework for assessing DCOGI specifically. The empirical phase demonstrates how the survey process was developed and undertaken, leading to the development of the beta version of the RESOGI assessment framework. The framework application phase shows how the RESOGI assessment framework is tested and validated. Detailed descriptions of each research phase explained in this chapter are presented Chapters 2, 4 to 7.

CHAPTER 4: DEVELOPMENT OF CONCEPTUAL ASSESSMENT FRAMEWORK OF HYBRID INDICATORS FOR DCOGI

4.1 Introduction

The literature review (Chapter 2) has deduced the lack of an integrated sustainability and resilience assessment framework specifically for DCOGI. This shortfall in knowledge has reinforced the need for a new hybrid assessment framework specific for DCOGI. It is on this basis that the current chapter puts forward a detailed description for the initial version of the proposed Resilience and Sustainable Oil and Gas Infrastructure (RESOGI) evaluation framework, a novel bespoke hybrid (sustainability and resilience) assessment framework for DCOGI systems. As stated in 3.2.2 the term "hybrid" refers to an integration of sustainability and resilience dimensions derived specifically for DCOGI. This chapter presents the process by which the initial conceptual assessment framework of hybrid indicators for DCOGI was developed; by conceptualizing what constitutes a hybrid assessment framework for DCOGI, following findings from literature review. The chapter begins by presenting the tools used to design the RESOGI framework including the hybrid model approach that aims to integrate the dimensions, indicators and metrics for sustainability and resilience as applicable to DCOGI, and then adopting the baseline sustainability and resilience indicators used to develop the proposed framework. Thirdly, the hybrid indicators are described, and the derived conceptual assessment framework for DCOGI is presented. The components presented herein will be further verified by stakeholders to the DCOGI through surveys carried out in the later part of this study and presented in chapter five.

4.2 Developing the RESOGI Assessment Framework

This section presents the hybrid model, and the hybrid indicator sets that are the bedrock of the RESOGI. Two distinctive approaches that are easy to distinguish were used (Sharifi et al., 2021; Wicher et al., 2019; Singh et al., 2012; Lundin, 2003;):

1) A top-down approach means that experts and researchers define the framework and the set of the indicators (Section 4.2.1 to 4.2.3)

2) A bottom-up approach features the participation of different DCOGI stakeholders in the design process of the framework and indicator selection (Chapter five).

4.2.1 The Hybrid Model

The literature review of existing efforts points to a need for an integrative approach to assessing complex systems and process performance. Sustainability and resilience principles and dimensions as related to DCOGI, are essential for conceptualizing and assessing DCOGI. Section 2.6 of the literature review has shown that integrating the principles and dimensions of sustainability and resilience is possible and is a valuable and necessary approach. Although this requires that through the integration process, existing shortfalls within the respective sustainability and resilience principles and dimensions are covered in a complimentary manner. E.g., where sustainability covers aspects of environment that resilience does not necessarily address. The hybrid concept approach proposed in this study is deemed consistent with the need to assess complex DCOGI systems, considering the complex socio-ecological problems associated with DCOGI explored in the literature review. The hybrid concept is detached from the non-integrative lineage of existing evaluation frameworks e.g., neither being eco-centric or policy-centric, not adopting a sustainability approach or resilience approach respectively etc. The hybrid model (figure 3.2) for DCOGI assessment aims to incorporate the principles and dimensions of sustainability into one assessment framework. This essentially implies embedding the core components of both sustainability and resilience concepts for example as shown in the illustrated model in figure 4.1. Key characteristics of both concepts are to be taken into consideration in DCOGI context, aimed for the development of a robust assessment framework of hybrid indicators for DCOGI. How this applies in practice for DCOGI is a key objective to be achieved during this study. This is initially addressed by identifying the hybrid indicators that would constitute the proposed conceptual assessment framework (Section 4.2.2). It is recognized that the issues with trade-offs and weightings for each component of individual concepts has to be reconciled and this is addressed in Section 5.6.2.2 and 5.6.3 of chapter five.



Figure 4.1: Conceptual Sustainability Considerations & Resilience Components

4.2.2 Selecting Hybrid Indicators for DCOGI

Through the lens of energy security, the literature review (Chapter two) highlighted the problems commonly associated with the DCOGI industry. This has helped to understand the factors that enable sustainability and resilience for DCOGI to be achieved more successfully. Thus, it has been possible to postulate the following seven themes (as capable of) strongly influencing the sustainability and resilience of DCOGIs:

1) Vulnerabilities,
2) Interdependencies,
3) Cost,
4) Scale,
5) Policy,
6) Governance, and
7) Redundancies etc.

These form the Headline hybrid indicators for the DCOGI Framework, which are further categorized into various proxy sub-indicators, broadly identified as:

- Security,
- Governance,

- Maintenance Requirement & Risk Management,
- Economic-Financial,
- Environment,
- Social, and
- Redundancy.

In combination these give a measure of the four characteristics, vital to improving the sustainability and resilience of DCOGI systems:

1. Longevity and Flexibility of Physical Structure.
2. Uninterrupted Delivery of Oil or Gas and their products.
3. Adequate Organizational and Management system.
4. Economic Competitiveness of Infrastructure system.

4.2.3 SPeAR® for Selecting Hybrid sub-Indicators for DCOGI

The systematic literature review highlighted that SPeAR® (Sustainable Project Appraisal Routine) is the most appropriate Infrastructure appraisal system, highly suitable for modifying, selected based upon its holistic considerations, flexibility. In addition, it is deemed as devoid of bias and has a pedigree of usage in its original and modified forms across numerous infrastructure projects both above and below ground (Braithwaite, 2007, Holt et al., 2010, Pearce et al., 2012, Zargarian et al., 2016). For example, GeoSPeAR was successfully developed for geotechnical projects (Holt et al, 2010) whilst USPeAR was developed for assessing the underground projects (Zargarian et al. 2016) and (Hojjati et al. 2016) modified it for Sustainability assessment of urban underground utility infrastructure projects. The successful application in wide range of areas, highly relevant to DCOGI further assures suitability of SPeAR® for use in this study.

The SPeAR® sustainability indicator sets are therefore considered as suitable baseline indicators for the selection of hybrid sub-indicators for DCOGI. SPeAR® framework is widely known for its flexibility, holistic considerations, and SPeAR® indicators can be removed or modified through a process call materiality review, requiring the mandatory involvement of a sustainability professional to assist with the materiality review, and taking into consideration any risk, legal-regulatory-internal & external

policy drivers, stakeholder concerns & societal trends, opportunity for innovation and best practice / peer-based norms (Venables et al., 2005; Braithwaite, 2007; Holt et al., 2010; Arup, 2012; Singh et al., 2012; Zargarian et al., 2016). For clarity, the selection process used herein is a quasi-modification and / or adaptation of relevant SPeAR® sustainability indicators considered applicable in DCOGI context, because the SPeAR® does not allow inclusion of indicators from other sources. However, as this is consistent with the top-down approach for the selection of indicators (where experts and researchers define the framework and the set of indicators), the derived indicators were selected and reviewed with an industry professional and sustainability expert who helped develop the original SPeAR® as described in section 3.2.2. As such, it was possible to adapt SPeAR® indicators using a qualitative selection and review process done in the form of yes / no answer with respect to suitability of SPeAR® sustainability indicators and in view of the seven headline themes (i.e., Security, Governance, Maintenance Requirement & Risk Management, Economic-Financial, Environment, Social, and Redundancy) considered for DCOGIs. Consideration was also given to ease of use and less time consuming for the RESOGI end user, which required that selected indicators are broadly encompassing and holistic but not too complex. To complete the selection process, several meetings cumulating to more than 30 hours were held with the industry professional and sustainability expert. The criteria for sifting the indicators where according to the form of either “incorporate” (due to the indicator being relevant) or “ignore” (due to indicator not considered relevant or broadly covered within indicator already selected e.g., food and agriculture, form and space, culture, equality are broadly considered under Social – stakeholder integration / cooperate social responsibility) - answers from the industry expert with respect to the themes and elements are further outlined in 4.3 and are presented in Table 4.1. The outcome of this filtering led to an alpha version of the RESOGI assessment framework (Table 4.1). The literature provided the narrative for each indicator as well as clearly explaining the relevance of the indicators to DCOGI, these are presented in section 4.3. Following the above step, the bottom-up approach for selecting and developing indicators is achieved in the next philosophical phase of the study. The purpose of this was to further validate the selected hybrid indicators and assess their suitability for DCOGIs by asking for critical feedback from stakeholders and practitioners (within in the oil and gas industry) (See Chapter 5 for survey responses).

Table 4.1: SPeAR® Indicator Sets and Relevance to the RESOGI

ORIGINAL INDICATORS	ACTION	SUB-INDICATOS	CONSIDERATIONS
Facilities Management	Incorporated	Usability	Ignored
		Appropriate technologies	Incorporated
		Whole-life-flexibility	Incorporated
		Operation and maintenance	Incorporated
Governance and Reporting	Incorporated	Monitoring and evaluation	Incorporated
		Information disclosure and reporting	Ignored
		Strategy	Incorporated
		Risk management	Incorporated
		Donations to voluntary and community organisations	Ignored
Economic Effect	Incorporated	Value for money	Incorporated
		Distortions to local economy	Incorporated
		Vitality and regeneration	Ignored
		Carbon pricing	Ignored
Employment and Skills	Incorporated	Labour standards	Ignored
		Employment creation	Incorporated
		Training	Ignored
		Access to Finance	Ignored
		Employment creation in construction	Incorporated
		Employment creation in operation	Incorporated
		Social mobility	Ignored
Site selection	Excluded	Site location	Ignored
		Planning intent	Ignored
		Diversity / mixed used	Ignored
Procurement	Incorporated	Local sourcing	Incorporated
		Global sourcing	Incorporated
		Procurement strategy	Incorporated
Equality	Excluded	Affordability	Ignored
		Designing for equality	Ignored
		Impacts and benefits	Ignored
		Land tenure	Ignored
		Displacements	Ignored
Informatics	Incorporated	Smart resource systems	Ignored
		Social interaction	Incorporated
		Public information	Incorporated
		Transport	Ignored
		Environmental quality	Incorporated
Innovation	Incorporated	Research and innovation	Incorporated
		Knowledge exchange	Incorporated
		Replication	Incorporated
		R&D spend	Incorporated
Soil and Land	Incorporated	Contaminated land	Incorporated
		Soil quality	Ignored
		Drainage systems	Ignored
Biodiversity	Incorporated	Protected species and habitats	Incorporated
		Conserving and improving local biodiversity	Incorporated
		Habitat connectivity	Ignored
Waste	Incorporated	Construction waste management plan	Incorporated

		Waste in operation	Incorporated
		Hazardous/ special waste	Incorporated
		Designing out waste	Incorporated
Materials	Incorporated	Materials efficiency in design	Incorporated
		Use of recycled or reused materials	Incorporated
		Environmental and sustainability impacts of materials	Incorporated
		Healthy materials	Incorporated
Water	Incorporated	Water pollution	Incorporated
		Water resources	Ignored
		Wastewater treatment & disposal	Ignored
		Water sources	Incorporated
		Water monitoring	Ignored
		Water supply	Incorporated
		Construction	Incorporated
Energy	Incorporated	Energy supply	Incorporated
		Energy conservation and efficiency	Incorporated
		Energy monitoring	Incorporated
		Daylighting	Ignored
Climate Change	Incorporated	Carbon management plan	Incorporated
		Social impacts of climate change	Ignored
		Physical impacts of climate change	Incorporated
		Carbon sequestration	Ignored
		Economics of climate change	Ignored
Air Quality	Incorporated	Ambient air quality	Incorporated
		Direct emissions	Incorporated
		Indirect emissions	Incorporated
		Ozone depleters	Ignored
Food and Agriculture	Excluded	Land use	Ignored
		Resilience	Ignored
		Resource and synergies	Ignored
		Community food growing	Ignored
Energy Generation	Incorporate	Renewables	Incorporated
		Low carbon energy	Incorporated
		Energy security	Incorporated
Energy Demand	Incorporated	Lighting	Ignored
		Heat demand	Ignored
		Cooling / ventilation	Ignored
		Construction energy reduction	Incorporated
		Energy monitoring	Incorporated
		Industrial energy reduction	Incorporated
		Appliances	Incorporated
		ICT	Incorporated
Noise Vibration	Incorporated	Construction noise	Incorporated
		Operational noise (internal to site)	Incorporated
		Operational noise (external)	Incorporated
		Vibration	Incorporated
Light Pollution	Excluded	Street lighting	Ignored
		Indoor light	Ignored
		Lighting in open spaces	Ignored
Community Facilities	Incorporated	Recreation	Ignored
		Education	Incorporated
		Healthcare	Incorporated

		Retail	Ignored
Culture	Excluded	Respecting socio-cultural identity	Ignored
		Cultural and religious facilities	Ignored
		Use of environment	Incorporated
		Intergenerational and gender practices	Ignored
		Archaeology and local heritage	Ignored
		Art	Ignored
Form and Space	Excluded	Density, height, scale, and massing	Ignored
		Public, private, and communal space	Ignored
		Landscape, townscape, and visual impact	Ignored
		Security	Incorporated
		Connectivity	Ignored
		Microclimate	Ignored
Stakeholder Engagement	Incorporated	Identification and analysis	Incorporated
		Engagement process and feedback	Incorporated
		Integrating stakeholders' comments	Incorporated
Health and Wellbeing	Incorporated	Access to green space	Ignored
		Community cohesion	Incorporated
		Institutions and social networks	Incorporated
		Indoor environment	Ignored
		Social vibrancy	Ignored
Transport	Excluded	Public transport infrastructure	Ignored
		Pedestrian design and facilities	Ignored
		Cycle design and facilities	Ignored
		Waterways	Ignored
		Freight traffic (logistics)	Incorporated
		Low emission vehicles	Incorporated
		Private vehicle use	Ignored
		Air travel	Ignored
Health and Safety	Incorporated	Health and Safety on construction sites	Incorporated
		Health and Safety in design	Incorporated
		Health and Safety in operation	Incorporated
Sustainable Behaviours	Excluded	Encouragement	Ignored
		Engagement	Ignored
		Leadership	Ignored
		Enabling	Ignored
Indigenous Culture	Excluded	Socio-cultural identity	Ignored
		Local heritage	Ignored
		Cultural and religious facilities	Ignored
		Use of environment	Ignored
		Intergenerational and gender practices Intergenerational and gender practices	Ignored
		Archaeology	Ignored
		Art	Ignored
Non-indigenous Culture	Excluded	Socio-cultural identity	Ignored
		Local heritage	Ignored
		Cultural and religious facilities	Ignored
		Use of environment	Ignored
		Intergenerational and gender practices	Ignored
		Archaeology	Ignored
		Art	Ignored

4.3 The Hybrid Indicators (Alpha Version)

This section presents the hybrid indicators derived from selection process outlined in the previous section incorporating factors that encompass the wide breadth of issues both internal and external to DCOGIs as they affect sustainability and resilience of DCOGIs. The indicator selection process, in the context of this study, integrated the identification and broad categorization of factors that affect the normal functioning of DCOGI systems view through the prism of sustainability and resilience. The indicators identified for sustainability and resilience are presented in tables 4.2 and 4.3 respectively. For sustainability, the indicators governance and Maintenance requirement & risk management and their listed sub-indicators are considered as applicable to resilience as resilience factors identified in the literature highlighted gaps in DCOGI operations, maintenance, interdependencies, non-compliance to regulations etc. and so can be considered hybrid indicators.

Table 4.2: Sustainability Indicators and Sub-Indicators Identified for DCOGI

INDICATORS	SUB-INDICATORS	APPLICABILITY
Economic-Financial	Market forces & politics effect.	All project phases (Planning, construction, operation).
	Cost (Direct & Indirect).	
	Design options & value.	
	Location options.	
	Economic effect.	
	Informatics & innovation.	
Environment	Climate change impacts.	
	Natural hazards.	
	Carbon critical design / low carbon emissions.	
	Pollution reduction / mitigation strategy.	
	Procurement/materials sourcing.	
	Biodiversity.	
	Waste management.	
	Energy efficiency.	
	Noise.	
Social	Stakeholder/end-user integration & interconnection.	All project phases
	Corporate social responsibilities	Operations
	Stakeholder satisfaction/product availability.	Operations
	Competitiveness.	Operations

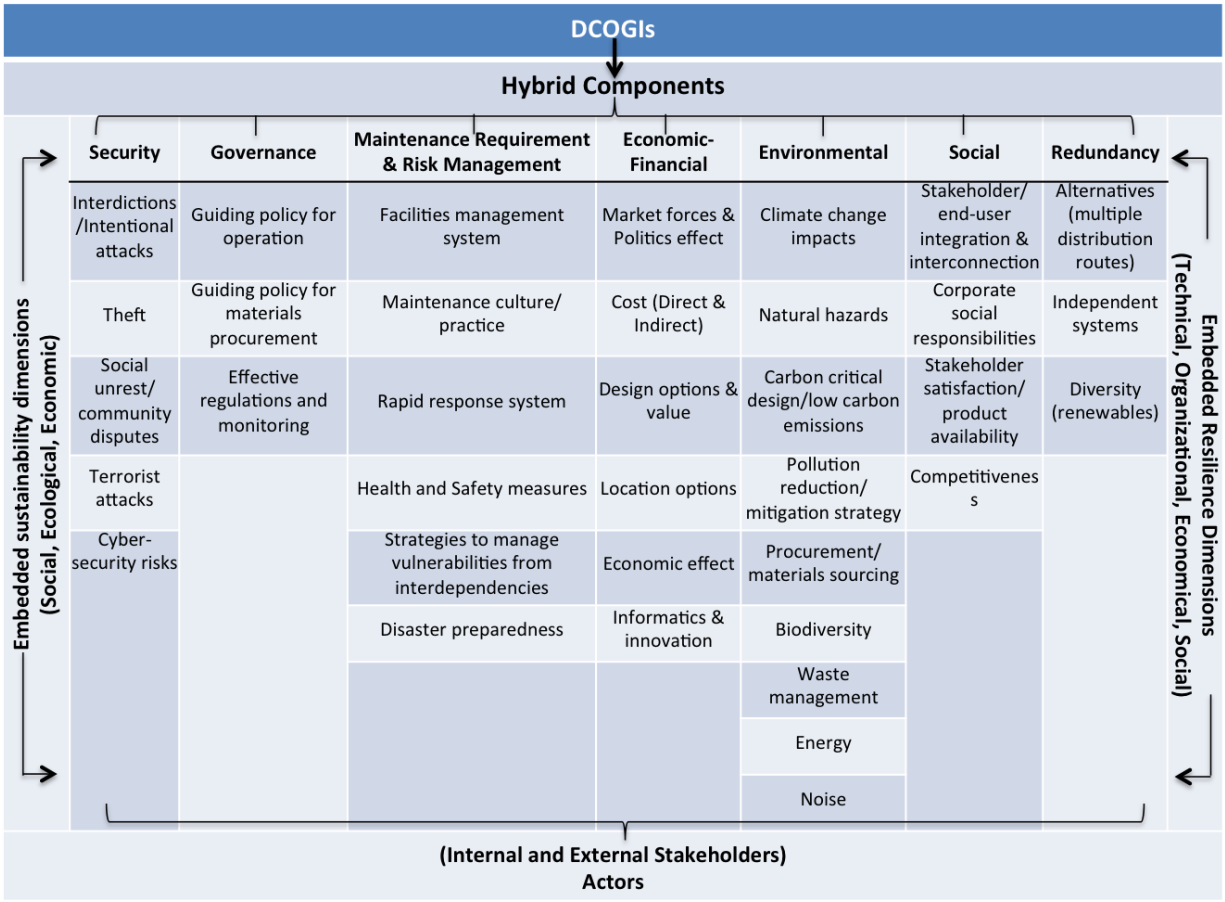
Table 4.3: Resilience Indicators and Sub-Indicators Identified for DCOGI

INDICATORS	SUB-INDICATORS	APPLICABILITY
Security	Interdictions/intentional attacks.	All project phases (Planning, construction, operation).
	Social unrest /community disputes.	
	Terrorist attacks.	
	Theft.	
	Cyber-security risks.	
Governance	Guiding policy for operation.	All project phases (Planning, construction, operation).
	Guiding policy for materials procurement.	
	Effective regulations and monitoring.	
Maintenance requirement & risk management	Facilities management system.	All project phases (Planning, construction, operation).
	Maintenance culture/practice.	
	Rapid response system.	
	Health and Safety measures.	
	Strategies to manage vulnerabilities from interdependencies.	
	Disaster preparedness.	
Redundancy	Alternatives (multiple distribution routes)	All project phases (Planning, construction, operation).
	Independent systems	
	Diversity (renewables)	

For resilience, the Economic-Financial indicator and listed sub-indicators are considered to also apply to sustainability. Although adapted from the SPeAR®, the literature as highlighted that cost considerations impact DCOGI resilience in related aspects e.g., pipeline quality, obsolete facilities, adequate security provision, location option, financing maintenance and training needs etc. These three indicators (Governance and Maintenance requirement & risk management and Economic-Financial) and their sub-indicators possess synergies between sustainability and resilience in DCOGI context and can be considered as hybrid, due to their applicability to both concepts. However, as proposed in this study and illustrated in figures 3.2 and 4.1, the outcome of the selection process is captured in the conceptual framework shown in Table 4.4 that serves as a basis for elaborations in the following

sections. The hybrid indicators and the ontological narrative of criteria for each of the 36 sub-indicators that support the seven headline indicators (themes), and the measures assigned are now presented in section 4.3.1.

Table 4.4: A conceptual & analytical framework of impact characterization – Hybrid Indicators for DCOGIs.



Security	Governance	Maintenance Requirement & Risk Management	Economic-Financial	Environmental	Social	Redundancy
Interdictions /Intentional attacks	Guiding policy for operation	Facilities management system	Market forces & Politics effect	Climate change impacts	Stakeholder/ end-user integration & interconnection	Alternatives (multiple distribution routes)
Theft	Guiding policy for materials procurement	Maintenance culture/ practice	Cost (Direct & Indirect)	Natural hazards	Corporate social responsibilities	Independent systems
Social unrest/ community disputes	Effective regulations and monitoring	Rapid response system	Design options & value	Carbon critical design/low carbon emissions	Stakeholder satisfaction/ product availability	Diversity (renewables)
Terrorist attacks		Health and Safety measures	Location options	Pollution reduction/ mitigation strategy	Competitivenes s	
Cyber-security risks		Strategies to manage vulnerabilities from interdependencies	Economic effect	Procurement/ materials sourcing		
		Disaster preparedness	Informatics & innovation	Biodiversity		
				Waste management		
				Energy		
				Noise		

4.3.1 The Hybrid Indicators described.

4.3.1.1 Headline Indicator 1: Security

4.3.1.1.1 Interdictions / Intentional attacks

This indicator refers to disruptions that can affect the DCOGI systems at all phases of development. Globally, intentional attacks on DCOGI systems are a problem particularly in politically unstable regions of the world (Anifowose et al., 2012; Chen et al., 2020). With the increasing trend of politically motivated actions, and threats from intentional attacks, it is vital to ensure that DCOGI systems are protected against

interdictions to guide against disruptions and resulting environmental impacts such as oil spill impacts, soil contamination, air pollution, fire outbreak, biodiversity depletion, health hazards, global and local economy effects etc. (Zhang & Ramirez-Marquez, 2013; Russo 2014; Rezazadeh et al., 2019). Some of the ways to avoid interdictions are to adopt lessons learnt from causes of previous attacks, establishing good social cooperate responsibilities, absorbing all external stakeholders (including Government, communities, NGOs, interest groups) in every life stage of the infrastructure system (Rezazadeh et al., 2019).

4.3.1.1.2 Theft

Theft of oil and gas products, DCOGI assets and confidential information are a major concern to infrastructure owners and insurers (Bajpai and Gupta, 2007; Chen et al., 2020). Theft of any sort is capable of disruptions at any stage of the infrastructure development mainly during construction and operations. Economy cost of loss of product or facilities could have a crippling effect, also reputational damage, and disruptions in product supply and energy generation, businesses, and other activities of various end-users (Bajpai and Gupta, 2007; Chen et al., 2020). It is important to ensure security of all DCOGI facilities from theft, owners can adopt policies that ensure redundancy exist in systems, readily available replacement procedures e.g. Just in Time methods of procurement, or warehousing of spare facilities. Real time monitoring and surveillance of infrastructure are recommended measures for guiding against theft.

4.3.1.1.3 Social unrest and community disputes

This indicator is capable of disrupting activities at all stages of the DCOGI systems life stage (construction to decommissioning), common in countries were DCOGI systems particularly pipeline networks crosses communities (Bajpai and Gupta, 2007). These are mainly caused by lack of economic benefits e.g., jobs, community infrastructure developments, interference with locales means of livelihood and cultural beliefs, conflicts of interest, deplorable environment by infrastructure owners etc. (Bajpai and Gupta, 2007; Anifowose et al., 2012; Ngoasong, 2014). To ensure a resilient and sustainable infrastructure system it is vital to involve all stakeholders and satisfy all community concerns (Chen et al., 2020). This process will be location / country specific, depending on relevant laws and planning processes.

4.3.1.1.4 Terrorist attacks

Oil and gas remain critical for future energy generation and manufacturing, albeit DCOGIs are often susceptible targets to terrorist attacks (Bajpai and Gupta, 2007; Razazadeh et al., 2019; Chen et al., 2020). Terrorist attacks on DCOGI infrastructures are not location specific, as DCOGIs are considered potential terrorist targets globally (Bosher et al., 2007; Onyeji et al., 2014). Today's world is full of uncertainties and of course a terrorist attack in a particular DCOGI geographical location could have widespread and global consequences (Bosher et al., 2007; Corallo et al., 2020). Given the unpredictable nature of terrorist attacks on DCOGIs and the global economic reliance on oil and gas. In the context of attaining a sustainable and resilient DCOGI, it is vital to ensure DCOGI systems are proactively protected against all forms of terrorism. All DCOGI owners should adopt both local and international security strategies, in places for protection against terrorist attacks.

4.3.1.1.5 Cyber-security risks

Cyber threats in the DCOGI industry have been on the increase over the last decade, and a cause of major disruptions (Russo, 2014; Onyeji et al., 2014). The number of incidents from cyber-attacks on one hand, and the increased level of sophistication of the attackers has continually grown (Onyeji et al., 2014; Estay et al., 2020). With the current trend of high cyber technology and the prospect of complete reliance on technology into the future, it is necessary for DCOGI owners to put in place forward looking policies to guide against cyber security risks both now and into the future. This indicator examines for measures against cyber security risks.

4.3.1.2 Headline Indicator 2: Governance

4.3.1.2.1 Guiding policy for operation

Considering the various infrastructures in the DCOGI industry, this indicator refers to existence and compliance to standards for developing and operating infrastructures and vital to attain DCOGI sustainability and resilience (Anifowose et al., 2012). Operators must be adequately and regularly trained on how to operate infrastructure, spot crisis early enough, respond to crisis when it does occur (Arup 2019; Rehak, 2020). This requires providing documented operation procedures, routine personnel trainings, and ability for personnel to make evidence-based judgments (Labaka et al.,

2016). The indicator is applicable to both internal and external stakeholders to the DCOGI.

4.3.1.2.2 Guiding policy for materials procurement

This indicator highlights the necessity for infrastructure owners and other stakeholders to show commitment to protecting the earth's resources. The literature has highlighted that existence of policy pressure enhances the attainment of sustainable and resilience DCOGI practices (Zhu et al., 2007a; Seuring & Müller, 2008a; Wu et al., 2012; ARUP, 2019).

4.3.1.2.3 Effective regulations and monitoring

DCOGI management should have well defined internal regulations for construction, operations and maintenance that is intermittently updated to comply with corresponding local, national, and international regulations (Wu et al., 2012; Ahmad et al., 2016; Labaka et al., 2016). This will also require an effective top - down internal monitoring system with a log of regular (daily) monitoring for adherence to regulations This will ensure an infrastructure that is reliable, safer, environmentally friendly, better prepared for any crisis and disruptions (Labaka et al., 2016).

4.3.1.3 Headline Indicator 3: Maintenance Requirement and Risk Management

4.3.1.3.1 Facilities management system

The resilience and sustainability of DCOGIs could heavily rely on the conditions of the infrastructure systems (Fabiano & Curro, 2012, Labaka et al., 2016; ARUP 2012 & 2019). Therefore, there must be a facilities management system in place that should delegate management responsibilities, plan for, and ensure maintenance compliance with manufacturing standards, maintain, manage an active reporting procedure as well as collaborations with both internal and external stakeholders or maintain infrastructure systems.

4.3.1.3.2 Maintenance culture and practice

This indicator assesses the existence of internal maintenance culture and practices in the DCOGI system. The literature e.g., Fabiano and Curro (2012); Labaka et al., 2016; ARUP 2012 & 2019 explicitly highlights the role of this indicator, as potentially a major hindrance to attaining sustainability and resilience of DCOGI

systems if not addressed. As this indicator is clearly linked to organizational resilience dimension, owners of DCOGI systems must ensure that maintenance culture and practices are at the core of their operations, as a preventive measure to crisis and disruptions. Past records of incidents in the DCOGI industry have been reported as due to poorly maintained DCOGI infrastructure systems e.g., the Exxon Valdez incident (Lin-Hi & Blumberg, 2011).

4.3.1.3.3 Rapid response system

This indicator refers to an emergency response system for a DCOGI system, for radical responses to abate any kind of crisis or disruptions to the operations of the system and events that could affect the society, the environment, and the economy. Responders should have been trained and know about technical characteristics of the infrastructure (Labaka et al., 2016; ARUP, 2019; Rehak, 2020). Independent systems (in form of bureaucratic strategy or redundant equipment) should exist in every dependent infrastructure system to tackle unforeseen crisis e.g., equipment break down, delays in supplies or deliveries, fire outbreak, explosion, rupture, natural hazards (Russo, 2014; Ahmad et al., 2016; ARUP, 2019). This indicator also assesses for procedures to coordinate with all external stakeholders that may be affected by the crisis and disruption or that should be involved in managing the crisis e.g., communities, government, and end-users. The indicator assesses for measures to detect early warning signals of crisis, understand impending event (e.g., from lessons learnt), adapt to the crisis and respond rapidly.

4.3.1.3.4 Health and Safety measures

Health and safety of all internal personnel, facilities and external stakeholders to a DCOGI system is paramount, activities from construction to operation pose a health and safety hazard within the systems (ARUP, 2019). Investing in health and safety procedures can potentially serve as a preventive or a first step to averting unexpected crisis (Pipeline magazine, 2017). This indicator assesses the quality of health and safety measures in terms of the broadness (covers for all potential risk and in every part of the infrastructure system), level of awareness, routine updates, organizational commitment to occupational well-being, impact on external factors e.g., the environment, locales/society etc.

4.3.1.3.5 Strategies to manage vulnerabilities from interdependencies

As DCOGI systems are nested and dependent systems in most cases, more often than not disruptions (that could lead to crisis) often arise from the results of ripple effects (Rinaldi, 2001; Ouyang, 2014; Ahmad et al., 2016). This indicator incorporates elements of both technical and organizational resilience and assesses for the existence of redundancy measures, alternatives, and strategic storage capacities, spare equipment, collaboration with external suppliers, ability of the system to deliver its functions during crisis.

4.3.1.3.6 Disaster preparedness

This indicator corresponds to the capacity and preparation of the DCOGI system to deal with disruptions or events as they occur (Labaka et al., 2016; ARUP, 2019; Rehak, 2020). This also includes assessing the preparedness of all external agents to the DCOGI systems e.g., suppliers, government, communities, feed-in systems and support facilities etc.

4.3.1.4 Headline Indicator 4: Economic-Financial

4.3.1.4.1 Market forces & Politics effect

Most oil and gas activities are highly influenced by market forces (demand and supply shifts) and political decisions (regulatory changes) at the international stage, because of the importance of the oil and gas industry to global energy needs and economic development (Karvetski & Lambert, 2012; Hamilton et al, 2016). From construction, operations, sustenance, growth, and management of the DCOGI systems are impacted by the reciprocal action and reaction of supply & demand and politics at international, national as well as local level. This indicator assesses the DCOGI system's strategies to withstand vulnerabilities to these conjoined yet opposed factors, in the face of dynamic and uncertain future.

4.3.1.4.2 Cost (Direct & Indirect)

Cost is deemed as a critical element to achieving sustainability and resilience of DCOGI systems (Labaka et al., 2016, ARUP, 2019). To the DCOGI system owner, investors, insurers, interest groups etc., there is need to ensure fiscal balance and expenditures in all life stages of the infrastructure system (e.g., from construction, operations, maintenance, crisis response, social responsibilities etc.) is kept at a

minimal; without compromising standards and quality of service. This requires adequate budget plan, investing in high quality facilities (in terms of durability, adopt innovative technologies) at early stages with a view to reduce long term cost, low cost of operations and maintenance, cost effective options, budgetary plan for crisis or unexpected disruptions for all stakeholders and the society (Ahmad et al., 2016; Labaka et al., 2016, ARUP, 2019). There should also be the potential for competitive advantage overtime, particularly with renewables. This indicator assesses for comprehensive cost considerations.

4.3.1.4.3 Design options & value

From interviews with industry experts, it was highlighted that adequate design options and value is vital to the sustenance and resilience of DCOGIs. E.g., trade-offs of value due to cost considerations, anti-theft and anti-vandalism, climate resilient infrastructure designs are factors for considerations. Reducing complexities and incorporating less additional redundant and safety systems in a DCOGI system makes it less difficult to manage and control functions of the system, this will also reduce the rippling effect of crisis or disruptions within the system (Perrow, 1984; Leveson, 2004; Sagan, 2004; Labaka et al., 2016). This indicator ensures the existence of such measures in all the life stages of a DCOGI system.

4.3.1.4.4 Location options

The locations of DCOGIs are critical to factors such as: Cost, administrative efficiency and transparency, environmental impact, societal well-being, tax and fiscal policies, protection of foreign investment (Bhatnagar and Sohal, 2005). Also, easy access to end-users and suppliers, logistics, soil conditions, climate change effects and weather conditions, security, technical / engineering conditions etc. (Pipeline magazine, 2017). The aforementioned are not exhaustive but constitute the areas for considerations when decisions are made, particularly at planning and design stages of DCOGI system development and may vary with different DCOGIs.

4.3.1.4.5 Economic Effect

Most DCOGIs influence the economic situations of the host communities, and in some cases, are the main stay of the economy in the region they exist (Bajpai and Gupta, 2007; Chen et al., 2020). The economy, as a one of the walls of sustainability,

influences on human well-being, through job opportunities, wealth creation, education etc. the existence of DCOGI should endeavour to make positive contributions to sustaining the economy of its host community (Ngoasong, 2014). The activities of DCOGI in the society should not in anywhere impact negatively on the economy e.g., impacts on means of livelihood like soil (farming), water (fishing), etc. and to ensure that host community's economy is diversified to withstand economic shocks (economic resilience) from DCOGIs.

4.3.1.4.6 Informatics & innovation

The literature review highlighted the impact of obsolete infrastructure facilities lacking updated technology, effect on the performance of DCOGI systems during normal operations and during crisis (Fabiano and Curro, 2012; ARUP, 2019; Lu et al., 2019). There is a need to upgrade and improve the performance and readiness for a crisis, by leveraging on new technologies and innovations, albeit this may require some trade-offs with cost (Lu et al., 2019). Investment in research and development and seek to adopt latest technologies to monitor the state of the DCOGI system and gather information that contribute considerable to the sustainability and resilience of DCOGI system (Labaka et al., 2016; Lu et al., 2019).

4.3.1.5 Headline Indicator 5 - Environment

4.3.1.5.1 Climate change impacts

A sustainable and resilient DCOGI system should be climate resilient, in readiness to both present day and future uncertainties of climate change, Climate resilience can be built in from the procurement stage of the DCOGI system development to the operations (Bosher et al., 2007). Climate change and energy security issues are an important aspect of sustainability and resilience strategy in the DCOGI industry (Escobar and Vredenburg, 2011; Fouquet, 2010). The DCOGI must not also contribute to climate change, considering DCOGI activities are commonly associated to impact on climate change (Grasso, 2019). This indicator assesses for any contribution to climate change and the readiness to respond to current and future climate induced crisis.

4.3.1.5.2 Natural hazards

Commonly, critical national infrastructures and DCOGIs are vulnerable to natural hazards (A.G.A, 2014; ARUP 2019; Zhu et al., 2015; Chen et al., 2020). The geographical and geological makeup of the location (location option) and the possibility of a natural hazard to occur should be considered when making decisions to develop DCOGIs. Based on the varying locations and their distinct natural hazard, location specific natural hazard preparedness measures should be considered and planned for over the system's lifetime.

4.3.1.5.3 Carbon critical design and low carbon emissions

The development and operations of DCOGIs of all types should have minimal contribution to climate change, less carbon foot and actively engage in the journey towards decarbonisation e.g., UN sustainable development goals provide an excellent benchmark (ARUP, 2019). This should be considered at planning, design, procurement, and construction stages of DCOGIs. Internal and external audits should be carried out to ensure compliance with this indicator.

4.3.1.5.4 Pollution reduction and mitigation strategy

This indicator assesses for measures to prevent pollution (e.g., Ambient air quality, emissions, ozone depleters, water pollution, land and soil pollution, drainages etc.) and compliance of infrastructure functions with international, national, and local standards. At all life stages of DCOGIs, pollution control measures should be incorporated and monitored. The indicator is deemed a vital requirement attain sustainability in critical energy infrastructures (ARUP 2012 & 2019).

4.3.1.5.5 Procurement and materials sourcing

To comply with the sustainability requirements under the environmental realm, which requires that earth resources should be exploited in a sustainable way (Wu et al., 2012; ARUP, 2019). This indicator assesses that materials used all through the DCOGI development life stage from construction to operations comply with such procurement standards, including sourcing raw materials from renewable. DCOGI asset owners should ensure that facilities (including energy and non-energy services) are procured from an environmentally responsible and reliable means.

4.3.1.5.6 Biodiversity

Protecting the eco-system and its flora and fauna, and habitat connectivity in respective geographical regions is a necessity (ARUP, 2012 & 2019), particularly as oil and gas activities are largely associated with practices like gas flaring, oil spills, fire incidents, infrastructures that interact and interfere with the ecosystem. Measures like ecosystem replacement could be considered and prevention of industry practices that could deplete biodiversity.

4.3.1.5.7 Waste management

It is vital to dispose and manage waste generated within the various DCOGI systems, this will help to curb pollution levels e.g., air, soil / ground, water pollution, attain sustainability needs (ARUP, 2012 & 2019). This requirement cut across all life stages of the DCOGI system, from construction to operation. Appropriate comprehensive waste management plans and practices should be put in place, also regular inspections and monitoring to ensure compliance to waste management standards e.g., regular inspection of slice gates, treatment of produced water and effluents, regular maintenance of facilities, waste segregation practices, waste recycling and reuse etc.

4.3.1.5.8 Energy

Within a DCOGI system, during construction and operations energy is being used to power construction equipment and operation facilities. It is vital to provide clear and definitive acceptable standards for energy use (ARUP, 2019). To save cost and minimize amount of energy used, cheaper, more efficient, and environmentally friendly sources of energy could be used. This may also require adopting innovative and advanced technologies, equipment and facilities / machineries that are energy efficient. Regular maintenance and inspection of infrastructure systems to monitor and ensure minimal energy use. There may be the trade-off between initial high cost and long-term savings.

4.3.1.5.9 Noise

Noise from DCOGI systems construction and operations are to be kept at a minimal, to reduce hazards to both internal (industry personnel's, construction workers, machine operators) and external (community / society, biodiversity) stakeholders (Pipeline magazine, 2017). Adequate noise monitoring and management procedures

should be used, procurement of noiseless equipment and machinery, use of noise hazard prevention personal protection equipment.

4.3.1.6 Headline Indicator 6: Social

4.3.1.6.1 Stakeholder / End-User Integration & Interconnection

The literature review e.g., Ahmad et al. (2016) and ARUP 2019 emphasizes this indicator is vital if sustainability and resilience is to be achieved in DCOGI. Ahmad et al. (2016) revealed the impact of stakeholder management on DCOGI sustainability and resilience. And highlighted the need for proactive stakeholder engagement strategies. This indicator assesses for efficacy of stakeholder - end-user management system, from planning, construction to operations and lifetime of the DCOGI system. It is expected that stakeholder a network would help in areas like crisis management (prevention and resolution), security of infrastructure (where there is a sense of co-ownership), economic development, promote well-being, customer satisfaction, sincerity of purpose by infrastructure owners and trust between stakeholders, lessons learnt and information sharing, competitive advantage, prevent external disruptions to operations (Resilient Organizations, 2012; Ruffner et al., 2010; Snyder and de Souza Briggs, 2003; Wenger et al., 2002).

4.3.1.6.2 Corporate Social Responsibilities (CSR)

It is good practice for DCOGI owners to contribute to the development of the surrounding environments and society at large (Ridley, 2011; Ngoasong, 2014). Usually, infrastructure owners have a memorandum of understanding with communities, governments, regulators and monitoring agents to agree and implement developmental projects. The projects are mainly focused on improving the livelihood and wellbeing in the society e.g., through job creation, employment, protecting heritage and culture, building schools and health services, generally support the economic growth and development of its host communities. This indicator assesses for CSR measures.

4.3.1.6.3 Stakeholder Satisfaction and Product Availability

To most stakeholders of the DCOGI industry, their main requirement is the continuous delivery of service. This indicator is one of the most important external factors for the DCOGI sustainability and resilience strategy (Seuring and Müller,

2008b). Customers and end-users are more concerned about product availability, and less concerned about the activities behind the scenes, albeit there may have an important role to play for instance in preventing crisis. Within the DCOGI industry, this often requires a clear liaison and stakeholder management strategy (ARUP, 2019). The above perception, however, may vary in different geographical locations. And further highlights, as mentioned earlier, the importance of stakeholder integration/interconnection to help improve resilience levels of DCOGI systems and ultimately sustain its services.

4.3.1.6.4 Competitiveness

According to Ahmad et al. 2016, competitiveness within the DCOGI industry enables functional sustainability and resilience goals. It is the responsibility of DCOGI owners to continue to deliver service to its customers and meet an ever-increasing demand for oil and gas (and products). This requires that infrastructure must continuously deliver service, even in the face of crisis (resilience). And require top management commitment to the building sustainability and resilience processes, promoting sustainability and resilience-based culture altitudes and values within the DCOGI and communicating it to external stakeholders and customers (Labaka et al., 2016.).

4.3.1.7 Headline Indicator 7: Redundancy

4.3.1.7.1 Alternatives (multiple distribution routes)

Incorporating alternatives and establishing redundancy into DCOGIs is required to increase sustainability and resilience (Ahmad et al., 2016; ARUP, 2019). This is a form of strategically building in redundancy into DCOGI systems, by ensuring that there are alternative distribution routes for product delivery, to prevent impacts of unexpected disruptions to operations and service delivery. Alternatives may vary depending on infrastructure e.g., multiple pipeline routes, multiple tanker routes, and multiple storage locations.

4.3.1.7.2 Independent systems

This considers creating a balance between reducing the complexities in DCOGI systems and building in redundancies, to enable the system withstand shocks and continue to deliver its service (Ahmad et al., 2016; ARUP, 2019). Therefore, the

indicator requires that redundancies should be built into DCOGI systems moderately, to reduce vulnerabilities and prevent triggering events from expanding to other systems because of too much complexity.

4.3.1.7.3 Diversity (renewables)

This indicator takes the dimension of organizational resilience, considers both internal and external stakeholders. This is a strategic approach to ensure they are diverse sources of energy to meet energy demand (Escobar and Vredenburg, 2011; Fouquet, 2010). DCOGI systems that need energy to function should ensure that diverse sources are strategically employed, and considerations should be given to renewable sources of energy (ARUP, 2019). This approach is considered as complimentary, integrative (in the context of energy transition strategy and climate change), and best practice for the DCOGI industry required to address the sustainability and resilience pressures (Ahmad et al., 2016). DCOGI owners could liaise with external stakeholders – customers – end-users to encourage the adoption of renewable sources of energy, to continuously meet energy demand. This could also serve as a corporate social responsibility consideration.

CHAPTER 5: SURVEY

5.1 Introduction

The chapter presents the second phase of the research that includes the survey conducted during the research. To develop the novel hybrid assessment framework for DCOGIs, it was deemed necessary to collate views and useful information from relevant stakeholders of the DCOGI industry. As stated in section 3.3.1, the survey is aimed to provide more insight from the literature review findings, current industry practices and challenges, and suggestions for development of the proposed hybrid indicators. The survey was achieved using focus group interviews, one-to-one interviews, Group Model Building (GMB) and survey questionnaire distribution. The make-up of survey participant included an array of stakeholders covering both internal and external aspects of DCOGIs, to reflect the different players required to achieve a sustainable and resilience DCOGIs highlighted in the literature review. For example, community indigenes (locals) and end-users, Non-Governmental Organisations, Government regulatory agencies, oil and gas industry practitioners and professionals, civil / construction engineers, academics etc.

In summary, the chapter begins by presenting the survey participants (section 5.2) i.e., respondent categories and background. The focus group interview responses and analysis of results are presented in 5.3. Section 5.4 of the chapter outlines the one-to-one interview responses and analysis of results. Opinions collated from the GMB participants and their relevance to the developed hybrid indicators are shown in section 5.5. In section 5.6 of the chapter, responses from distributed questionnaire are shown. Finally, analysis of the questionnaire results including determination of indicator weights and the criticality association between the hybrid indicators and various DCOGIs are also outlined in the chapter.

5.2 Stakeholder and Survey Respondent

The respondents included field engineers, marine personnel, construction engineers, supervisors / monitoring engineers, engineers in charge of oil storage and distribution, crude control engineers, distribution evaluation engineers, geoscientist, Petro-

physicist, safety managers, project managers, pipeline maintenance engineers, sales managers, claims analyst, oil and gas product marketers and transport personnel's, academic researchers, community leaders and prominent indigenes, managers and executive directors of downstream sectors (multi-nationals), government officials in charge of policy formulation and law making, construction contractors etc. The organisations include Shell, Exxon Mobil, Mobil oil, AGIP, Baker Hughes, Schlumberger Nigeria, NNPC, BuroHappold Engineering, Severn Energy, Orlean Invest, Oando, Ministry of petroleum Nigerian, Ministry of Environment, Servitco limited, Nigerian Products Marketing Company, Spaces For Change/Friends of the Earth, Westpaq, Bay Matrix, ATTDF etc. for practitioners, the highest number of years of experience was 30years and the lowest was 2years (Table 5.1).

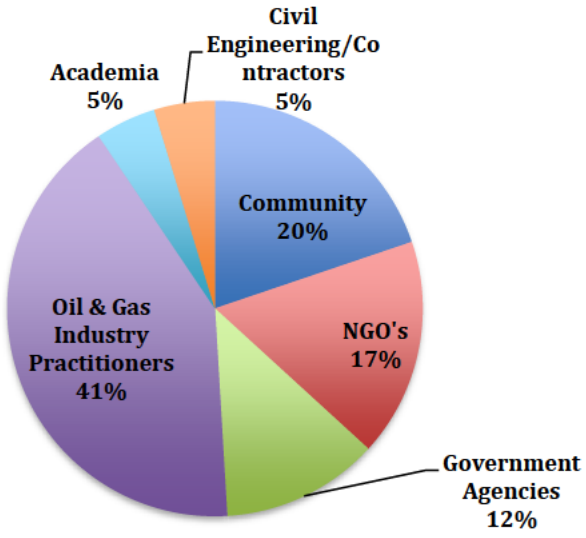


Figure 5.1: Categories of Questionnaire Respondents

Table 5.1: Background of a Cross Section of Survey Stakeholders

STAKEHOLDERS	ORGANISATION	ROLE	NO. OF YEARS
OIL AND GAS COMPANY	BAKER HUGHES	FIELD ENGINEER GENERAL	6 YEARS
OIL AND GAS COMPANY	SCHLUMBERGER NIGERIA	FIELD ENGINEER	5 YEARS
OIL AND GAS COMPANY	SHELL	MARINE PERSONNEL	10 YEARS
OIL AND GAS COMPANY	MOBIL OIL	MAINTENANCE ENGINEER	5 YEARS
OIL AND GAS COMPANY	SERVITECO LIMITED	DOWNSTEAM DIRECTOR	5 YEARS
OIL AND GAS COMPANY	MOBIL OIL	DISTRIBUTION EVALUATION	8 YEARS
OIL AND GAS COMPANY	EXXON MOBIL	CRUDE STORAGE / DISTRIBUTION	12 YEARS
OIL AND GAS COMPANY	EXXON MOBIL	CONSTRUCTION/TRAINING	4 YEARS
OIL AND GAS COMPANY	SHELL	PROJECT ENGINEER (PIPELINE)	10 YEARS
OIL AND GAS COMPANY	MOBIL OIL	MANAGER SUPPLY & DISTRIBUTION	10 YEARS
OIL AND GAS COMPANY	EXXON MOBIL	GEOSCIENTIST	8 YEARS
OIL AND GAS COMPANY	MOBIL OIL	PETROPHYSICIST	18 YEARS
OIL AND GAS COMPANY	EXXON MOBIL	PROJECT PLANNING	15 YEARS
OIL AND GAS COMPANY	EXXON MOBIL	ORG METHOD OFFICER	6 YEARS
OIL AND GAS COMPANY	EXXON MOBIL	SENIOR GEOSCIENTIST	16 YEARS
OIL AND GAS COMPANY	NES AFRICA LIMITED	SAFETY MANAGEMENT COORDINATOR	4 YEARS
OIL AND GAS COMPANY	AZIENDA GENERALE ITALIANA PETROLI (AGIP)	PERFORMANCE MANAGER	2 YEARS
OIL AND GAS COMPANY	WESTPAQ	FOCUS GROUP	4 YEARS
OIL AND GAS COMPANY	BAY MATRIX	FOCUS GROUP	5 YEARS
GOVERNMENT AGENCY	PETROLEUM PRODUCTS MARKETING COMPANY LIMITED	MANAGER MARKETING	20 YEARS
GOVERNMENT AGENCY	PETROLEUM PRODUCTS MARKETING COMPANY LIMITED	PRODUCT MARKETING	9 YEARS
GOVERNMENT AGENCY	MINISTRY OF ENVIRONMENT	ENGINEER / SUPERVISOR	15 YEARS
GOVERNMENT AGENCY	NIGERIAN NATIONAL PETROLEUM CORPORATION	PROJECT MANAGER	12 YEARS
GOVERNMENT AGENCY	NIGERIAN PRODUCTS MARKETING COMPANY	MANAGER	24 YEARS
GOVERNMENT AGENCY	MINISTRY OF PETROLEUM	POLICY FORMULATION	4 YEARS
GOVERNMENT AGENCY	PETROLEUM PRODUCTS MARKETING COMPANY LIMITED	PRODUCT STOCK	2 YEARS
GOVERNMENT AGENCY	NIGERIAN NATIONAL PETROLEUM CORPORATION	PRODUCT TRANSPORT PERSONEL	3 YEARS
GOVERNMENT AGENCY	PETROLEUM PRODUCTS MARKETING COMPANY LIMITED	PROJECT OFFICER	20 YEARS
GOVERNMENT AGENCY	NIGERIAN NATIONAL PETROLEUM CORPORATION	PROJECT SUPERINTENDENT	12 YEARS

GOVERNMENT AGENCY	NIGERIAN NATIONAL PETROLEUM CORPORATION	PROJECT ENGINEER	3 YEARS
GOVERNMENT AGENCY	NIGERIAN NATIONAL PETROLEUM CORPORATION	INFRASTRUCTURE MAINTANCE DEPUTY MANAGER	16 YEARS
GOVERNMENT AGENCY	NIGERIAN NATIONAL PETROLEUM CORPORATION	PROJECT MANAGER	10 YEARS
GOVERNMENT AGENCY	NIGERIAN NATIONAL PETROLEUM CORPORATION	CRUDE OIL MARKETING / CLAIMS ANALYST	12 YEARS
GOVERNMENT AGENCY	NIGERIAN NATIONAL PETROLEUM CORPORATION	GAS INFRASTRUCTURE MANAGEMENT	9 YEARS
GOVERNMENT AGENCY	NIGERIAN NATIONAL PETROLEUM CORPORATION	SUPERITENDENT TECHNICAL	5YEARS
GOVERNMENT AGENCY	NIGERIAN NATIONAL PETROLEUM CORPORATION	HEALTH SAFETY AND ENVIRONMENT	4 YEARS
GOVERNMENT AGENCY	NIGERIAN NATIONAL PETROLEUM CORPORATION	QUALITY CONTROL OFFICER	20 YEARS
COMMUNITY	CONFLICT RESOLUTION	CONSULTANT	40 YEARS
GOVERNMENT AGENCY	NIGERIAN NATIONAL PETROLEUM CORPORATION	MAINTENANCE ENGINEER	10 YEARS
GOVERNMENT AGENCY	MINISTRY OF PETROLEUM	MANAGER SALES / OPERATIONS	30 YEARS
GOVERNMENT AGENCY	MINISTRY OF PETROLEUM	MAINTENANCE ENGINEER	8 YEARS
GOVERNMENT AGENCY	PETROLEUM PRODUCTS MARKETING COMPANY LIMITED	SUPERVISOR / MONITORING	5 YEARS
GOVERNMENT AGENCY	MINISTRY OF PETROLEUM	DIRECTOR DOWNSTREAM	9 YEARS
GOVERNMENT AGENCY	PETROLEUM PRODUCTS MARKETING COMPANY LIMITED	MANAGING DIRECTOR	5 YEARS
GOVERNMENT AGENCY	DEPARTMENT FOR BUSINESS ENERGY AND INDUSTRIAL STRATEGY		3 YEARS
GOVERNMENT AGENCY	MINISTRY OF PETROLEUM	POLICY FORMULATION	2 YEARS
GOVERNMENT AGENCY	MINISTRY OF PETROLEUM	ENGINEER / SUPERVISOR	3 YEARS
GOVERNMENT AGENCY	MINISTRY OF PETROLEUM	FACILITIES MANAGEMENT	15 YEARS
OIL AND GAS COMPANY	EXXON MOBIL	GEOPHYSICAL APPLICATIONS	4 YEARS
GOVERNMENT AGENCY	MINISTRY OF ENVIRONMENT	EIA ASSESSOR	3 YEARS
GOVERNMENT AGENCY	DEPARTMENT FOR BUSINESS ENERGY AND INDUSTRIAL STRATEGY		3 YEARS
COMMUNITY	HIGHER INSTITUTION	RESEARCHER / COMMUNITY LEADER	37 YEARS
CONSTRUCTION COMPANY	ARUP		8 YEARS
CONSTRUCTION COMPANY	ARUP		2 YEARS
CONSTRUCTION COMPANY	BURO HAPPOLD		5 YEARS
NON-GOVERNMENTAL ORGANISATION	AFRICAN TECHNOLOGY TRANSFER AND DEVELOPMENT FORMATION	EXECUTIVE DIRECTOR / FOCUS GROUP	6 YEARS
NON-GOVERNMENTAL ORGANISATION	SPACES FOR CHANGE / FRIENDS OF THE EARTH	FOCUS GROUP	7 YEARS
NON-GOVERNMENTAL ORGANISATION	SPACES FOR CHANGE / FRIENDS OF THE EARTH		6 YEARS
NON-GOVERNMENTAL ORGANISATION	SPACES FOR CHANGE / FRIENDS OF THE EARTH		5 YEARS

5.3. Focus Group Interviews

As described in sections 3.3.3 and 3.3.3.1, the focus group interviews and responses are presented in table 5.2 below.

Table 5.2: Responses from Focus Group

Interview Questions	Group Response	Individual Response
Q6. Do you know about the oil and gas distribution infrastructure in your community?	Yes we know	
Q7. Do the oil and gas distribution infrastructure owners come to the community often?	Half of the group said yes they come around, others said they don't come around.	1. No the infrastructure owners do not come to the community, only when there is an incident. (School teacher – has lives within the communities since birth).
Q8. Were you involved in the impact assessment / planning process of the oil and gas distribution infrastructure?	No we were never involved in any planning activities for the distribution infrastructures.	
Q9. Were the community indigenes involved in the placement or management of the oil or gas distribution infrastructure?	No we were not involved.	
Q10. Have there been problems between the communities and the oil or gas distribution infrastructure companies?	Yes, severally we have had clashes with the companies.	
Q11. Has the government been involved in resolving the problem between the communities and the oil or gas distribution infrastructure companies?	Yes the government do get involved. It is usually the few times we meet and hear from government representatives.	
Q12. Do you think that more can be done to improve communication between the communities, the government, and the oil or gas infrastructure owners?	Yes, a lot can / should be done.	1. Pre-communication to host communities and involving community persons as stakeholders in ownership of oil or gas distribution infrastructure company (Business development consultant – lives within the communities for more than 15 years). 2. The must be sincerity on the parts of government and the oil or gas infrastructure owners in dealing with the communities. The infrastructure owners must resist their usual attitude of divide and rule when dealing with the communities. They must develop the culture of involving the communities in any major decision and seeking to communicate directly with us as frequently as possible (A university academic – lives within the communities all their life). 3. Oil or gas companies, government and its agencies should relate directly with their host communities, rather than through intermediaries. Meetings with communities should be routine, possibly on quarterly basis (Conflict Resolution Consultant – lives within the communities all their life).
Q13. Do you feel it is the government's responsibility to work with the oil or gas pipeline distribution infrastructure owners in protecting community's interest?	Yes, the government needs to do so.	
Q14. Are you satisfied with the location of the oil or gas distribution infrastructure in your community?	Most of the respondents said yes, few said they were not satisfied.	
Q15. Do you feel it is your responsibility to protect the oil or gas infrastructures in your communities?	Yes we feel so.	
Q16. Do you think if you were involved in the planning and management of the oil or gas distribution infrastructure in your community you will take more responsibility to protect the infrastructure?	Yes we will be committed to protecting the infrastructures within our communities.	

Q17. Do you feel you benefit more from the oil or gas infrastructures in your communities?	No.	
Q18. Do you feel that the communities benefit more from the oil or gas infrastructures?	Most of the respondent said no, few persons thought that the communities benefit more through projects and influx of people.	
Q19. Do you understand the effects from the operation of oil or gas distribution infrastructures in your communities?	Most of the respondents strongly understood the effects on economic activities in their communities. The next were effects on the environment and natural resources. The least understood was the effect on their social welfare.	1. The economic activities in our communities have been adversely affected. Farming and fishing, the primary occupation have been hindered by repeated oil spills occasioned by ruptured oil pipeline / transport systems. The presence of a few super rich oil workers who can afford to buy goods at exorbitant prices have caused problem to the majority who have little or no money to spend. There is the issue of ground and surface water pollution (School teacher – lives within the communities since birth). 2. The effect in terms of environmental hazards, degradation of natural resources and no doubt good economic activities by creating jobs for people (Business development consultant – lives within the communities for more than 15 years). 3. Local communities are exploited and discriminated against economically. Mostly people from Major ethnic groups are usually preferred to the locals. Moral decadence and general social dislocation. Terrible environmental degradation and destruction (consultant conflict resolution – lives within the communities all their life).
Q20. Do you feel there is more effect during the construction of oil or gas distribution infrastructure in your communities?	Yes there are effects mainly on the economy of the area. A few of the indigenes are involved in unskilled labour, others are mostly displaced from their sources / means of livelihood without compensation. We also have effects on our health (particular children and the elderly), our farm crops.	1. The positive effect of creating jobs for the communities indigenes and creating a boom for the economy of the communities through influx of persons coming to do business with the oil or gas companies (Business development consultant – lives within the communities for more than 15 years).
Q21. Any further comments you may like to add, in support of your answers?		1. The greatest hazard the communities suffer is devastation of the environment, water pollution, air pollution constantly causing health problems, destruction to means of livelihood like fishing, farming and allied occupation of engagements of communities (School teacher – lives within the communities since birth). 2. The oil or gas infrastructure host communities are short changed by major ethnic groups who are at the helm of affairs in the federal government and who unfortunately also man and own the oil or gas distribution infrastructures. The oil or gas infrastructure owners pay penalties for air pollution to the federal government and not a penny of this monies gets to the oil or gas infrastructure host communities that are directly affected by oil or gas transport activities (University academic – lives within the communities all their live).

5.3.1 Summary of responses from focus group

Focus group responses suggest that majority of the indigenes / locals of host community know about the DCOGI in the community, notably there is a lack of involvement and communication. In the words of a participant *"No the infrastructure owners do not come to the community, only when there is an incident"*. It was also revealed that the communities are mostly not involved in the planning and management of the DCOGI within their communities. Although the aforementioned do not reflect a global practice as to if its similar practice else way in the world, the responses are consistent with the findings from literature review (Chapter 2). Lack of involvement of host communities, as stakeholders to the DCOGI, are widely known causes for intentional attacks on DCOGI systems. Past practices of only recruiting low skilled laborers at construction stages have also been criticized. The focus group interviews also revealed that this has been the cause of past disruptions to DCOGIs due to civil clashes and community unrest. It was also mentioned that the government usually gets involved after such unrest, in trying to resolve issues. However, this is not a sustainable approach. Reports from BEIS (2017) highlighted the need to move away from a fire brigade or reactive approach that seems to be the norm in the DCOGI industry, albeit lessons are usual learnt. If proactive measures are put in place, were an established communication, integration and interconnection between the locales, the operators and the government exist, it was possible to avert any forms of disruption from unrest. A platform for open discussions and potential conflict resolution. Respondents believe pre-communication and involving community persons as stakeholders in ownership, sincerity on the parts of government and infrastructure owners in dealing with the communities e.g., avoiding divide and rule approach, use of intermediaries that create room for dishonest practices and to hold routine meetings with community stakeholders.

Focus group responses also show that there are expectations that the government should take responsibility of ensuring existence of communication channels with all stakeholders to a DCOGI. Furthermore, feelers from respondents suggest diverging views between locales regarding the benefits of DCOGI within their communities. While some acknowledge the positive effects on the local economy, others express concern over the high cost of living caused by the view industry workers that are rich, whiles majority of locales are relatively poor; there is also concern on environmental

impacts from DCOGIs during disruptive incidents e.g., oil leakages on ground and surface water pollution. The issue of moral decadence and exploits of locales and discrimination mainly in favour of non-locale workers (expatriates, highly skilled workers) were also mentioned *"The oil or gas infrastructure host communities are short-changed by major ethnic groups who are at the helm of affairs in the federal government and who unfortunately also man and own the oil or gas distribution infrastructures. The oil or gas infrastructure owners pay penalties for air pollution to the federal government and not a penny of this monies gets to the oil or gas infrastructure host communities that are directly affected by oil or gas transport activities"* all of which should reflect in the proposed assessment framework for DCOGI. At the construction stage of e.g. a refinery or oil or gas processing and distribution facility, there are feelers from participants that there are benefits to low skilled workers from the communities through short term employment although most locales are displaced from their means of livelihood without appropriate compensation e.g. farmers whose lands are acquired; also health hazards during operations as in the words of a participant *"The greatest hazard the communities suffer is devastation of the environment, water pollution, air pollution constantly causing health problems, destruction to means of livelihood like fishing, farming and allied occupation of engagements of communities"*

Findings from the focus groups interviews mainly relates to external factors to the DCOGI that are related to government policy, organizational and corporate social responsibility, environment impacts and the social aspects of sustainability. A brisk juxtaposition with literature review findings reveals consistency and therefore validates findings from literature review and the components of the conceptual hybrid assessment framework proposed for DCOGI systems.

5.4 One-to One Interviews

As described in sections 3.3.3, the one – to – one interview and responses are presented in table 5.3 below.

Table 5.3: Opinions Obtained from Interviews

INTERVIEWEES	Respondent 1	Respondent 2	Respondent 3	Respondent 4	Respondent 5	Respondent 6	Respondent 7
1. Are you familiar with the concept of resilience in the context of downstream critical oil and gas distribution systems?	Yes. Ability to bounce back despite the unfavorable business conditions.	Yes. In spite persistent disruptions of operations due to attacks etc. Government is determined to keep the system operational and product available.	Yes. Ability of the overall system to ensure the adequacy of fuel supply to markets affected by disruption by infrastructure or supply disruption, regardless of the cause.	No	Yes. Disaster resilience. Dynamic response to natural disaster. Poor investment of gas transport infrastructure.	No	No
2. Do you think resilience and sustainability are related issues?	Yes	Yes. With resilience, we can have sustainability in the downstream operations.	Yes. Many of the central parts of sustainability also happen to be core pillars of resilience. For a system to be truly resilient.	Yes. Resilience is actually a necessary condition for sustainability to exist.	Yes. Resilience in both its social and ecological manifestations is an important aspect of the sustainability of resource utilization.	Yes	Yes
3. Do you think resilience could (and should) be integrated into assessment tools as an indicator or rating codes?	Yes	Yes	Yes	Yes. An assessment or rating of downstream distribution system should necessarily incorporate the 4 strategic components of resilience.	Yes. Assessment tools for low carbon, climate resilient, energy efficiency, integrated waste management.	Yes	Yes
4. Do you think resilience is a familiar concept in the planning, design, development and operation of downstream critical oil and gas infrastructures?	No	Yes	Yes	Yes. Most downstream distribution systems are deliberately designed to have a given level of resilience.	Yes. National security and energy policy, infrastructure resistance to disruptive challenges, threat of terrorism.	No	Yes
5. What do you think describes the current notion of resilience for downstream critical oil and gas infrastructures?	Longevity / Flexibility of Physical Structure. Uninterrupted Distribution of products. Adequate Organizational / Management system. Economic Competitiveness of Infrastructure Owner.	Longevity / Flexibility of Physical Structure and Uninterrupted Distribution of Oil or Gas and their products.	Longevity / Flexibility of Physical Structure and Adequate Organizational / Management System.	Longevity / Flexibility of Physical Structure and Uninterrupted Distribution of Oil or Gas and their products.	Uninterrupted Distribution of products. Economic Competitiveness of Infrastructure Owner. Security wherever possible. Technology. Convergence of energy. Also robust infrastructure.	Longevity / Flexibility of Physical Structure	Uninterrupted Distribution of Oil or Gas and their products

6. Achieving sustainability and resilience of downstream critical oil and gas infrastructures requires the collaboration of every stakeholder including end users and host community indigenes.	I strongly agree	I strongly agree	I strongly agree	I strongly agree	I strongly agree. Commitment. Honesty. Good leadership. Safety. Distribution of wealth. Preserve environment.	I strongly agree	I strongly agree. The safety and reliability of gas infrastructures is subject to community's acceptability especially in the oil and gas dependent regions of the world.
7. In your view, what factors are most capable of disrupting the operations of downstream critical oil and gas infrastructure systems?	Ignorance of operations by the organized labor and perceived insincerity of government.	Interruption on the supply and distribution chain.	Pipeline failures, either natural or third party, refinery failures and or government policies.	When there is a breakdown of existing collaboration between stakeholders that leads to a breach of the distribution.	Human factors, man made disaster and terrorism. Natural disasters. Earthquakes. Hurricane. Violations.	Lack of awareness, illiteracy and poverty.	Corruption, unpatriotic, poverty, illiteracy, and lack of integrity.
8. In your view, what measures can be put in place to prevent disruptions of downstream critical oil and gas infrastructures?	Proper education and openness.	Security of our pipelines and other oil and gas facilities	Effective security of infrastructure systems, which is all encompassing, that involves community ownership and ensure collaboration of all the stakeholders. Effective maintenance planning of pipelines and refineries, depots and jetties as well as equipment necessary for pipeline operations.	Constant review of the dynamics involved in the collaboration between stakeholders with the view of refining and fine-tuning of rough patches.	Follow and apply relevant standards of operation and safety regulations.	Stakeholder management, installing adequate infrastructure e.g. power and water in host communities.	Using patriotic law enforcement agents to safe guard the infrastructures, because not all the law enforcement agents are honest. Some are part of the problem. Involving the host communities to watch and safeguard the infrastructures can yield positive result.
9. Based on your experience, please state potential vulnerable components / factors that are capable of causing disruptions to the operation of downstream oil and gas distribution systems.	Labor unions in the industry.	Inadequate security and maintenance.	Equipment failures, pipeline failures, refinery failures, pipeline failure. Government polices that either encourage or discourage local refining capacity.	Neglect of host communities, poor maintenance culture and non-compliance to standards and protocols.	Human factors (drugs or alcohol influence on duty). Health of employees. Training and competence. Security.	Community clashes	Unpatriotic law enforcement agents could be culpable for disruptions of infrastructure systems.
10. Based on your answer above, please state how disruptions of critical oil and gas distribution infrastructures are currently prevented and mitigation strategies if any.	No clear plan	Adequate security measures.	Call out contracts is in place for rapid response for pipeline failures. Third party pipeline security arrangement is also in place for better efficiency.	The idea of host community policing of distribution systems has worked in Nigeria.	Security. Rules and regulations must be followed. New improve technologies. Recommendation and standards.		At present government is trying to fight corruption. This may reduce the rate, at which our law enforcement agent connive with oil and

							gas infrastructure vandals, to steal and disrupt operations.
11. Briefly state the role host communities can play to ensure oil and gas infrastructure safety and energy security?	See the industry as belonging to them.	Their full participation in the oil and gas activities.	Host communities if involved and empowered by the government, stand a chance of better securing and protecting the facilities.	Policing of distribution systems is best achieved when host communities are involved.	Conceptualizing and measuring energy security. To ensure a cleaner future. Analyzing critical infrastructure. Energy policy.	By working against disruption of oil and gas facilities and reporting defaulters to relevant authority.	The can safeguard the oil and gas distribution pipelines and other facilities; hence it will serve as a source of income to them. Hence, they can deliver.
12. In your view, do you think cost considerations by infrastructure owners can influence the achievability of sustainability goals or resilience of downstream critical oil and gas infrastructures?	Very likely	Very likely	Very likely	Very likely. E.g. in Nigeria the prohibitive cost of the Horizontal Directional Drilling Technology has impacted on the adaptability, reliability and resistance of the distribution system (Specifically the pipeline network).	Very likely	Very likely	Very likely. Any investment that will not yield results, deserve no time, energy and money.
13. Do you think the nature of resilience changes depending on the scale of infrastructure?	Very likely	Very likely	Very likely	Very likely		Not sure	Likely
14. Please state, if any, known ways of assessing sustainability and resilience of downstream critical oil and gas distribution systems.	None	None	Availability of products in the market, sufficiency and or strategic reserve and how long it will absorb the shocks of disruption in the system.	None	Conceptualizing and qualitative study in the field. Designing resilient sustainable systems.		
15. How would you rate the current methods of assessing sustainability and resilience of downstream oil and gas distribution systems?	Poor	Good	Fair	Poor	Fair	Poor	Good
16. In your view, is the application of a set of principles or guidelines useful in achieving long-term effectiveness of sustainability and resilience that can inform the operation of oil / gas infrastructures?	Yes	Yes	Yes	Yes	Yes.	Yes	Yes

17. In your view, do you think a value based/quantitative approach (e.g. establishing performances of the infrastructure that should be sustained over the life time of the service delivery), is rather useful in achieving the long-term effectiveness of sustainability and resilience?	Yes	Yes	Yes	Yes	Yes	Yes	Yes

INTERVIEWEES	**Respondent 8**	**Respondent 9**	**Respondent 10**	**Respondent 11**	**Respondent 12**	**Respondent 13**	**Respondent 14**
1. Are you familiar with the concept of resilience in the context of downstream critical oil and gas distribution systems?	Yes	No	Yes. The ability to prepare, adapt to change, to withstand or face a disruption or change and to be able to recover or bounce back.	Yes. Ability to adapt to change and ability to survive crisis.	No	Yes. Ways and manner in which downstream oil and gas facilities could be prevented from damage for sustained and continuous supply of oil and gas for consumption.	Yes. The resistance the system should overcome if they are to achieve their objectives.
2. Do you think resilience and sustainability are related issues?	Yes	Yes	Yes. When the resilience level is high, it implies that you can sustain your goal.	Yes. Resilience refers to survival, which is same with sustainability.	Yes	Yes. Sustainability comes after resilience.	Yes. If the resilience is achieved, then it should be sustained
3. Do you think resilience could (and should) be integrated into assessment tools as an indicator or rating codes?	Yes	Yes	Yes. This will make organizations to be at rest, since change is permanent.	Yes. It could be, it should be because it is an integral part of business success in a fast changing environment.	Yes	Yes.	Yes. Resilience is a critical index and plays a critical role in the sustainability of the system, so it should be integrated as an indicator or rating codes.
4. Do you think resilience is a familiar concept in the planning, design, development and operation of downstream critical oil and gas infrastructures?	No	No	Yes. This will be captured at the design stage and well planned.	Yes. I think it should be part of the areas mentioned above, but I guess it is just hidden in planning jargons without using the word resilience.	Yes	Yes. Assessing possible ways and activities that could serve as set back to implement the above and improve on them.	No
5. What do you think describes the current notion of resilience for downstream critical oil and gas infrastructures?	Longevity / Flexibility of Physical Structure.	Longevity / Flexibility of Physical Structure	Uninterrupted Distribution of Oil or Gas and their products.	Economic Competitiveness of Infrastructure Owner.	Longevity / Flexibility of Physical Structure and Uninterrupted Distribution of Oil or	Longevity / Flexibility of Physical Structure. Uninterrupted	Uninterrupted Distribution of Oil or Gas and their products.

					Gas and their products.	Distribution of Oil or Gas and their products. Adequate Organizational/Management system. Economic Competitiveness of Infrastructure Owner.	
6. Achieving sustainability and resilience of downstream critical oil and gas infrastructures requires the collaboration of every stakeholder including end users and host community indigenes.	I agree	I agree	I strongly agree	I strongly agree. There is no alternative to that or else the business is heading for a failure.	I strongly agree	I strongly agree. The collective collaboration of every stakeholder remains the only way the downstream oil and gas infrastructure can be safe guarded and sustained.	I strongly agree. Achieving sustainability and resilience is not a one-man show, all the stakeholders should be involved and in this case. Collaboration should be the watchword.
7. In your view, what factors are most capable of disrupting the operations of downstream critical oil and gas infrastructure systems?	Non-community / stakeholders inclusion.	Not involving all stakeholders.	Security i.e. vandalization of pipelines and reliability of critical equipment's.	Lack of proper planning, inclusion of preparation for contingency.	Vandalism.	Insurgency (in form of military and or terrorism in cases of the middle east, Nigeria, some part of India), sabotage (oil pipeline vandalization and theft), improper monitoring of pipelines right of ways, political instability etc.	Inadequate government policies and the "I don't care" attitude of the stakeholders.
8. In your view, what measures can be put in place to prevent disruptions of downstream critical oil and gas infrastructures?	Stakeholder interaction.	Involving all stakeholders. All hands on deck.	Resilience should be deployed.	Assets quality management.	Proper stakeholder engagement, legislation, use of horizontal directional drilling technology when facilities are to be built in vandalism prone areas.	Creation of employment for the youths, education of the youths, proper monitoring of oil and gas facilities, good government policies on environment protection / conservation.	There should be visible government presence (realistic policies) and active stakeholders (end-users) inclusive who should voice their grievance as at when due and act accordingly.

9. Based on your experience, please state potential vulnerable components / factors that are capable of causing disruptions to the operation of downstream oil and gas distribution systems.	Vandalization.	Vandalization.	Vandalization.			Oil theft / pipeline vandalization, militancy issues, Insurgency, conflicts, bad government policies, poor road networks / social amenities.	Community / social unrest.
10. Based on your answer above, please state how disruptions of critical oil and gas distribution infrastructures are currently prevented and mitigation strategies if any.	Community inclusion.	Inclusion.	Replacement of aged equipment and application of reliability centered maintenance policy.			Education of the youths involved in such crimes, provision of amnesty, provision of basic amenities / infrastructure (e.g. roads, schools) to areas that are hitherto marginalized, improved corporate social responsibilities on part of operating oil or gas companies, employment and integration of the youths into the oil or gas business etc.	Setting up of special task forces, use of military, police, and community vigilante groups.
11. Briefly state the role host communities can play to ensure oil and gas infrastructure safety and energy security?	As watchdog	Sense of ownership.	Securing the infrastructures.			Engaging the youths of the communities as part of the security forces to protect the facilities traversing their communities, from external forces that may come to destroy the facilities.	Awareness programmes and community vigilante groups.
12. In your view, do you think cost considerations by infrastructure owners can influence the achievability of sustainability goals or resilience of downstream critical oil and gas infrastructures?	Likely	Likely	Very likely	Very likely	Likely	Not sure. Cost considerations go with environmental concerns.	Not sure. The cost implication is really high and without government assistance, infrastructures owner's effort may be futile.

13. Do you think the nature of resilience changes depending on the scale of infrastructure?	Not sure	Not sure	Very likely	Very likely	Likely	Not sure	Likely
14. Please state, if any, known ways of assessing sustainability and resilience of downstream critical oil and gas distribution systems.			Using software's to measure integrity of infrastructure.			Environmental considerations, political and economic stability, issues of militancy, oil theft are also of great concern for sustainability and resilience of the downstream oil or gas infrastructure system.	
15. How would you rate the current methods of assessing sustainability and resilience of downstream oil and gas distribution systems?	Fair	Fair	Poor	Poor	Fair	Fair	Poor. Majority of the end-users are not satisfied and they have lost hope on the government and are non-challant about assessing the development in the system.
16. In your view, is the application of a set of principles or guidelines useful in achieving long-term effectiveness of sustainability and resilience that can inform the operation of oil / gas infrastructures?	Yes	Yes	Yes	Yes	Yes	Yes	Yes. The wake-up call is here and should all the stakeholders take up their responsibilities, then the change has come.
17. In your view, do you think a value based / quantitative approach (e.g. establishing performances of the infrastructure that should be sustained over the life time of the service delivery), is rather useful in achieving the long-term effectiveness of sustainability and resilience?	Yes	Yes	Yes	Yes	Yes	No	Yes. Life is all about value. If a value-based approach is in place, then sustainability will be achieved.

INTERVIEWEES	Respondent 15	Respondent 16	Respondent 17	Respondent 18	Respondent 19	Respondent 20	Respondent 21
1. Are you familiar with the concept of resilience in the context of downstream critical oil and gas distribution systems?	Yes. The concept of resilience refers to ability of critical oil and gas distribution infrastructure e.g. pipelines to remain efficient after use/maintenance overtime.	Yes. My organization always ensure that it fix all disruptions of any form to keep the business moving.	Yes.	Yes. Resilience has an integral part which is reliability applied in the entire process of the oil and gas downstream.	No	Yes. Because the downstream is the energy needs for economic growth. It is required always.	Yes. This is a way to adapt to the challenges and threat faced when there is a problem with the distribution system.
2. Do you think resilience and sustainability are related issues?	Yes.	Yes. Because without resilience, sustainability will not be possible.	No	Yes. Resilience makes sustainability possible.	Yes	Yes.	Yes. Sustainability is like a tool to keep the system operating.
3. Do you think resilience could (and should) be integrated into assessment tools as an indicator or rating codes?	Yes.	Yes.	Yes.	Yes. Resilience should be integrated to provide for sustainability and safeguard unforeseen impacts.	Yes	No	Yes
4. Do you think resilience is a familiar concept in the planning, design, development and operation of downstream critical oil and gas infrastructures?	No.	Yes. You have to take resilience into cognizance before going into downstream business to avoid failure.	No	No	Yes. I think the four strategic components i.e. adaptability, reliability, resistance, response & recovery are in existence the oil and gas distribution business.	No	No
5. What do you think describes the current notion of resilience for downstream critical oil and gas infrastructures?	Longevity / Flexibility of Physical Structure.	Uninterrupted Distribution of Oil or Gas and their products.	Uninterrupted Distribution of Oil or Gas and their products.	Longevity / Flexibility of Physical Structure. Uninterrupted Distribution of Oil or Gas and their products. Adequate Organizational/Management system and Economic Competitiveness of Infrastructure Owner.	Longevity / Flexibility of Physical Structure.	Longevity / Flexibility of Physical Structure, Uninterrupted Distribution of Oil or Gas and their products. Ensuring safety of infrastructure, financing and maintenance, governance and management.	Uninterrupted Distribution of Oil or Gas and their products, Economic Competitiveness of Infrastructure Owner.

6. Achieving sustainability and resilience of downstream critical oil and gas infrastructures requires the collaboration of every stakeholder including end users and host community indigenes.	I strongly agree	Strongly agree. Economic, environmental, social and financial factors.	I agree	I strongly agree	I strongly agree	I agree	Strongly agree
7. In your view, what factors are most capable of disrupting the operations of downstream critical oil and gas infrastructure systems?	Vandalism, lack of maintenance culture, poor investment in new infrastructure.	Environmental and financial factors.	Militant attacks on they facilities.	Substandard equipment's, inadequate organizational management systems, interrupted distribution of oil or gas products.	Community disturbance.	Sabotage, supply of products, management, personnel (trained & motivated), corruption.	Vandalism, inefficiency, lack of project management, lack of appropriate laws.
8. In your view, what measures can be put in place to prevent disruptions of downstream critical oil and gas infrastructures?	Host community participation in security of assets.	Securing the facilities and ensuring adequate finance for the upkeep of the organization.	Government negotiation skill and adequate funding of security system.	Host community corporation. Making provision for sustainability and resilience.	Effective engagement with the community and surveillance to prevent sabotage.	Security, well-trained & motivated personnel, services.	Deregulation. Security.
9. Based on your experience, please state potential vulnerable components / factors that are capable of causing disruptions to the operation of downstream oil and gas distribution systems.	Vandalism, rupture through wear and tear, inadequate maintenance, use of obsolete equipment and technology.	Labor conflicts and inadequate financial support for the business.	Incessant labour strikes are such factors.	Violence by host communities, pipeline vandalism, infrastructure failure.	Community perception of neglect, illiteracy.	Trucking accidents, funding and natural disaster, health safety and environment (HSE) issues, vandalism.	Lack of accountability, bad maintenance culture.
10. Based on your answer above, please state how disruptions of critical oil and gas distribution infrastructures are currently prevented and mitigation strategies if any.	Host community participation in the security of assets, sectioning of pipelines through replacement of worn out sections.	There should be industrial harmony and adequate finance to keep it functioning.	Again government negotiation skill and adequate funding of security system.	Engaging the host community, protection and prevention of infrastructure vandalization and use of quality equipment.		Safety issues are addressed, security monitoring, motivated staff. Consultations on host communities.	New technology, surveillance
11. Briefly state the role host communities can play to ensure oil and gas infrastructure safety and energy security?	Vandalism is most times perpetuated by indigenes. Incentivized host community participation will reduce vandalization of assets by indigenes.	They are organized internal security to check vandalization and sensitize the communities on the evil of vandalization.	Engage them in vigilante functions on they infrastructures.	Ensuring peace for operations of the oil or gas sector.	Community surveillance	Take ownership, constant consultations, regulatory monitoring, HSE compliance, staff training.	Local vigilante, cooperation within them.
12. In your view, do you think cost considerations by infrastructure owners can influence the achievability of sustainability goals or resilience of downstream critical oil and gas infrastructures?	Likely	Likely	Very likely	Very likely	Likely	Very likely. Cost will influence negatively or positively. To fund the pillars of sustainability will ensure achievability.	Very likely

13. Do you think the nature of resilience changes depending on the scale of infrastructure?	Very likely	Likely	Likely	Very likely	Likely	Likely	Very likely
14. Please state, if any, known ways of assessing sustainability and resilience of downstream critical oil and gas distribution systems.	None		None		Assessment and certifications issued regulatory bodies like DPR.	Environmental management systems, auditing process and procedure, records of activities and consultation performance based assessment.	Efficiency
15. How would you rate the current methods of assessing sustainability and resilience of downstream oil and gas distribution systems?	Poor	Good	Poor	Fair	Good	Fair. Need to improve system.	Poor. It has not been sustainable.
16. In your view, is the application of a set of principles or guidelines useful in achieving long-term effectiveness of sustainability and resilience that can inform the operation of oil / gas infrastructures?	Yes. It will provide a yardstick for measurement of long-term effectiveness of sustainability and resilience and aid comparability between periods (years).	Yes	Yes	Yes	Yes	Yes	Yes. Although the guidelines are hardly adhered to.
17. In your view, do you think a value based / quantitative approach (e.g. establishing performances of the infrastructure that should be sustained over the life time of the service delivery), is rather useful in achieving the long-term effectiveness of sustainability and resilience?	Yes	Yes	Yes	Yes	Yes	Yes. To some extent.	Yes

INTERVIEWEES	**Respondent 22**	**Respondent 23**	**Respondent 24**	**Respondent 25**	**Respondent 26**	**Respondent 27**	**Respondent 28**
1. Are you familiar with the concept of resilience in the context of downstream critical oil and gas distribution systems?	Yes.	Yes. It is to make product constantly available.	No.	No.	No.	Yes. I am more familiar with the four components, each as an entity. I am not sure of them being packaged together as a concept and tagged “resilience”.	No.

2. Do you think resilience and sustainability are related issues?	Yes.	Yes. Resilience is to respond quickly while Sustainability is the ability to maintain what you have responded to.	Yes.	Yes. Without determination, the challenge in the downstream is such that to remain in business you need resilience and sustainability.	Yes. The resilience of a system would clearly show how sustainable it would be.	Yes. To sustain your business, you always need a robust system that is resilient to disruptions.	Yes.
3. Do you think resilience could (and should) be integrated into assessment tools as an indicator or rating codes?	Yes.	Yes. To measure response to issues	Yes.	Yes.	Yes.	Yes. It should be integrated into assessment tools. A highly resilient system has a better chance of surviving disruption both in the short term and long term.	Yes.
4. Do you think resilience is a familiar concept in the planning, design, development and operation of downstream critical oil and gas infrastructures?	Yes. We do cathodic protection.	Yes. It is necessary, since it deals / shoulder on demand and response.	Yes.	No.	Yes.	Yes. Generally the word "resilience" is a less often used word, though the four strategic components i.e. adaptability, reliability, resistance, response & recovery; are very well integrated into various designs and operations of downstream sector especially.	No.
5. What do you think describes the current notion of resilience for downstream critical oil and gas infrastructures?	Adequate Organization / Management system	Uninterrupted Distribution of Oil or Gas and their products.	Adequate Organization / Management system.	Uninterrupted Distribution of Oil or Gas and their products.	Uninterrupted Distribution of Oil or Gas and their products.	Longevity / Flexibility of Physical Structure. Uninterrupted Distribution of Oil or Gas and their products. Adequate Organizational / Management system. Economic Competitiveness of	Oil and gas downstream distribution infrastructure is often characterized by frequent shutdowns due to economic sabotage / vandalism driven in most part by abject poverty in most locations.

						Infrastructure Owner. Virtually any activity that transforms to sustainable operational efficiency and optimized productivity should directly / indirectly inferred to be indicative of resilience.	
6. Achieving sustainability and resilience of downstream critical oil and gas infrastructures requires the collaboration of every stakeholder including end users and host community indigenes.	I strongly agree	I agree	I strongly agree	I strongly agree	I strongly agree	I strongly agree. Continuous feedbacks from the end-user as well as good relationship with host communities are both critical to achieving sustainable productivity.	I strongly agree
7. In your view, what factors are most capable of disrupting the operations of downstream critical oil and gas infrastructure systems?	Failure in following through planned checks and repairs, vandalism.	Deliberate vandalization of critical gas and oil infrastructure.	Security	Vandalism and aging infrastructure.	Host community stakeholders.	Several factors: industrial actions, aging facilities, insecurity, hostile operational environment, political instability, and organizational / managerial problem.	The activities of infrastructure vandalism and oil & gas products theft.
8. In your view, what measures can be put in place to prevent disruptions of downstream critical oil and gas infrastructures?	Full government participation in the protection of critical assets.	Education and technological monitoring of infrastructure.	Local content	Pro-active measures and investment in new technology.	Create incentives for host community participation.	Improved relationship with host communities, good industrial relations, good facility management system.	Provision of adequate security using technology and government forces.

9. Based on your experience, please state potential vulnerable components / factors that are capable of causing disruptions to the operation of downstream oil and gas distribution systems.	Lack of willingness to carry out statutory / planned maintenance, vandalism.	Corruption	Importation, vandalization of infrastructure.	Youth unemployment and aging infrastructure.	Company's operation philosophy. Repairs of facilities should be done in-house.	Security, intentional sabotage by host communities, social unrest.	Disruption of supply.
10. Based on your answer above, please state how disruptions of critical oil and gas distribution infrastructures are currently prevented and mitigation strategies if any.	More of reaction measures.		Trucking of products.	Improve community's relationship, security.	For now mainly security agents' intervention is being used.	Continuous stakeholders engagement, good community relations, good risk management system.	Community policing. Using of government forces.
11. Briefly state the role host communities can play to ensure oil and gas infrastructure safety and energy security?	They can play as stakeholder, partners' in the business.	Education and involving them in the security.	Provision of security and maintenance of facilities through local content.	Act as first line defense for infrastructure in their locality.	Most vandals reside, or use the host communities as haven to lunch attack	Host communities can help in protecting facilities.	
12. In your view, do you think cost considerations by infrastructure owners can influence the achievability of sustainability goals or resilience of downstream critical oil and gas infrastructures?	Very likely.	Very likely	Likely	Very likely	Unlikely	Very likely	Likely
13. Do you think the nature of resilience changes depending on the scale of infrastructure?	Likely	Very likely	Likely	Likely	Likely	Very likely	Likely
14. Please state, if any, known ways of assessing sustainability and resilience of downstream critical oil and gas distribution systems.	Cathodic protection and pigging.						Fresh investment to meet the current global demand for oil and gas products and the provision of adequate security. While the demand for oil and gas has grown over the years, the provision of infrastructure remains the same over several years in the downstream sector.
15. How would you rate the current methods of assessing sustainability and resilience of downstream oil and gas distribution systems?	Fair	Good	Fair	Poor	Fair	Fair	Poor

16. In your view, is the application of a set of principles or guidelines useful in achieving long-term effectiveness of sustainability and resilience that can inform the operation of oil / gas infrastructures?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
17. In your view, do you think a value based/quantitative approach (e.g. establishing performances of the infrastructure that should be sustained over the life time of the service delivery), is rather useful in achieving the long-term effectiveness of sustainability and resilience?	Yes	Yes	Yes	Yes	Yes	Yes	Yes

INTERVIEWEES	**Respondent 29**	**Respondent 30**	**Respondent 31**	**Respondent 32**	**Respondent 33**	**Respondent 34**	**Respondent 35**
1. Are you familiar with the concept of resilience in the context of downstream critical oil and gas distribution systems?	Yes.	Yes. The ability to recover from shocks in the supply chain for sustainability.	Yes. Suppleness to our major and independent marketers.	Yes	No	Yes. The ability of infrastructure to withstand external destructive forces or to last long.	Yes. Adaptability is the key word; producer and environment respond to the demands of business.
2. Do you think resilience and sustainability are related issues?	Yes.	Yes. To sustain a distribution system, the system must be resilient.	Yes. Suppleness and tolerance are almost the same.	Yes. Sustaining the downstream distribution business via efficient strategies, policies would help the industry to be more resilient.	Yes	Yes	Yes. To stay in business, refusal to quit in the face of challenges means Resilience and Sustainability.
3. Do you think resilience could (and should) be integrated into assessment tools as an indicator or rating codes?	Yes.	Yes. Resilience is critical to the survival of any distribution system.	Yes. As an indicator.	Yes.	Yes	Yes	Yes. Could be done in privy, by individuals.
4. Do you think resilience is a familiar concept in the planning, design, development and operation of downstream critical oil and gas infrastructures?	Yes. Risk assessment.	Yes. The term 'resilience' is not common, but activities in the downstream point to building resilience.	Yes. The ability of the system to come back to its former state.	Not sure	No	Yes. The resilience of infrastructure is a critical factor in how long the infrastructure will last and the value that will be obtained from it.	Yes. That's the reason for the phrases like 'WHAT IF'

5. What do you think describes the current notion of resilience for downstream critical oil and gas infrastructures?	Uninterrupted Distribution of Oil or Gas and their products.	Longevity / Flexibility of Physical Structure, Uninterrupted Distribution of Oil or Gas and their products, Adequate Organizational/Management system.	Longevity / Flexibility of Physical Structure, Uninterrupted Distribution of Oil or Gas and their products, economic competitiveness of infrastructure owner.	Longevity / Flexibility of Physical Structure, Adequate Organizational/Management system.	Longevity / Flexibility of Physical Structure.	Longevity / Flexibility of Physical Structure, Uninterrupted Distribution of Oil or Gas and their products.	Economic competitiveness of infrastructure owner.
6. Achieving sustainability and resilience of downstream critical oil and gas infrastructures requires the collaboration of every stakeholder including end users and host community indigenes.	I strongly agree	I strongly agree. Community impact can be significant.	I strongly agree	Strongly agree as all parties needs to collaborate e.g. without the cooperation of the host community the sustainability will be threatened.	I strongly agree	I strongly agree. Though the infrastructure system may possess physical resilience, a break in the chain can be caused by sabotage from some stakeholders.	I Strongly agree. Ant break in the chain-link disrupts the cycle.
7. In your view, what factors are most capable of disrupting the operations of downstream critical oil and gas infrastructure systems?	Sabotage and equipment failure.	Accessibility - Road, rail, sea. Government policies, competition.	Labour unrest, vandalism and lack of capital.	Inadequate maintenance expertise, political instability and security challenges, non-collaboration with host communities.	Equipment failure, community unrest, personnel inexperience.	Sabotage, poor maintenance, poor design.	Host communities. Vandalism
8. In your view, what measures can be put in place to prevent disruptions of downstream critical oil and gas infrastructures?	Regular assessment of equipment and infrastructures / monitoring.	Long-term regulatory policies, road infrastructure, and management capability.	Employer and the in-house union.	Develop an impressive maintenance culture and local expertise, and improve on host community involvement to reduce security issues.	Harmonious relationship with host community, equipment reliability, personnel training.	Security, pressure valves and indicators, more flow stations and metering.	Enforcement of integrity in all stages.
9. Based on your experience, please state potential vulnerable components / factors that are capable of causing disruptions to the operation of downstream oil and gas distribution systems.	Pipelines and valves	Inadequate management structure, pipeline access, government policies, competitive activities, security.	Vandalism and union unrest.			Sabotage.	Structural / facility failure, spills, corruption, dissatisfaction of residents of host community.
10. Based on your answer above, please state how disruptions of critical oil and gas distribution infrastructures are currently prevented and mitigation strategies if any.	Risk based assessment / monitoring.	Security enhancement and community awareness programs.	Management being in good terms with the union.			Security guards, host community participation.	Constant review and upgrade of structures and facilities, and integrity.

11. Briefly state the role host communities can play to ensure oil and gas infrastructure safety and energy security?	Prevention of turndown caused by sabotage by securing critical infrastructures.	Collaboration with the operators for common good of all stakeholders.	By monitoring the facilities and policing.	By providing an enabling environment for the infrastructure to operate in a safe and efficient manner without security interference.	Pivotal role. Should be integrated in the chain of operations.	Identifying saboteurs and weak points for infrastructure.	By not joining or encouraging pipeline vandalism. Trained to be 'owners'.
12. In your view, do you think cost considerations by infrastructure owners can influence the achievability of sustainability goals or resilience of downstream critical oil and gas infrastructures?	Likely	Likely. Drive to maximum profit can compromise sustainability goals.	Very likely	Likely. Such businesses as these are usually capital intensive and sustainability and resilience would have cost implications.	Very likely	Likely	Very likely. Budgeting cannot be rule out in any business.
13. Do you think the nature of resilience changes depending on the scale of infrastructure?	Likely	Likely	Likely	Likely	Likely	Very likely	Likely
14. Please state, if any, known ways of assessing sustainability and resilience of downstream critical oil and gas distribution systems.	Uninterrupted oil / gas product delivery. Fit for purpose infrastructure.		Through objectives setting.		Stakeholders to confer OEM's of distribution systems.	Infrastructure durability, capacity.	On the periodic scale of smooth and un-interrupted operations.
15. How would you rate the current methods of assessing sustainability and resilience of downstream oil and gas distribution systems?	Good		Good	Fair	Fair	Poor	Fair. There is always room for improvement.
16. In your view, is the application of a set of principles or guidelines useful in achieving long-term effectiveness of sustainability and resilience that can inform the operation of oil / gas infrastructures?	Yes	Yes	Yes	Yes	Yes	Yes	Yes. Any set of principles and guidelines to subject to periodic review for authenticity.
17. In your view, do you think a value based/quantitative approach (e.g. establishing performances of the infrastructure that should be sustained over the life time of the service delivery), is rather useful in achieving the long-term effectiveness of sustainability and resilience?	Yes	Yes.	Yes	Yes	Yes	Yes	Yes. The infrastructure feeds / sustain itself by so doing.

5.4.1 Summary of Opinions Obtained from One-to-One Interviews

From the interview responses, it is possible to extract very vital findings. As regards respondent's knowledge of sustainability and resilience in the context of DCOGI, majority of the respondents are familiar with the terms and acknowledged that resilience was required to keep the DCOGI systems in operation. The interpretations of the resilience for example varies but were all within the core principles and aspects resilience in the context of DCOGI. For example, respondents 3, 23, 31,14 who are in marketing department of NNPC understood resilience in terms of "adequate fuel supply to market affected by infrastructure or supply disruptions". Respondents 34, 5, 13, who are field engineers and technicians ascribed sustainability and resilience of DCOGIs to security of physical infrastructure, rapid response, and recovery after a failure. Whiles respondents 15, 16, 23, 25, 26, 27, 10, who are strategic managers gave overarching interpretations.

It is widely acknowledged that sustainability and resilience in the context of DCOGI are related. Specifically, respondents (4, 2, 3, 5, 10, 13, 14, 16, 18, 26, 27, 30, 32) portrayed resilience as the prerequisite to achieving sustainability within the DCOGI system. However, respondent 11 (strategic manager), 25 (strategic manager), 31 (marketing) and 3 (marketing) conceive sustainability and resilience as similar concepts. Example respondent 3 suggesting "*Many of the central parts of sustainability also happen to be core pillars of resilience for a system to be truly resilient*." Both positions are consistent with varying opinions within the literature and points to the view that both concepts are related and used interchangeable. The respondent's views are inclined towards the integration of both concepts. Such inclination supports the theory postulated in this study, for the combine assessment of sustainability and resilience. And further affirms the suggestions within the literature that sustainability alone is not sufficient to address the increasing frequency of disruptions in the DCOGI industry. Furthermore, when asked if both concepts could be integrated into an assessment tool as indicators, majority of respondents agreed to this. Respondents were assertive that components of both concepts are required for the survival of the DCOGI industry.

All the respondents agree that the collective input of the broad array of stakeholders to the DCOGI industry is required to achieve sustainability and resilience of DCOGIs. From the responses, it is widely suggested that host communities or locales can support the security of physical infrastructure through collaboration with owners. They are varying responses as regards existing sustainability and resilience assessment methods within the DCOGI industry. To this end, it is not possible to obtain a collective respond to that regard, suggesting no unified assessment methods exist. When asked to rate the current assessment methods, current disintegrated DCOGI industry sustainability and resilience assessment methods were mainly rated between poor to fair. Notably, respondents who rated current assessment methods as good were the managers who are at strategic levels. Resulting in inconsistent views across the different stakeholders. In generally, the findings from the survey responses are consistent with literature review findings, and provide key contributions enabling the development of the proposed RESOGI.

5.5 Group Model Building

The group model building process is described in sections 3.3.3.2; the responses and relevance to the RESOGI framework are presented in here table 5.4 below.

Table 5.4: Opinions Collated from the GMD Participants and Relevance to Hybrid Indicators - RESOGI
They are in no order

OPINIONS	RELEVANCE TO RESOGI - HYBRID INDICATORS
Reduction of carbon emissions from gas turbines (USING AMOZINE, DIMINE, WATER). This and other technology exist but not in use.	Low carbon emissions (Environment Pillar).
Use of Combine circle instead of open circle.	Informatics & innovation (Economic-Financial Pillar)
Use of patrol teams, security officials, community security / vigilante (i.e. given money to safeguard the pipelines). E.g. Pirates use anchors to destroy pipeline, others use dynamite.	Applicable to all indicators in the security pillar.
Measures to prevent vandalization - caused mainly by sabotage, politically motivated attacks, ignorance. E.g. vandalism of gas infrastructures is only motivated, as resources cannot be stolen unlike oil.	Interdictions / Intentional attacks (Security pillar).
Embed alternative pipeline routes and distribution nodes into infrastructure systems. Asset owners only employ reactive measures rather than proactive, alternatives are proposed only after disruptions occur. Lessons learnt are taken forward.	Alternatives – Multiple distribution routes (Redundancy Pillar).
Application of ring main technique – that provides multiple sources of product supply (gas or oil) into a system e.g. at distribution nodes, sub-stations. Vital if no other means to transport resources are available – during suggested effective emergency repairs, online repair (to examine the nature of any damage), and to improve surveillance.	Alternatives – Multiple distribution routes (Redundancy Pillar).
Use of real time monitoring, use of satellites monitoring. E.g. Cyber security is restrictive, cannot stop attacks on infrastructure systems. Cyber security is difficult to prevent - internal sabotage - internal security.	Applicable to all indicators in the security pillar.
Lack of proper plan / location of infrastructure, legacy assets are not traceable. Even with poles and identifiers are usually difficult to locate. Location of asset should be strategic, away from houses/communities, inaccessible by locales.	Guiding policy for operation (Governance Pillar).
Measures to protect infrastructures e.g. pipelines, distribution nodes that are often easy target by organized criminals who capitalize on their locations. In the case of gas, pressure monitoring can help detect disruptions. Cathodic protection can be used for gas pipes to prevent corrosion, based on cathode and anode. Helps identify were damage occurs to enable prompt responses for repairs	Location option (Economic-Financial Pillar). Also applicable to all indicators in the security pillar.
Negligence by asset owners, poor monitoring and maintenance cultures.	Facilities Management System and maintenance culture/practice (Maintenance Requirement & Risk Management Pillar).

Preventive measures are mainly reactive, informed by an occurrence of an incident. The target should be about preventing disruptions from occurrence, existing measures are reactive and often disruptions still occur. Even with cyber monitoring and software's.	Need for proactive measures – RESOGI Hybrid indicators should be utilized for future proofing, from planning / construction to decommissioning stage of infrastructure system.
Awareness and involvement of locales/indigenes is vital, alternative routes for pipes can still be vandalized / disrupted.	Stakeholder / End-User Integration & Interconnection (Social Pillar).
Consider depth of infrastructure e.g. pipeline, security conscious/driven design options.	Design Options / Value (Economic-Financial Pillar).
Constant security patrol and real time monitoring seen as more effective than cyber security which only aids identify location of disruption.	Applicable to all indicators in the security pillar.
Climate change impact considered minimal on infrastructure except if manufacturers or asset owners do not develop infrastructure to standard before commissioning. Standard life span of asset, rather likely to affect resources e.g. temperature could affect conditions of gas.	Climate change impacts (Environment Pillar). Also guiding policy for materials procurement (Governance Pillar).
Cathodic Protection is a maintenance practice. If not properly done can reduce the life of pipeline.	Facilities Management System and Maintenance Culture / Practice (Maintenance Requirement & Risk Management Pillar).
Lack of well-trained infrastructure / plant operators.	Facilities Management System (Maintenance Requirement & Risk Management Pillar).
No energy mix.	Diversity – Renewables (Redundancy Pillar).
Lack of forward thinking, lack of policy continuity by successive governments / company executives, bureaucratic hurdles, corrupt system of government, lack of sincerity of purpose.	Guiding policy for operation (Governance).
Disconnect between field engineers and managers at strategic levels.	Stakeholder "internal" integration & interconnection (Social Pillar).
Poor maintenance.	Maintenance culture / practice (Maintenance Requirement & Risk Management Pillar).
Climatic conditions affect equipment and some cases product itself - environmental conditions can affect functioning, usually has cost implications.	Climate change impacts (Environment Pillar). Also cost (Economic-financial).
Oxygen deprivation to organisms as gas escapes from infrastructure, absorbs oxygen e.g. in the case of a disruption or explosion.	Biodiversity (Environment Pillar)
Use of anti-corrosive alloys of metal e.g. cobalt, nickel - for design options and value, maintain standard.	Design options and value (Economic-Financial Pillar). Also guiding policy for materials procurement (Governance).
Terrain determines how pipes are laid - to prevent acid rain - soil and climate conditions should be taken into consideration.	Pollution reduction / mitigation strategy (Environment Pillar).
Design type - floating and non-floating tanker lids, open roof with thin film (polyester) that expands as product move. Spheres for containment of gas, for LPG is	Disaster preparedness, Health and Safety measures (Maintenance Requirement & Risk Management Pillar), Design options and value (Economic-Financial Pillar)

user friendly, for LNG – use buried tanks or bond with tough enforcement that act as breakers during a disaster.	
Climate impact on tankers - depends on geographical location, heat can affect product. Example of recommended practice includes use of vents in tankers.	Guiding policy for operation (Governance). Also pollution reduction / mitigation strategy (Environment Pillar),
Use of Strategic Storage Systems e.g. in Yokohama, Japan. Use of large-scale storage tankers capable of storing over 1 million barrel of product, instead of pipelines due to natural disasters like earthquake and other disruptions. Also use of surface hoes to siphon products.	Strategies to manage vulnerabilities from interdependencies, Disaster preparedness (Maintenance Requirement & Risk Management Pillar).
Employment to indigenes during and after constructions, scholarships to indigenes.	Corporate social responsibilities (Social Pillar)
Contracts using community liaising contractors.	Stakeholder / end-user integration & interconnection (Social Pillar)
Also check it for liquidified gas at temperatures and temperature effects on product.	Strategies to manage vulnerabilities from interdependencies, Disaster preparedness (Maintenance Requirement & Risk Management Pillar).
Government policies in the downstream sector e.g. the subsidy regime in Nigeria, impedes the industry from achieving its potential.	Effective regulations and monitoring (Governance)
Current Practice – trade-off between building in redundancy and cost considerations e.g. multiple pipelines.	Redundancy Pillar
Barges have risk – relating to time – mainly due to weather conditions e.g. high tides. Also security issues e.g. pirate attacks. Cost of risk could go to third parties – in some cases risk are shared between insurance company's and product owner.	Strategies to manage vulnerabilities from interdependencies, Disaster preparedness (Maintenance Requirement & Risk Management Pillar).
Embed measures to reduce impact from disasters e.g. tankers with protective films to prevent spills, protective shields to prevent rupture.	Disaster preparedness (Maintenance Requirement & Risk Management Pillar).
Maintain products in its containment condition to avoid hazards e.g. LNG conditioned 1/600 times compressed to make it liquid.	Facilities Management System and maintenance culture / practice (Maintenance Requirement & Risk Management Pillar).
Rupture considered more risky than fire outbreak – the later can be control with quick response procedures in place, rupture have spontaneous effect e.g. atomic bomb effect, and have cascading impact on human and biodiversity.	Rapid response system, Strategies to manage vulnerabilities from interdependencies, Disaster preparedness (Maintenance Requirement & Risk Management Pillar).
Depending on terrain – storage facilities can be located e.g. on barges, floating vessels or ships instead of buried in the ground or on ground. For pipeline, terrain would determine type of insulation – coating to reduce impact on environment, would also depend on the climate condition of geographical area.	Design Options / Value (Economic-Financial Pillar), pollution reduction / mitigation strategy (Environment Pillar),
When ask – it appears the knowledge and know-how, though piece meal, exits within the industry. Why do disruptions still occur? People, politics, corruption e.g. in developing countries – unqualified persons manning the industry or related government agency.	Politics effect (Economic-Financial Pillar)

Propose use of dual fuel turbines e.g. gas, fuel oil or diesel, hydropower, solar power. E.g. whiles waiting for fixtures or routine maintenance.	Diversity (renewables)
Recommend industry to create and operate collective, sector-wide industry-led schemes to maintain supply if normal supply operations are disrupted.	Strategies to manage vulnerabilities from interdependencies, Disaster preparedness (Maintenance Requirement & Risk Management Pillar).
Recommend aligning downstream sector with protections that apply to allied sectors.	Strategies to manage vulnerabilities from interdependencies, Disaster preparedness (Maintenance Requirement & Risk Management Pillar).
Ensure future / new investors to the sector are financially sound and operationally capable.	Guiding policy for operation (Governance Pillar)
Partner with government to enable government to support supply resilience, improvements and schemes in the downstream sector.	Stakeholder / end-user integration & interconnection (Social Pillar)
Partner with relevant unions to minimize impacts from industrial actions.	Stakeholder / end-user integration & interconnection (Social Pillar)
The deliberate attacks on oil and gas distribution infrastructures globally have significantly affected the resilience of the downstream infrastructure system.	Intentional attacks (Security Pillar)

5.5 Questionnaires

Questionnaire 2 (See appendix) described in sections 3.3.2.

5.5.1. Analysis of Section Two of the Questionnaire

Section two of the survey questionnaires composed of several questions aimed at achieving the objective 5 of the research. The following sections presents the analysis of the responses.

Definitions of Resilience for Downstream Critical Oil and Gas Infrastructure System

From the survey, industry practitioners, when asked about their view on sustainability and resilience in the context of DCOGIs, 70.6% said they were familiar with the concepts while 23.5% said no (Figure 5.2), very few were not sure. Although majority had heard of resilience and sustainability, there was a clear disparity in the level of awareness. Practitioners at strategic level (Managers) were aware of the collective components of both concepts, but those at field (field engineers) only knew based on residual knowledge and acknowledged that there was no clear application of the concepts in practice. It was deduced that although individual components were known e.g., adaptation, response, and recovery, they concept (mainly resilience) are not widely known in the industry.

Interpretation of Sustainability and Resilience for Downstream Critical Oil and Gas Infrastructure Systems

There were diverging views about the current notion of resilience in the industry; most practitioners thought that in the context of this study resilience refers to uninterrupted distribution of oil and gas products, next to longevity and flexibility of physical structure. Interest group / NGO respondents were on the side of the former, there were considerations for adequate organizational / management systems and economic competitiveness also.

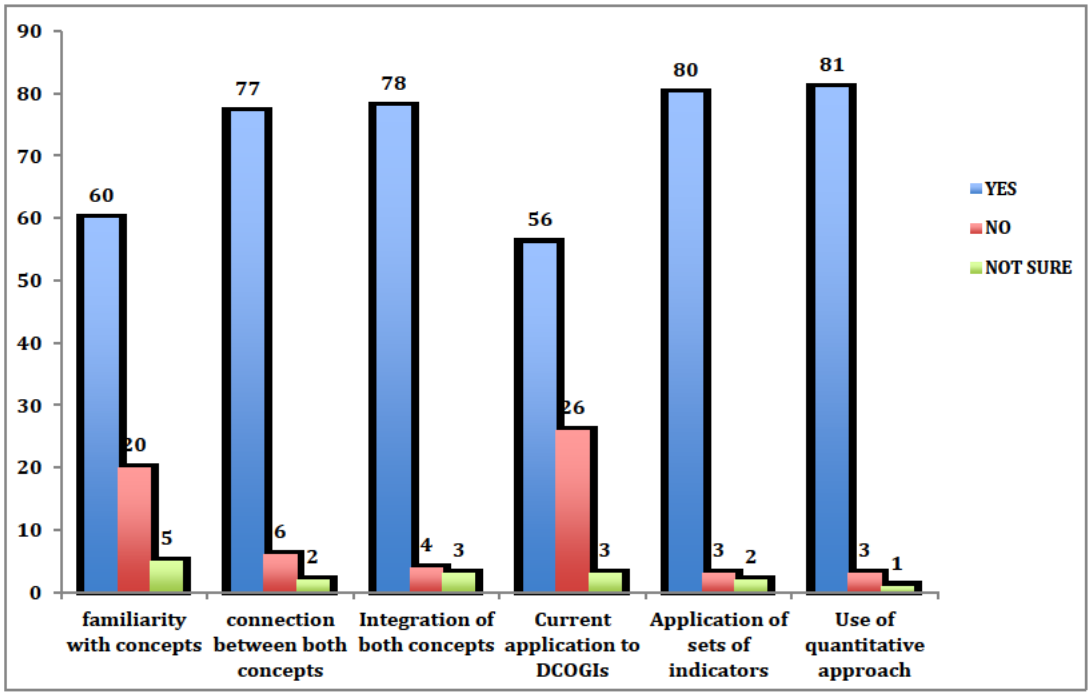


Figure 5.2: Questions regarding the concepts of Sustainability and Resilience for DCOGIs

Scale

All respondents said that resilience is likely to change depending on scale of the infrastructure.

Views on Applicability and Measurement

When asked about application of the concepts during planning, design, development and operations of downstream oil and gas distribution infrastructures; 66% of respondents (figure 5.2) said yes implying that they are usually considerations for sustainability and resilience although what is thought to be resilience is regarded more of the physical hardness of infrastructure. Questionnaire respondents were asked to rate the current methods of assessing sustainability and resilience of downstream oil and gas infrastructure. 57.6% said the current methods were fair, 23.5% said it is poor, but 18.2% (reflecting about 16 of the 85 valid responses) said it was good. The argument is that the reality on the ground (particularly in the developing country's) does not reflect the efficacy of current methods albeit uncertainties may exist. From observations during the research, respondents who said the current methods were good appeared to be mainly senior managers that tern to be defending their organization's strategy, but the majority (mainly field engineers and Government agency personnel's) clearly said it was fair / poor nevertheless they all agreed that there is need to develop more effective assessment tool. The downtime monitoring was a recurring theme mentioned as existing strategy.

Views on Integration of Sustainability and Resilience Indicators for RESOGI

90.5% and 91.7% of respondent respectively (Figure 5.2) thought that both concepts are related issues and could be integrated into assessment tools as an indicator or rating codes and should be addressed simultaneously.

Summary of Analysis

94.1% and 95% of respondents agreed that application of a set of principles or guidelines, and a quantitative approach to achieve sustainability and resilience were valid, although with some caveats like ensuring that guidelines are duly respected by all stakeholders without compromise and continuous improvement over time. There was the issue of lack of transparency by infrastructure owners and lack of communication with host communities and Government agencies, which directly fits into the social indicators. Prominent community indigenes gave their view on models that could feel in the gap, which implies that effective communication between stakeholders is a vital factor.

A summary of recurring issues, and recommendations made by respondents that are considered into the development of the proposed framework are as follows:

- Lack of adequate security for infrastructures
- Obsolete / Ageing facilities
- Industrial unrest
- Lack of public awareness (infrastructure as a national property for all of us)
- Non-adherence to guidelines by infrastructure owners
- Vandalism / deliberate attacks
- Proper stakeholders / community relations management
- Legislation
- Use of trackers
- Real time monitoring
- Natural disasters / accidents
- Forward looking assessment tools
- Adapting to changing climate

- Use of cathodic protection
- Resettlement and relocation management
- Site security plans / safe buffer zones around facilities.
- Accessibility – road / rail infrastructure
- Sincerity of purpose by all stakeholders / divide and rule approach
- People – vision – politics

The aforementioned reflects the various opinions of respondents that have been simplified into broad contents. Three sets of tables prompting the interviewees to rate significance, relative importance and to rate the impacts of each indicator and necessary conditions on sustainability and resilience respectively were added. This allows the investigator to determine the weighting of each indicator, identify levels of risk, and further validating the relevance of the indicators and necessary conditions. The conclusions that determine the features of (and supports the development of) the proposed hybrid assessment framework are as follows:

- There is no indication that an established assessment tool exists amongst practitioners.
- Existing assessment methods are widely considered deemed for improvement in line with changing realities.
- There is no shared understanding of the meaning of resilience in the context of oil and gas distribution systems. The concept is conceived as emerging and they composition is not widely known by practitioners.
- The issue of variation in terms of scale is recognized, even though is vaguely understood.
- Interconnectedness between stakeholders is a must do.
- Incorporating resilience into assessment tools as indicators was generally perceived as positive; also, that resilience can be assessed both quantitatively and qualitatively.
- There is a unified opinion that sustainability and resilience are better assessed together, with the recurring notion that resilience is crucial for attaining sustainability.

5.5.2. Analysis of Section Three of Questionnaire

This section is aimed at achieving objective 6 of the research, which has to do with determining the significance of the hybrid indicators and developing a weighting system for the RESOGI. It presents the derived significance and weightings of the hybrid indicators using stakeholders' responses. Responses from the questionnaire are presented in table 5.5. The results highlight the number of respondents to each sub-indicator indicating their choice of relevance towards the sustainability and resilience of DCOGIs.

5.5.3 Assessing the Significance of the Indicators on Achieving Sustainability and Resilience

The following analyses of the responses are carried out in line with the objective 6 of this research. The next step is to assess the criticality levels of the indicators, it is expected that some indicators will have more influence towards attaining the long-term functioning of the DCOGIs, and this may vary in different implementation phases. Based on the responses collated from respondents, a table of indicator significance is developed. The respondents were asked to assess the criticality of each hybrid indicator towards achieving a resilient and sustainability DCOGIs on a scale of 1 – 4 (1 being very low and 4 being very high). Their responses are presented in table 5.5. After collation of the responses, data are ordered to allow for simple interpretation of the results, an approach adapted from Labaka et al., (2016). In this approach an arithmetic mean, median and mode are obtained, as the range of mean values is concentrated in the middle values (i.e., between 8.5 and 25.6 in one decimal place). A new scale is prepared (Table 5.6), divided into four levels with the ranges for the mean values. Based on this new scale, the final criticality table that shows the significance of each indicator for DCOGIs is developed (Table 5.7). The results show most of the indicators in the high and very high levels of significance, in exception of noise and disruptions from cyber security that were on the low levels of significance. The results generally are considered in this study as a quasi-validation of the hybrid indicators in terms of their impact on the sustainability and resilience of DCOGIs as previously identified and discussed in the literature review (Chapter 2). Notably, noise and cyber security issues show low significance based on the responses. Nevertheless, both are still relevant as the issues relating to noise and cyber security are in recent times reported to soar within the oil and gas industry.

Table 5.5: Section 3 Corresponding Questionnaire Responses (TP – Total Participant)

HEADLINE INDICATORS	SUB INDICATORS	VERY LOW	LOW	HIGH	VERY HIGH	TP
Security	Interdictions / Intentional attacks	9	7	16	53	85
	Theft	4	7	17	57	85
	Social unrest / community disputes	4	6	35	40	85
	Terrorist attacks	19	7	26	33	85
	Cyber-security risks	37	27	11	10	85
Governance	Guiding policy for operation	6	11	29	39	85
	Guiding policy for materials procurement	5	12	32	36	85
	Effective regulations and monitoring	8	9	24	44	85
Maintenance Requirement & Risk Management	Facilities management system	7	11	27	40	85
	Maintenance culture / practice	9	10	23	43	85
	Rapid response system	6	11	26	42	85
	Health and Safety measures	3	11	33	38	85
	Strategies to manage vulnerabilities from interdependencies	9	30	34	12	85
	Disaster preparedness	13	31	18	23	85
Economic-Financial	Market forces & Politics effect	1	13	34	37	85
	Cost (Direct & Indirect)	4	18	29	34	85
	Design options & value	3	20	29	33	85
	Location options	2	21	29	33	85
	Economic effect	1	20	34	30	85
	Informatics & innovation	7	44	19	15	85
Environmental	Climate change impacts	21	28	19	17	85
	Natural hazards	15	35	18	17	85
	Carbon critical design / low carbon emissions	18	26	30	11	85
	Pollution reduction / mitigation strategy	18	23	29	15	85
	Procurement / materials sourcing	8	28	38	11	85
	Biodiversity	10	34	40	1	85
	Waste management	9	29	36	11	85
	Energy	6	27	41	11	85
	Noise	28	24	27	6	85

Social	Stakeholder / end-user integration & interconnection	4	20	29	32	85
	Corporate social responsibilities	1	30	24	30	85
	Stakeholder satisfaction / product availability	6	19	28	32	85
	Competitiveness	6	23	32	24	85
Redundancy	Alternatives (multiple distribution routes)	9	22	30	24	85
	Independent systems	9	28	26	22	85
	Diversity (renewables)	18	27	30	10	85

Table 5.6: Range of arithmetic mean values for the levels of the new scale.

Levels in the new scale	Range of arithmetic mean values
Very Low	0-8.5
Low	8.6-17.0
High	17.1-25.5
Very High	25.6-34.0

Table 5.7: Global Significance of the indicators on Sustainability and Resilience of DCOGI.

HD Indicators	Indicators	Scale			
		Very Low	Low	High	Very High
Security	Interdictions/Intentional attacks				✓
	Theft				✓
	Social unrest/community disputes				✓
	Terrorist attacks			✓	
	Cyber-security risks		✓		
Governance	Guiding policy for operation				✓
	Guiding policy for materials procurement				✓
	Effective regulations and monitoring				✓
Maintenance Requirement & Risk Management	Facilities management system				✓
	Maintenance culture/practice				✓
	Rapid response system				✓
	Health and Safety measures				✓
	Strategies to manage vulnerabilities from interdependencies			✓	
	Disaster preparedness			✓	
Economic-Financial	Market forces & Politics effect				✓
	Cost (Direct & Indirect)				✓
	Design options & value				✓
	Location options				✓
	Economic effect				✓
	Informatics & innovation			✓	
Environmental	Climate change impacts			✓	
	Natural hazards			✓	
	Carbon critical design/low carbon emissions			✓	
	Pollution reduction/mitigation strategy			✓	
	Procurement/materials sourcing			✓	
	Biodiversity			✓	
	Waste management			✓	
	Energy			✓	
	Noise		✓		
Social	Stakeholder/end-user integration & interconnection				✓
	Corporate social responsibilities			✓	
	Stakeholder satisfaction/product availability				✓
	Competitiveness			✓	
Redundancy	Alternatives (multiple distribution routes)			✓	
	Independent systems			✓	
	Diversity (renewables)			✓	

In order to facilitate a more robust sustainability and resilience assessment of DCOGIs, this study also aimed to provide sufficient information regarding significance of the hybrid indictors to a range of DCOGI, the result that will serve as guidance for end-users when using the RESOGI framework. With this in view, the respondents were also asked to identify the associations between the indicators for a range of DCOGIs (in section five of the questionnaire), the responses give a broad insight for decision making for the DCOGI industry and other stakeholders. A color-coded criticality table (Table 5.17) is designed based on the responses. Further analysis is carried out using different methodologies in deriving weightings. First using the Average Weighting Methodology, and further validation using the Analytical Hierarchy Process in the following sections.

5.5.5 Development of Weightings for The Hybrid Indicators

As part of this study, the weightings of the indicators are calculated. This process is expected to give further insight to the relevance of the sub-indicators to achieving sustainability and resilience of DCOGI. Firstly, the weighted average methodology has been adopted to calculate the average weight of the sub-indicators. The method has been recently adopted by Gelman (2007), and Zargarian (2017). The weightings, as obtained, determine the relative importance of each sub-indicator on the average weighted value. The method involves making an assumption on the equality between the seven headline indicators with respect to DCOGI. Each headline indicators equals 14.285%, of which the weights of all the sub-indicators are calculated from the 14.285%. The equation for calculating the average weight, obtained from the study by Arunagiri & Gnanavelbabu (2014), is presented in equation 5.2. The derived weights for the hybrid indicators are presented in table 5.9.

$$\overline{W} = \frac{\sum_{i=1}^{n} N_i s_i}{\sum_{i=1}^{n} N_i} \qquad \textbf{Equation 5.2}$$

As an illustration of the weighted average methodology, an example of how the results were obtained applying equation 5.2 to the sub-indicator ‘Cyber Security’ is presented in table 5.8. For cyber security, 37 respondents rated the indicator very low significance, 27 respondents rated cyber security low, 11 rated high and 10 rated very high (Table 5.5). The weighted average for the cyber security indicator derived from the calculation is 1.93. Then the sum of weighted average for all the indicators in the security pillar is derived as 14.9. Thereafter, the derived weighted average for each sub-indicator in the security pillar is recalculated out from 14.285% for the pillar, which equals the final weight of 1.85033 (Table 5.9). As rule of thumb to confirm

that the derived weights for each sub-indicator under a headline indicator are accurate, the weights should sum up to the 14.285% for the pillar as shown in table 5.9. The average weights for the sub-indicators set have been derived by calculating the average of each sub-indicator in the respective pillars.

Table 5.8: Weighted Average Methodology Calculation for 'Cyber Security'

CONDITION	HITS (N_i)	SCORE (s_i)	$N_i \times s_i$
Very Low	37	1	37
Low	27	2	54
High	11	3	33
Very High	10	4	40
$\sum_{i=1}^{4} N_i s_i = 37 + 54 + 33 + 40$			164
$\sum_{i=1}^{4} N_i = 37 + 27 + 11 + 10$			85
Weighted average ($\overline{w}$) = 164 / 85			1.93
Sum of Weighted average for the headline indicator (Security)			14.9
Weighted average out of 14.285% = (1.93 / 14.9) × (14.285 / 100)			1.85033

5.5.5.1 Security

For the security pillar, the highest weight is theft with a weight of 3.34 (Table 5.9), followed by intentional attacks with 3.19 (Table 5.9) and social unrest with 3.16 (Table 5.9). Terrorist attack was weighted 2.73 (Table 5.9) and the least weight in this pillar is cyber security risk that weighs 1.85 (Table 5.9). The high weight for theft here mainly reflects the views of the product marketers and personnel working in sales and distribution that raised concerns about theft of products usually from both internal and external agents. Intentional attacks are also quite common particularly in regions of the world with social instability, insurgency and politically motivated ones aimed at economic destabilization e.g., in Nigerian recently a major gas distribution infrastructure was destroyed with explosives causing loss of power generation and black-out, impact on businesses and other social impacts. The perpetrators claimed the government at the centre was marginalizing them. Similarly, social unrest and community disputes have trends like the former. Usually from disagreement between communities, government and infrastructure owners and could also be politically motivated. Terrorist attacks are usually more targeted, linked to insurgency and economic sabotage. Interestingly, cyber security is weighted lowest much in contrary to the increased cyber security issues globally. It does appear that within the downstream oil and gas industry, cyber security issues do not have much impact on the sustainability and resilience of the business.

Table 5.9: Calculated Weightings for The Hybrid Indicators

HEADLINE INDICATORS	SUB INDICATORS	SUB – WEIGHTING % (w)	HEADLINE – WEIGHTING % (W)
Security	Interdictions/Intentional attacks	3.19255	(W1) = 14.285
	Theft	3.34594	
	Social unrest/community disputes	3.16379	
	Terrorist attacks	2.73236	
	Cyber-security risks	1.85033	
		Average w = [2.857]	
Governance	Guiding policy for operation	4.75170	(W2) = 14.285
	Guiding policy for materials procurement	4.72182	
	Effective regulations and monitoring	4.81147	
		Average w = [4.762]	
Maintenance Requirement & Risk Management	Facilities management system	2.51994	(W3) =14.285
	Maintenance culture/practice	2.5194	
	Rapid response system	2.55969	
	Health and Safety measures	2.57559	
	Strategies to manage vulnerabilities from interdependencies	2.04298	
	Disaster preparedness	2.06683	
		Average w = [2.381]	
Economic-Financial	Market forces & Politics effect	2.53418	(W4) = 14.285
	Cost (Direct & Indirect)	2.40942	
	Design options & value	2.58096	
	Location options	2.40942	
	Economic effect	2.40942	
	Informatics & innovation	1.94157	
		Average w = [2.381]	
Environmental	Climate change impacts	1.53748	(W5) = 14.285
	Natural hazards	1.57641	
	Carbon critical design/low carbon emissions	1.55694	
	Pollution reduction/mitigation strategy	1.60884	
	Procurement/materials sourcing	1.69318	
	Biodiversity	1.53748	
	Waste management	1.66723	

	Energy	1.73210	
	Noise	1.37530	
Average w = [1.587]			
Social	Stakeholder/end-user integration & interconnection	3.65234	(W6) = 14.285
	Corporate social responsibilities	3.56824	
	Stakeholder satisfaction/product availability	3.61630	
	Competitiveness	3.44810	
Average w = [3.571]			
Redundancy	Alternatives (multiple distribution routes)	5.13310	(W7) = 14.285
	Independent systems	4.95042	
	Diversity (renewables)	4.20147	
Average w = [4.762]			

5.5.5.2 Governance

In this pillar, the weights obtained presents effective regulations and monitoring as the highest with 4.81, guiding policy for operation for weighted 4.75 and closely followed by guiding policy for material procurement that weighs 4.72. Effective regulations and monitoring is reasonably high due to their importance for day-to-day operations of DCOGIs. From the literature, most disasters that have occurred within the DCOGI industry have been partly due to noncompliance to industry regulations. The surveys revealed concerns of lack of trust and sincerity of purpose within the industry and other players like the government's agencies that are corrupt, particularly with reporting and monitoring were lack of adherence to regulations are not reported or dealt with by the books.

5.5.5.3 Maintenance Requirement & Risk Management

The weights assigned to the indicators are quite sensible and seemingly reflects the perception in the industry. Health and safety measures with 2.57 and rapid response system with 2.55 have the highest weights reflecting the spate of fire incidences, spills, gas explosions, truck accidents, other security related incidence etc. within the industry. It is highly critical to have these measures and response systems in place to manage any such incidents. The surveys have also revealed that even though fire can be contained quicker, gas explosions so catastrophic and safety measures must be taken seriously. Facilities management systems and maintenance culture have been weighted 2.51 indicating the importance of adequate management of facilities e.g., pumps, pipelines, truck maintenance, barges against breakdowns and spills. Survey responses revealed

loss of oil products from poorly maintained trucks and aged pipelines etc. disasters preparedness weighs 2.06 and strategies to manage vulnerabilities weigh 2.04. Although the two weighed least in the pillar, their importance cannot be underestimated, as there are strongly linked to the other indicators in the pillar and ultimately their potential to reduce or avert disruptions and crisis within and outside the industry.

5.5.5.4 Economic-Financial

Weights on indicators in this pillar present a similar level of significance seen with the maintenance requirement & risk management pillar as they are closely weighted. Design options and value is the highest at 2.58 closely followed by market forces and politics effect with 2.53. The literature and one to one interview with practitioners have revealed the importance of design options and value as well as market forces due to the significant influence they have regarding disruptions to operations of DCOGI. For example, a DCOGI owner invest in well-designed oil pump or distribution pipeline system, this is expected to last longer without failing, ability to withstand harsh weather conditions, require less maintenance over the life span etc. Interviews with construction workers revealed clients most often would want to save cost and would sometimes compromise long term value. Market forces and politics also is vital to the operations of DCOGIs particularly influence on demand and supply of products. Factors like pricing usually determined by the global market, geo-political interest, and economic competitiveness usually affect the availability of oil or gas products. Cost, location option and economic effect indicators tally with weighting of 2.40. Cost is a core indicator as it is involved with almost all other indicators on the framework, adequate allocation of cost and budgeting e.g., for crisis or unexpected disruptions, is critical to DCOGI sustenance and resilience management (Labaka et al., 2016). Strategic location of DCOGI systems is also vital for aspects such as security, technical / engineering conditions, logistics, environmental conditions that could disrupt operations or the products e.g., temperature conditions could affect oil or gas transport and this could also be linked to design options, also location of infrastructure and vulnerability to aggressors (Labaka et al., 2016). Economic effect is also important especially as it relates to external factors to the DCOGIs. In this pillar informatics has the least weight with 1.94 however this does not reflect the need to regularly update technology that is directly proportional to the performance of DCOGI systems e.g., interviews with practitioners revealed the impact of obsolete facilities on performance, similarly, to cyber security this indicator is not considered to have as much impact to the sustainability and resilience of DCOGIs by the stakeholders.

5.5.5.5 Environmental

The results demonstrate that the indicator with the highest weight is energy; with the weight of 1.73 this is sensible. With global concern for energy efficiency and competitiveness within and out the oil and gas industry e.g., with the global campaign for renewables, energy efficiency should be considered in all developmental phases of DCOGIs from construction to decommissioning. Procurement / material sourcing is rated 1.69 followed by waste management with 1.66. Considerations for these indicators are vital because there are closely linked with the global campaign to sustain earth resources, a core element of sustainability. Considerations for natural hazard and carbon critical design came third and fourth with weights of 1.57 and 1.55 respectively. These are very important indicators for DCOGIs sustenance and resilience to disruptions. In Japan for instance, which is an earthquake prone region, measures are taken to transport oil product with flexible hoes and trucks, also use of floating and strategic storage facilities. Carbon critical design and emission reduction is a vital effort to minimize carbon impact to climate change and a key component to achieving sustainability. Interestingly as it affects both internal and external stakeholder, climate change impact and biodiversity have been weighted the least in this pillar with 1.53. Within the industry, practitioners do not consider climate change to have much impact on DCOGIs. Biodiversity is also an indicator that is often being considered by lip service mostly in developing countries. The importance of these two indicators to achieving sustainability and resilience generally cannot be overemphasized; thereby both should not be ignored.

5.5.5.6 Social

Stakeholder / end-user integration and interconnection has the highest weight in this pillar at 3.65, respondents have highlighted that DCOGI operators are largely detached from their host communities. The issue of lack of communication with local residence, government regulatory agencies, emergency service providers has been described has a “recipe for disaster”, with the potential impact on infrastructure security e.g., preventing external disruptions to operations and response to disasters. Stakeholder satisfaction / product availability is weighted 3.61, this reflects the views of most interviewees and stakeholders of the DCOGI industry, their main requirement is the continuous delivery and of service. The survey revealed that customers/end-users are more concerned about product availability, and less concerned about the activities behind the scenes, albeit there may have an important role to play for instance in preventing crisis. The above perception, however, may vary in different geographical locations. Which further highlights, as

mentioned earlier, the importance of stakeholder integration / Interconnection to help improve resilience levels of DCOGI systems and ultimately sustain its services.

The next indicator in this pillar is corporate social responsibilities, which is weighted 3.56. This is reasonable because it is good practice for DCOGI owners to contribute to the development of the surrounding environments and society at large. Usually, infrastructure owners have a memorandum of understanding with communities, governments, and regulators/monitoring agents to agree and implement developmental projects within local / host communities. The projects are mainly focused on improving the livelihood and wellbeing in the society e.g., through job creation, employment, protecting heritage and culture, building schools and health services, generally support the economic growth and development of its host communities. There is emphasis on supporting high skilled and sustainable job as suppose to the current practice where operators only facilitate low skilled jobs through apprentices, and this is not sustainable. Competitiveness weighted the least in this pillar with 3.44, this indicator is crucial to the operators and investors as it is the responsibility of DCOGI owners to continue to deliver service to its customers and meet an ever-increasing demand for oil and gas (and products). This requires that infrastructure must continuously deliver service, even in the face of crisis (resilience). This may require top management commitment to the building sustainability and resilience processes, promoting sustainability and resilience-based culture altitudes and values within the DCOGI and communicating it to external stakeholders / customers.

5.5.5.7 Redundancy

The indicator with the highest weight in this pillar is the alternatives (Multiple distribution routes) weighted 5.13. This indicator is important as it allows for alternative distribution routes for product delivery, to prevent impacts of unexpected disruptions on operations and product delivery e.g., multiple pipeline routes, multiple tanker routes, and multiple storage locations. Respondents noted the use of down time monitoring to assess continuity of service, e.g., to replace a flow pump, to shut down operations for repairs or maintenance purposes. This indicator allows to strategically build-in alternatives for continuous delivery of service. Independent systems is weighted 4.95, this weight demonstrates the effectiveness of this indictor towards achieving sustainability and resilience, considers creating a balance between reducing the complexities in DCOGI systems and building in redundancies, to enable the system withstand shocks and continue to deliver its service and reduce vulnerabilities and prevent triggering events

from expanding to other systems because of too much complexity. Diversity is weighted 4.20, this indicator weight though weighted the least in this pillar is vital indicator for attaining sustainability. Much against the negative perception of oil and gas use, imbedding diversity into DCOGIs e.g., adoption of renewable sources of energy within the DCOGI system and encouraging end-users to adopt mix of energy use. This indicator could also be linked to corporate social responsibility consideration. In the following section, the AHP method is used to verify the calculated weightings with the WAM, using also questionnaires completed by DCOGI stakeholders during the survey.

5.5.6 Analysis of Section Four of Questionnaire-Development of Hierarchy and Weightings for the Headline Indicators

Section four of the survey questionnaire was designed to achieve objective 4 of the research; here the analytical hierarchy process (AHP) is applied to derive weights for the hybrid indicators. Figure 5.3 presents the step-by-step AHP process for deriving weights, following which the process for the headline indicators is presented first.

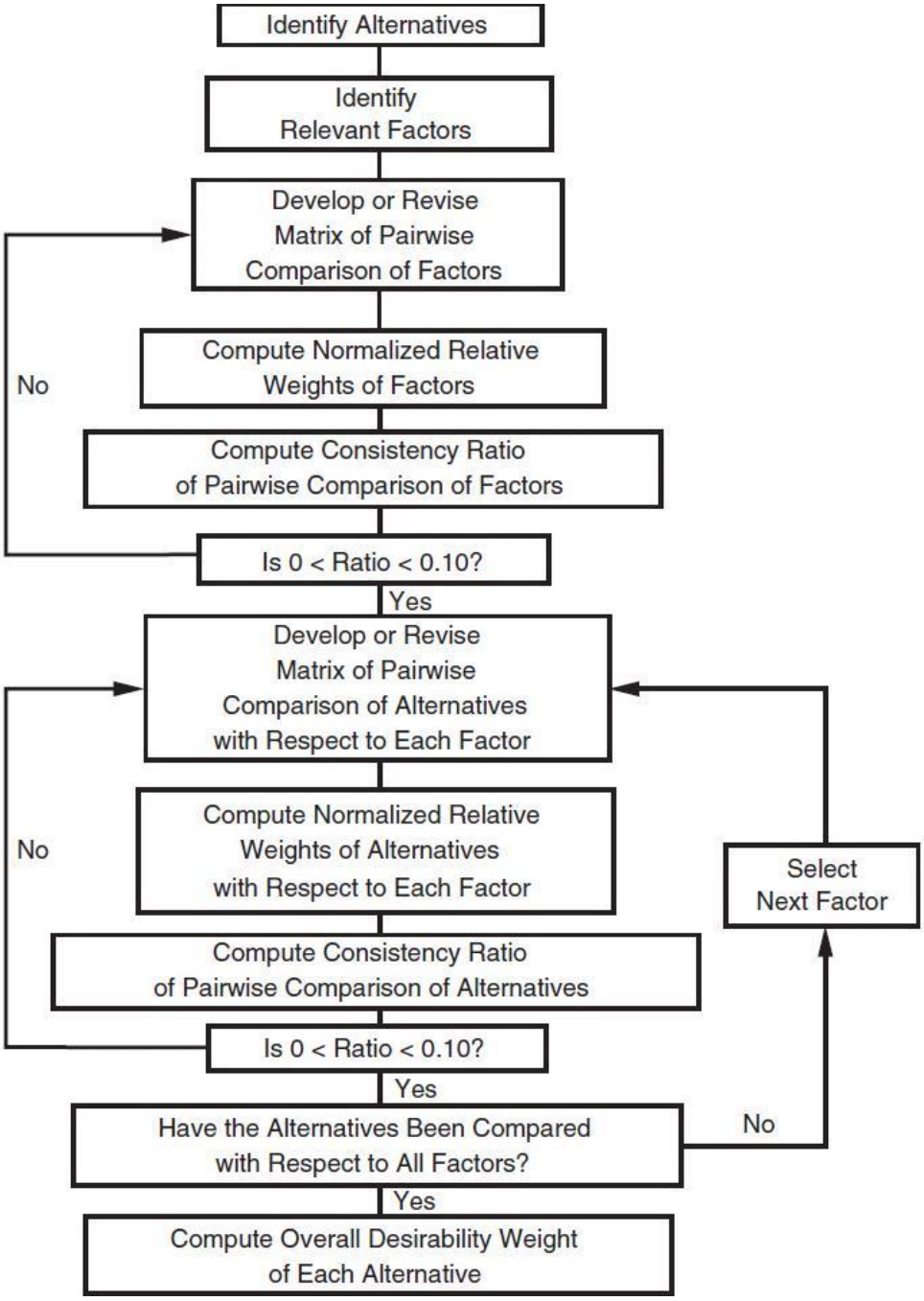


Figure 5.3 Flow chart of the pairwise comparison process (Adapted from Badiru & Cheung, 2002)

Step 1 – Structuring the hierarchy: The first step is establishing the problem in the form of a hierarchy. For this study a seven level AHP model was developed in which the highest level represents the goal (i.e., Resilient and Sustainable DCOGI). The intermediary level represents the overarching criteria, in this study are the headline hybrid indicators (i.e., C1 – C7), and the importance for DCOGI has been assumed equal. The lowest level represents the subsidiary criteria, which in this study are the sub-hybrid indicators.

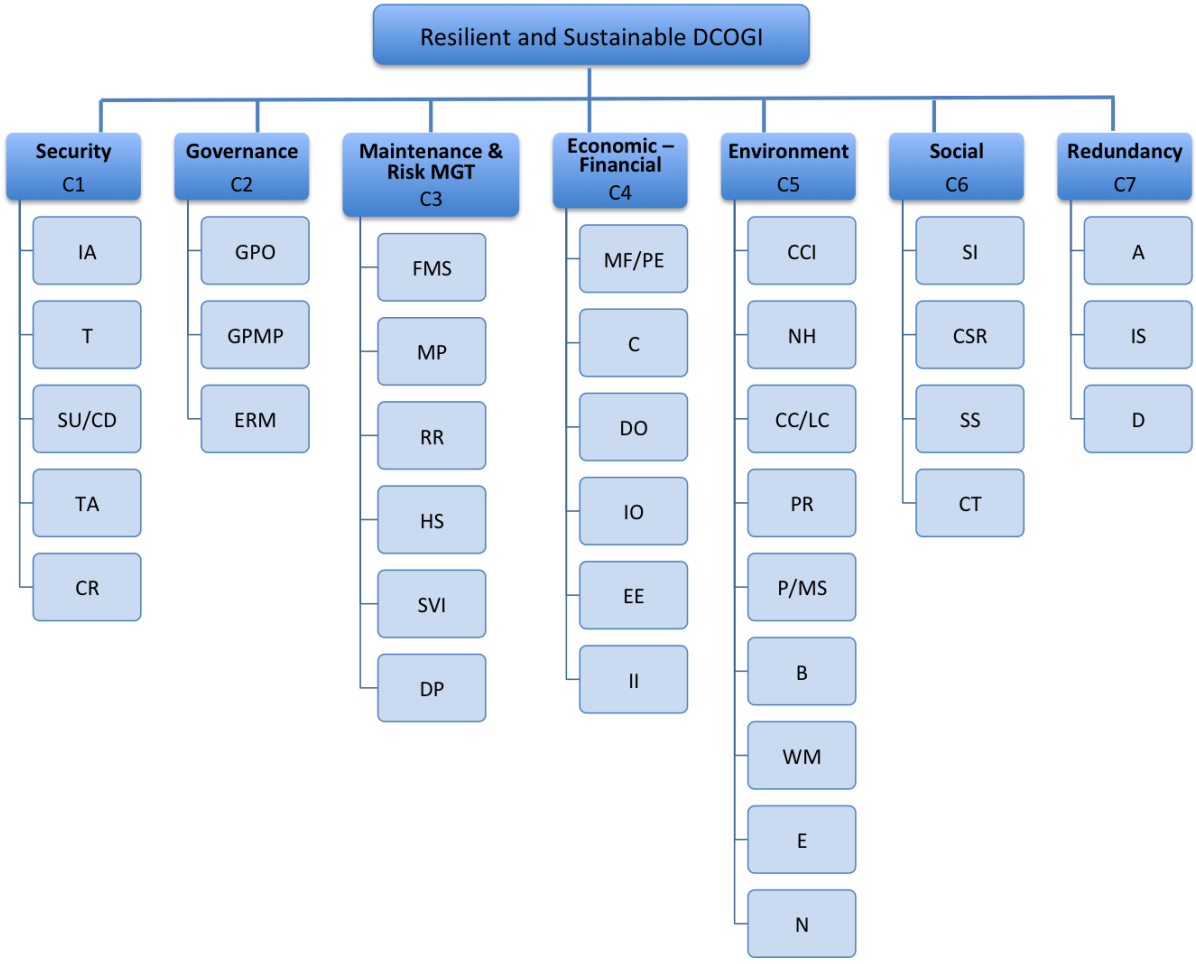


Figure 5.4: Hierarchy of the Utilised Seven Level AHP Model

Step 2 – obtaining the criteria weighting: the second step involves making a comparison matrix to determine the relative importance of each alternative in the same level. These qualitative pairwise comparisons are assigned values according the following scale (9, 7, 5, 3, 1, 1/3, 1/5, 1/7, 1/9) introduced by Saaty (1980); their meanings are shown in table 5.11. To find the weighting for 'n' criteria, equation 5.3 is used to find the number of required comparisons.

$$N = \frac{(n^2 - n)}{2} \quad \textbf{Equation 5.3}$$

Where; N is the number of required comparisons n is the number of criteria

Step 2.1 – Making comparison matrix: As shown in table 5.10 and 5.12, the number of comparisons for the seven headline indicators are 6 for security, 5 for governance, 4 for maintenance and risk mgt., 3 for economic-financial, 2 for environment, 1 for social. A matrix evaluating results of the 'subsidiary criteria' with respect to the overall 'goal' is obtained, following instructions used by Triantaphyllou and Mann (1995) and Curiel-Esparza and Canto-perello (2013). The diagonal elements of the matrix are always one and it is only necessary to fill up the upper triangle matrix. The following rules must be followed to fill the upper triangle matrix: 1) if the judgement value is on the **left** side of 1, we put the **actual judgement** value. 2) if the judgement value is on the **right** side of 1, we put the **reciprocal** value. To fill the lower triangle matrix, the reciprocal values of the upper diagonal is used if used. If α_{JI} is the element of row I column j of the matrix, then the lower diagonal is filled using the equation 5.4.

$$\alpha_{JI} = \frac{1}{\alpha_{ij}} \quad \textbf{Equation 5.4}$$

Equation 5.5 is used to compare N elements (i.e. number of criteria, for example C_1 to C_n, and specify the relative weighting (priority or significance) of C_i with respect to C_j) by αij and form a square matrix A = (αij) of order n with the constraints that $\alpha ij = \frac{1}{\alpha ji}$, for i ≠ j, and $\alpha ii = 1$. Such a matrix is called a reciprocal matrix.

Equation 5.5

$$An \times n = (aij)\, n \times n = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & 1 & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} \text{ Where } a_{ji} = \frac{1}{a_{ij}} \text{ i, j = 1, 2, …, n}$$

Step 2.2 Priority Vectors: requires computing the priority vector also called the normalized principal Eigen vector.

Table 5.10: Questionnaire to Assess Main Criteria

With respect to the overall goal, possible alternatives for hybrid assessment of DCOGI	
Q1	How important is security (C1) when it is compared to governance (C2)
Q2	How important is security (C1) when it is compared to maintenance requirements & risk management (C3)
Q3	How important is security (C1) when it is compared to economic-financial (C4)
Q4	How important is security (C1) when it is compared to environment (C5)
Q5	How important is security (C1) when it is compared to social (C6)
Q6	How important is security (C1) when it is compared to redundancy (C7)
Q7	How important is governance (C2) when it is compared to maintenance requirements & risk management (C3)
Q8	How important is governance (C2) when it is compared to economic-financial (C4)
Q9	How important is governance (C2) when it is compared to environment (C5)
Q10	How important is governance (C2) when it is compared to social (C6)
Q11	How important is governance (C2) when it is compared to redundancy (C7)
Q12	How important is maintenance requirements & risk management (C3) when it is compared to economic-financial (C4)
Q13	How important is maintenance requirements & risk management (C3) when it is compared to environment (C5)
Q14	How important is maintenance requirements & risk management (C3) when it is compared to social (C6)
Q15	How important is maintenance requirements & risk management (C3) when it is compared to redundancy (C7)
Q16	How important is economic-financial (C4) when it is compared to environment (C5)
Q17	How important is economic-financial (C4) when it is compared to social (C6)
Q18	How important is economic-financial (C4) when it is compared to redundancy (C7)
Q19	How important is environment (C5) when it is compared to social (C6)
Q20	How important is environment (C5) when it is compared to redundancy (C7)
Q21	How important is social (C6) when it is compared to redundancy (C7)

Table 5.11: 9-Point Scale for Pairwise Comparisons in AHP For Evaluation, Notation And Their Meaning

Notation	Meaning	Intensity of Importance
EI	A criterion or alternative is extremely important to another	9
VI	A criterion or alternative is very strongly important to another	7
MI	A criterion or alternative is moderately important to another	5
SI	A criterion or alternative is slightly important to another	3
QI	A criterion or alternative is equally important to another	1
SN	A criterion or alternative is slightly not important to another	1/3
MN	A criterion or alternative is moderately not important to another	1/5
VN	A criterion or alternative is very strongly not important to another	1/7
EN	A criterion or alternative is extremely not important to another	1/9

Table 5.12: Evaluation Results Of Main Criteria With Respect To The Overall Goal

N/B* TR (Total Response)

Pairwise Criteria	EI	VI	MI	SI	QI	SN	MN	VN	EN	TR
Security vs. Governance	45	10	4	5	21					85
Security vs. Maintenance Requirements & Risk Management	48	17	12	3	4			1		85
Security vs. Economic-Financial	49	17	6	3	6	2			2	85
Security vs. Environment	40	12	15	10	4	2	2			85
Security vs. Social	16	12	17	7	28	2	3			85
Security vs. Redundancy	10	13	9	9	34	7		3		85
Governance vs. Maintenance Requirements & Risk Management	24	19	7	2	9	24				85
Governance vs. Economic-Financial	42	27	6	3	7					85
Governance vs. Environment	21	23	7	7	23	4				85
Governance vs. Social	12	20	10	12	6	24			1	85
Governance vs. Redundancy	7	15	18	9	8	25	1	1	1	85
Maintenance Requirements & Risk Management vs. Economic-Financial	16	12	13	8	32	3	1			85
Maintenance Requirements & Risk Management vs. Environment	16	15	10	13	28	3				85
Maintenance Requirements & Risk Management vs. Social	9	11	16	9	13		26		1	85
Maintenance Requirements & Risk Management vs. Redundancy	14	12	14	6	7	1	29	1	1	85
Economic-Financial vs. Environment	42	13	9	13	6		2			85
Economic-Financial vs. Social	10	16	13	10	32	3	1			85
Economic-Financial vs. Redundancy	13	12	10	10	35	2	1	1	1	85
Environment vs. Social	9	17	12	13	7	3	23	1		85
Environment vs. Redundancy	3	12	12	12	13	1	28	3	1	85
Social vs. Redundancy	6	7	7	16	39	2	1	1	6	85

Table 5.13: AHP pairwise comparison matrix and calculation for the seven headline indicators

	C1	C2	C3	C4	C5	C6	C7
C1	1	9	9	9	9	1	1
C2	0.111111111	1	7	2	7	0.5	0.333333
C3	0.111111111	0.142857143	1	3	3	0.2	0.2
C4	0.111111111	0.5	0.333333333	1	1	0.166667	0.166667
C5	0.111111111	0.142857143	0.333333333	1	1	0.142857	0.142857
C6	1	2	5	5.999988	7.000007	1	1
C7	1	3.000003	5	5.999988	7.000007	1	1
Sum	**3.44444**	**15.78571**	**27.66666**	**27.99997**	**35.00001**	**4.00952**	**3.84285**

Table 5.14: Normalized relative weight for the headline indicators

	C1	C2	C3	C4	C5	C6	C7
C1	0.290322	0.570135	0.325301	0.321428	0.257142	0.249406	0.260223
C2	0.032258	0.063348	0.253012	0.071428	0.199999	0.124703	0.086741
C3	0.032258	0.009049	0.036144	0.107142	0.085714	0.049888	0.052044
C4	0.032258	0.031674	0.012048	0.035714	0.028571	0.041567	0.043370
C5	0.032258	0.009049	0.012048	0.035714	0.028571	0.035629	0.037174
C6	0.290322	0.126696	0.180722	0.214285	0.200000	0.249406	0.260223
C7	0.290322	0.190045	0.180722	0.214285	0.200000	0.249406	0.260223
Sum	1	1	1	1	1	1	1

Step 3 – determining consistency ratio: Consistency ration (CR) is used to assess ranking consistency and is calculated by dividing the consistency index by the random consistency index, as described by Saaty (1980). A consistency ratio of 0.10 or less is usually advised (Saaty, 1980). If the CR is less than a threshold value, then the matrix can be considered as having an acceptable consistency and the derived priorities from the comparison matrix are meaningful.

Consistency ratio is calculated as follows:

Equation 5.6

$$CR = \frac{CI}{RI}$$

Where RI is Random Index (described below)

Equation 5.7

$$CI = \frac{(\lambda_{max} - n)}{(n-1)}$$

λ_{max} is the maximum eigenvalue of the matrix.

The RI, in Equation 5.6, is an experimental value that depends on the n value. Table 5.15 shows the RI values suggested by Saaty (1994).

Table 5.15: RI Values (Saaty, 1994)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Table 5.16: AHP Results for Headline Indicators

HEADLINE INDICATOR	WEIGHTING (w)	CONSISTENCY RATIO
Security	0.35399	0.087 < 0.1 ok
Governance	0.11489	
Maintenance Requirement & Risk Management	0.04588	
Economic-Financial	0.03101	
Environmental	0.02436	
Social	0.20748	
Redundancy	0.22238	

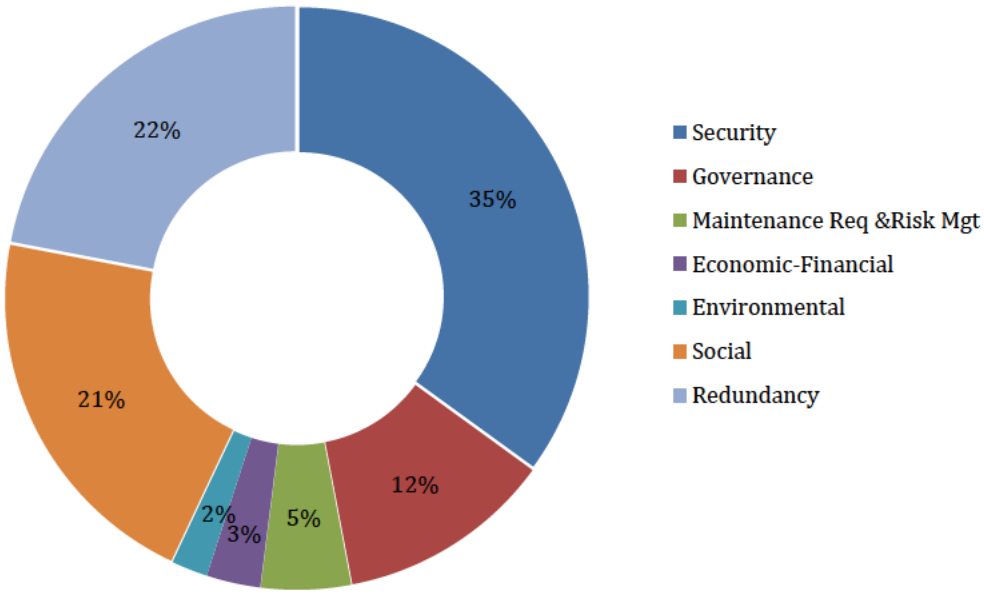


Figure 5.5: The weights of each indicator for the overall goal

5.5.7. Analysis of Section Five of Questionnaire

Section five of the survey questionnaire was designed to derive the criticality levels of each sub-hybrid indicators for achieving sustainability and resilience using six DCOGIs namely pipeline, storage facilities, barges/ships, rail, distribution nodes. This section presents the results of the survey as follows.

Pipeline:

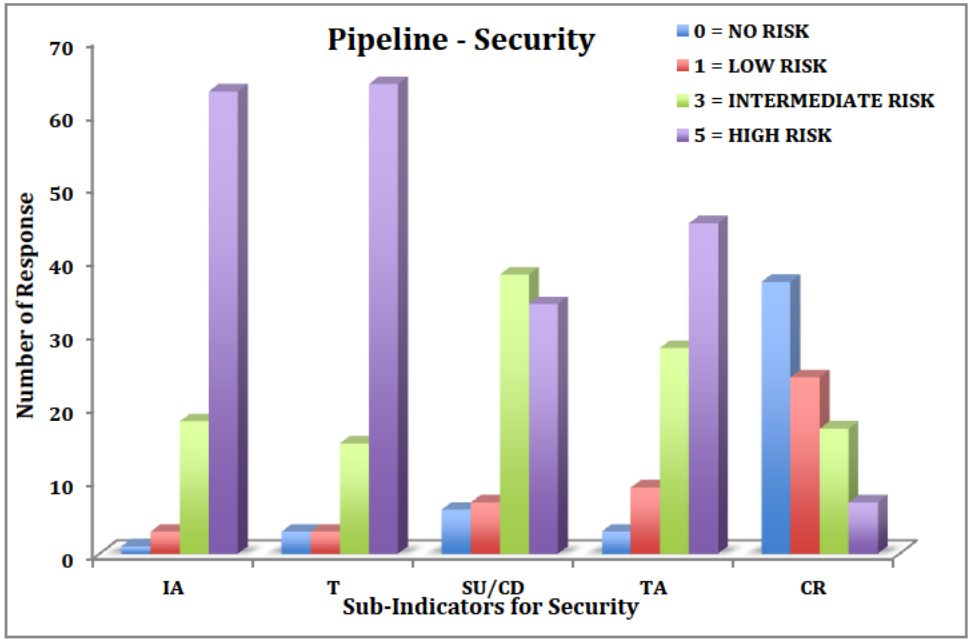


Figure 5.6a Response for security

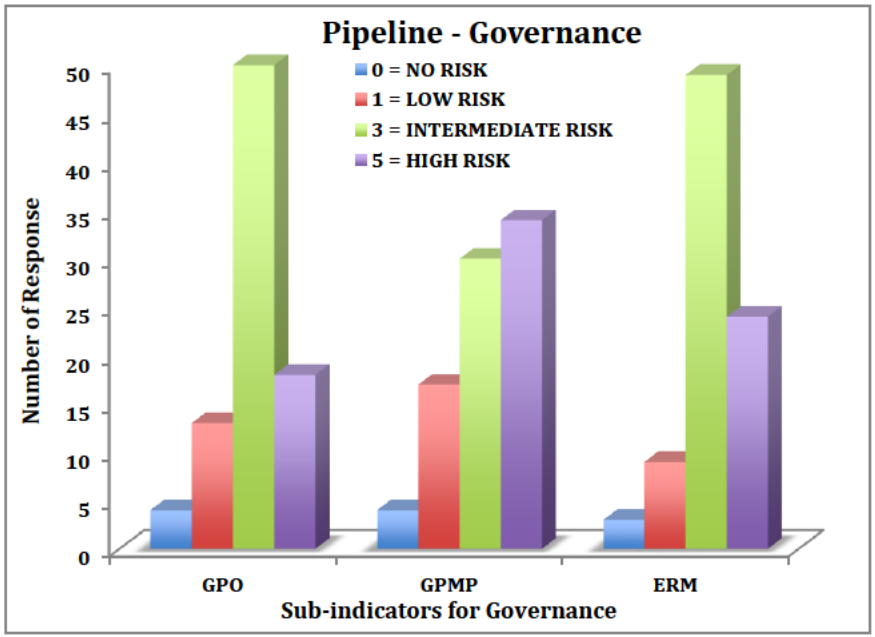


Figure 5.6b Response for Governance

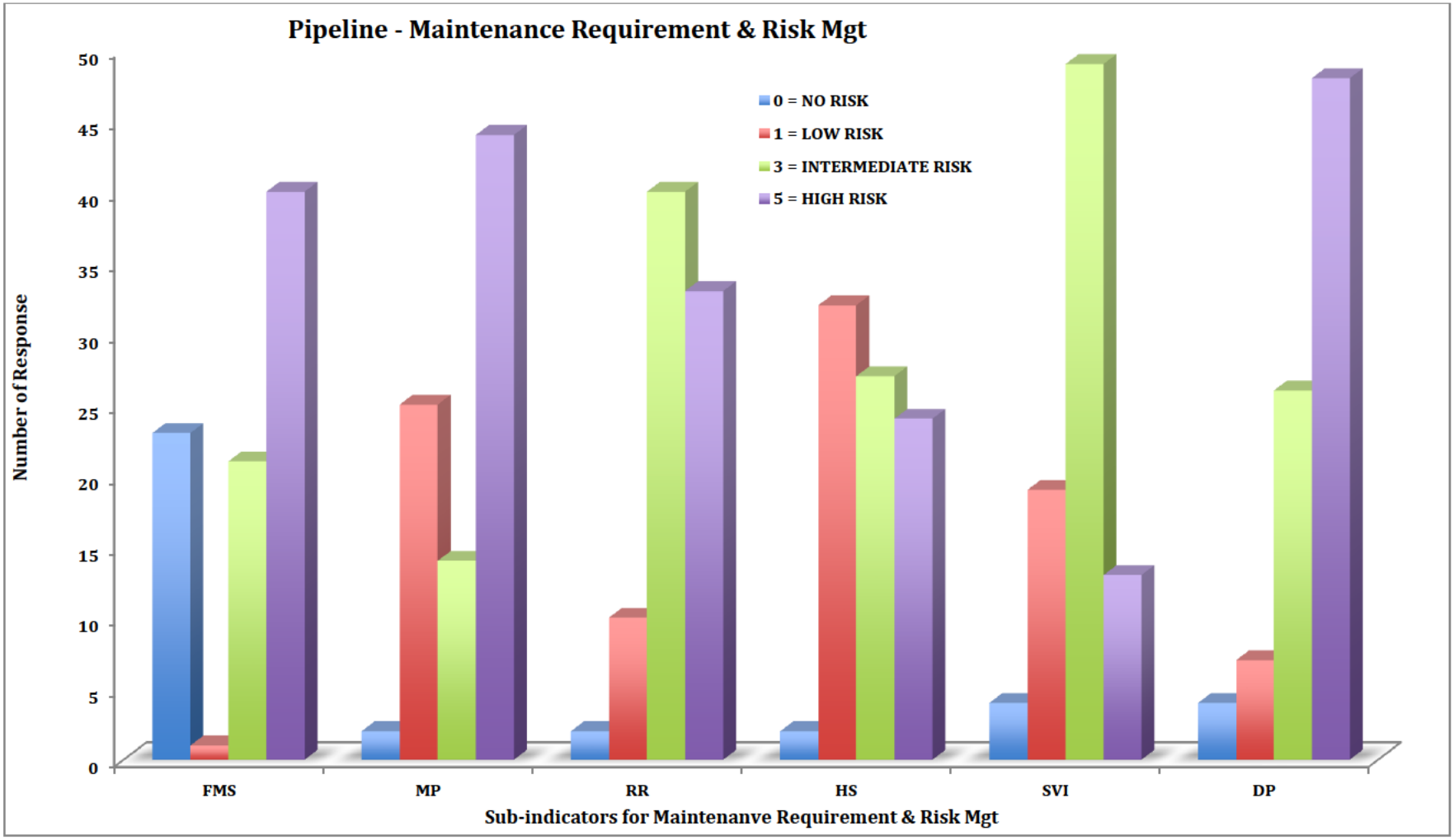


Figure 5.6c Response for Maintenance Req. & Risk Mgt.

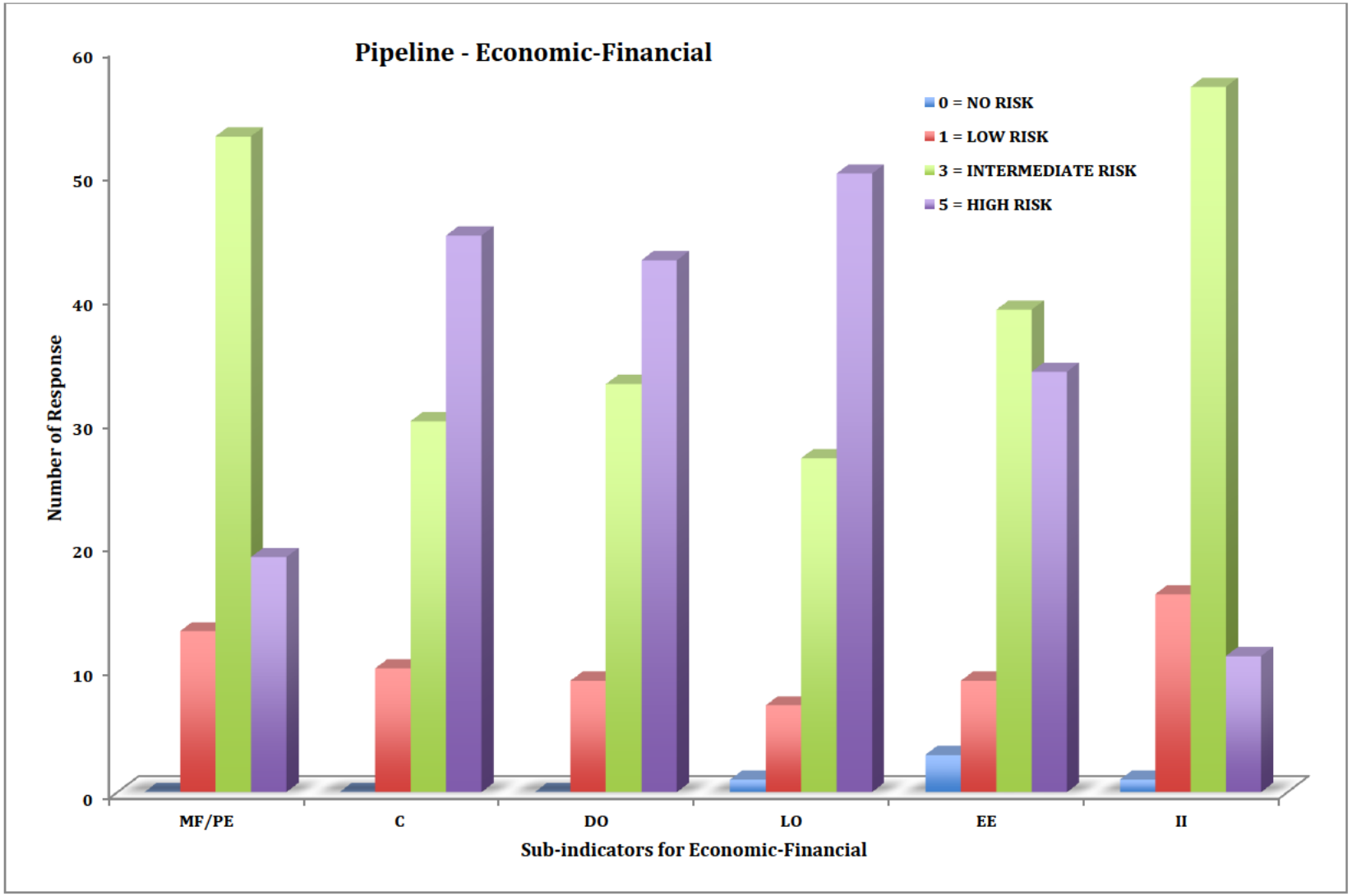


Figure 5.6d Response for Economic-Financial

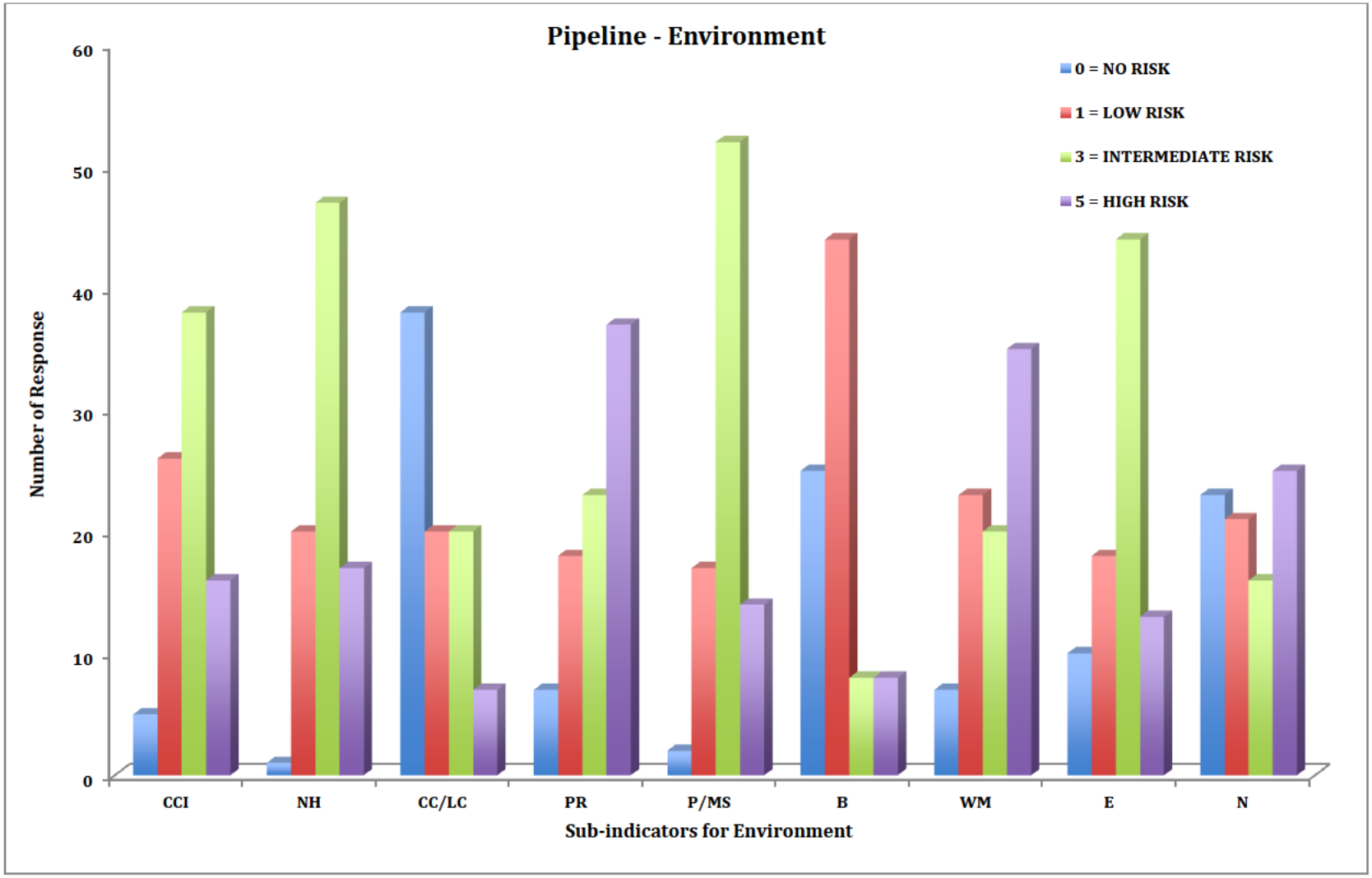


Figure 5.6e Response for Environment

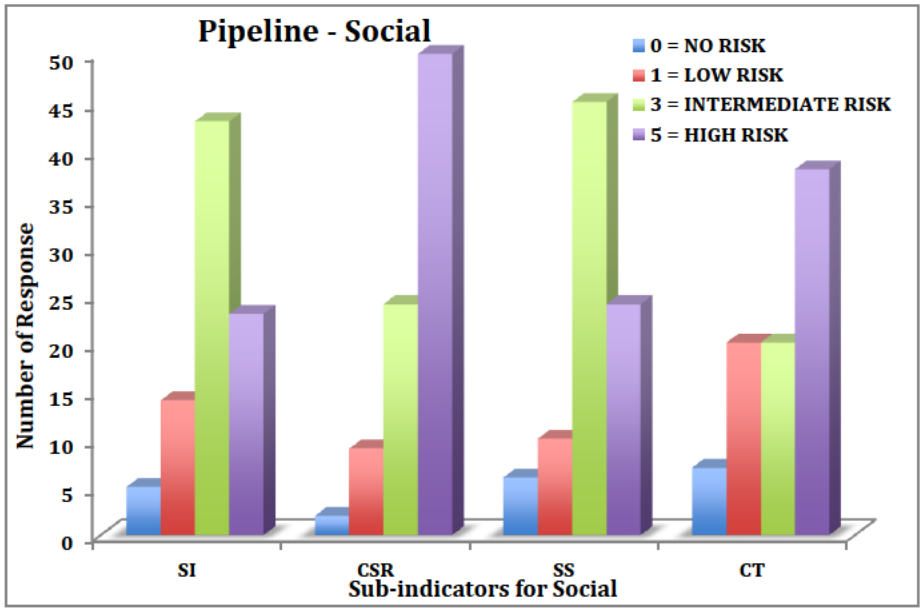


Figure 5.6f Response for Social

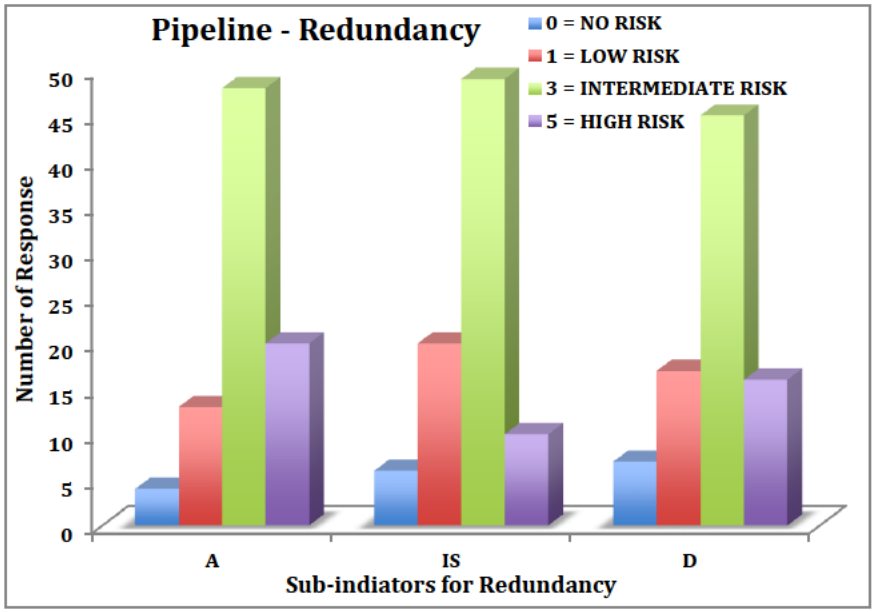


Figure 5.6g Response for Redundancy

Figure 5.6 (a – g): Survey Responses for Pipeline

Storage Facility:

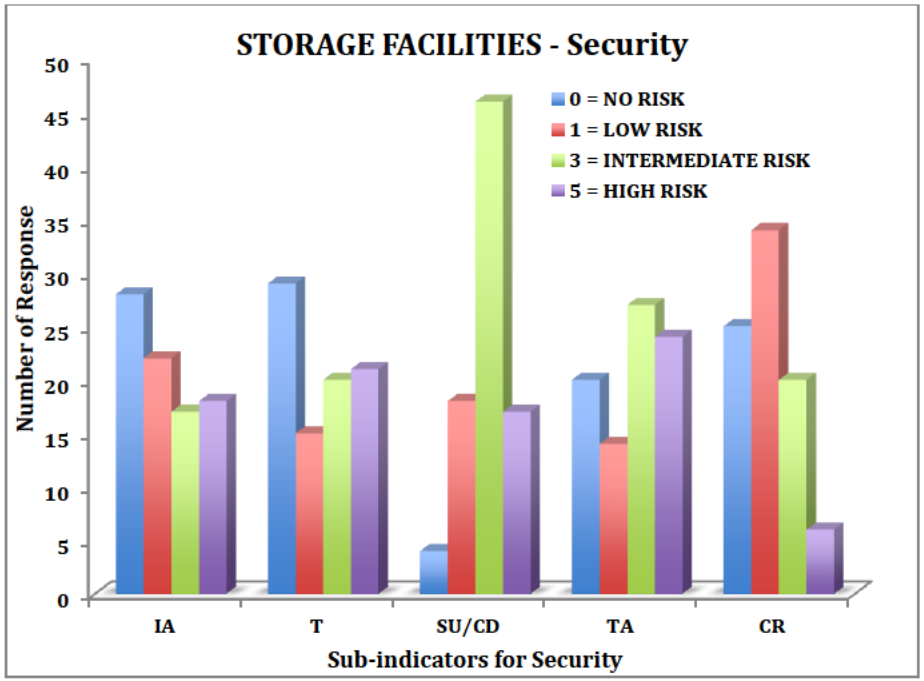


Figure 5.7a Response for security

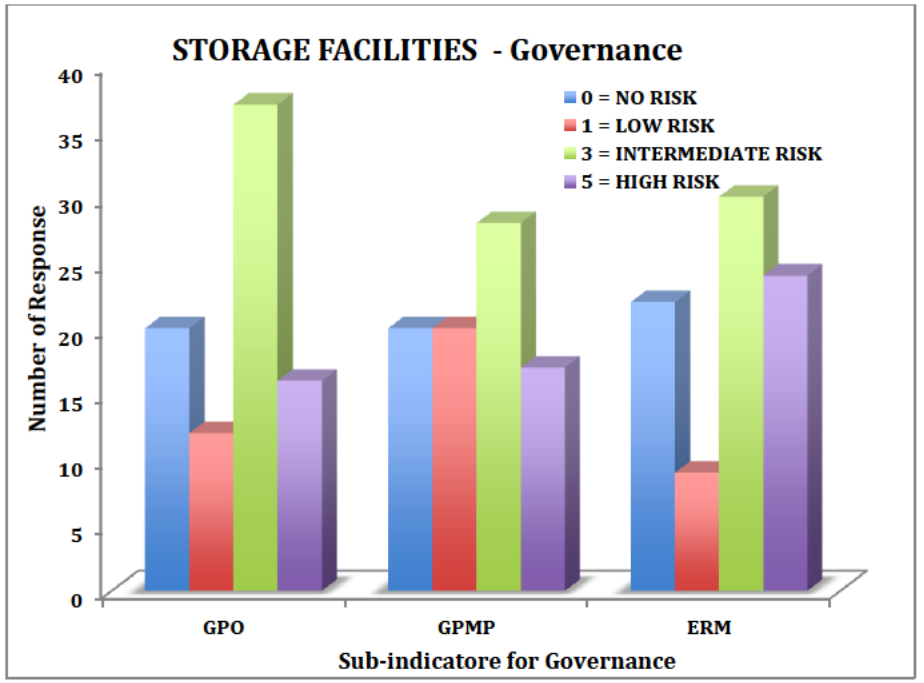


Figure 5.7b Response for Governance

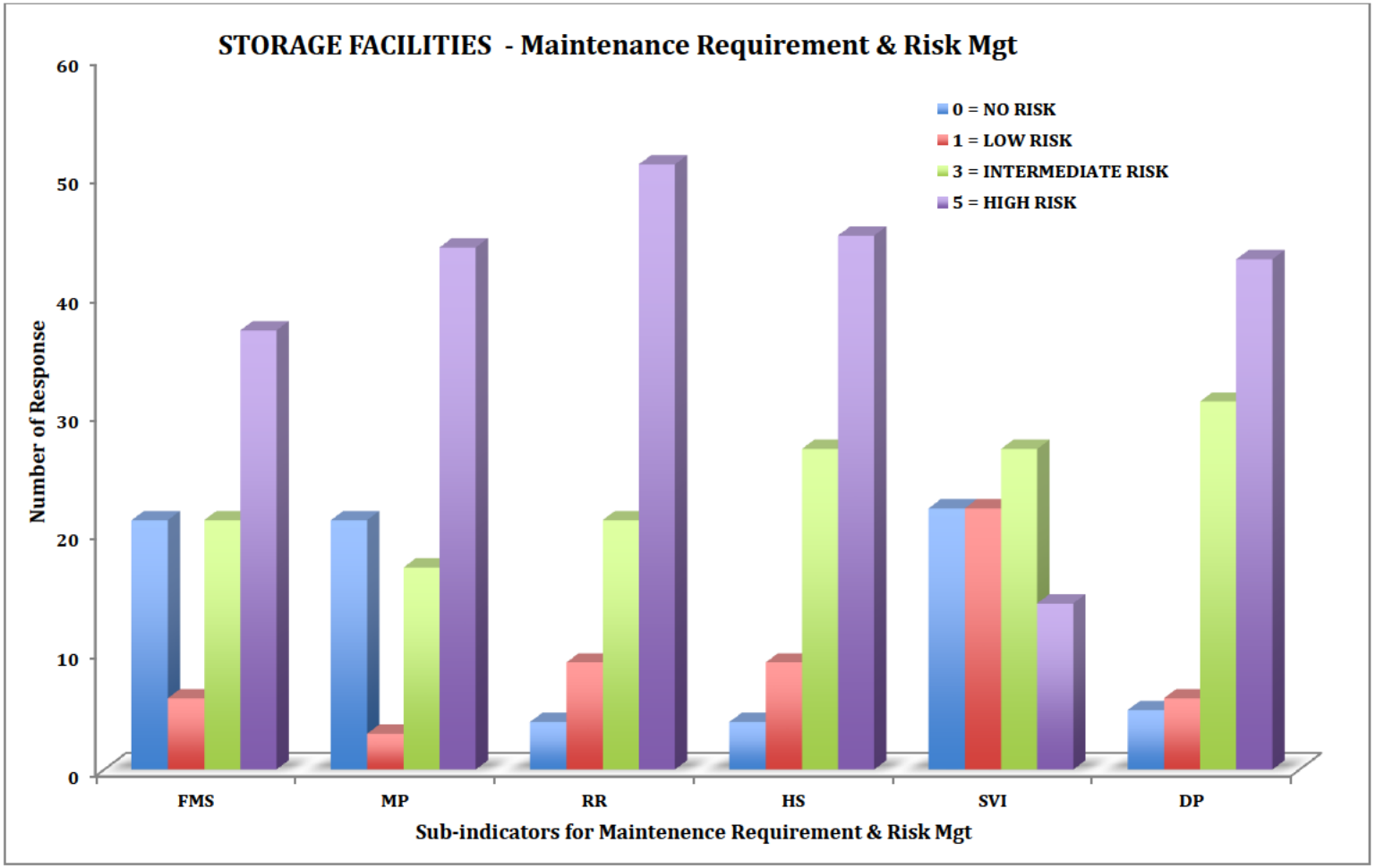


Figure 5.7c Response for Maintenance Req. & Risk Mgt.

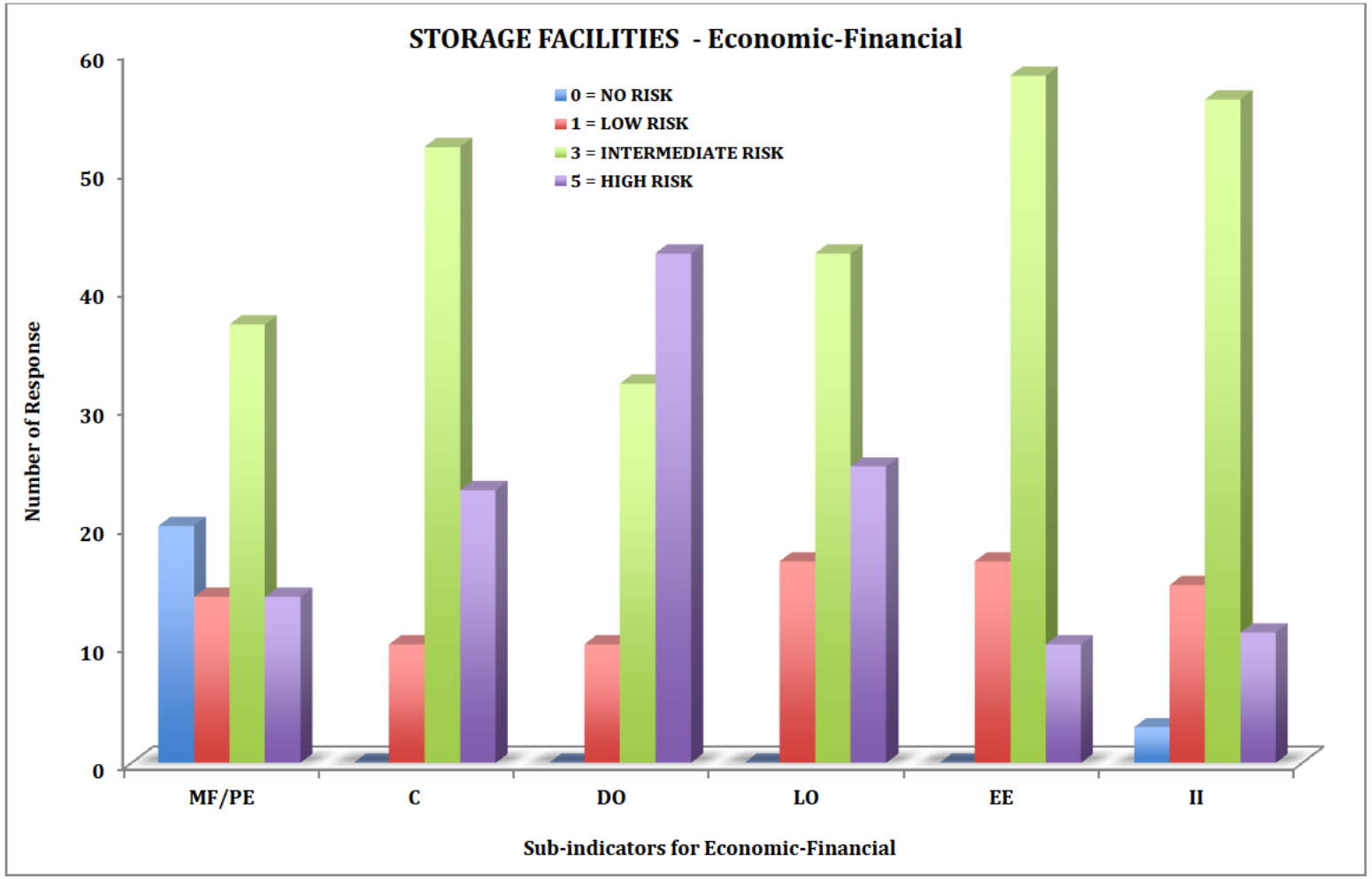


Figure 5.7d Response for Economic-Financial

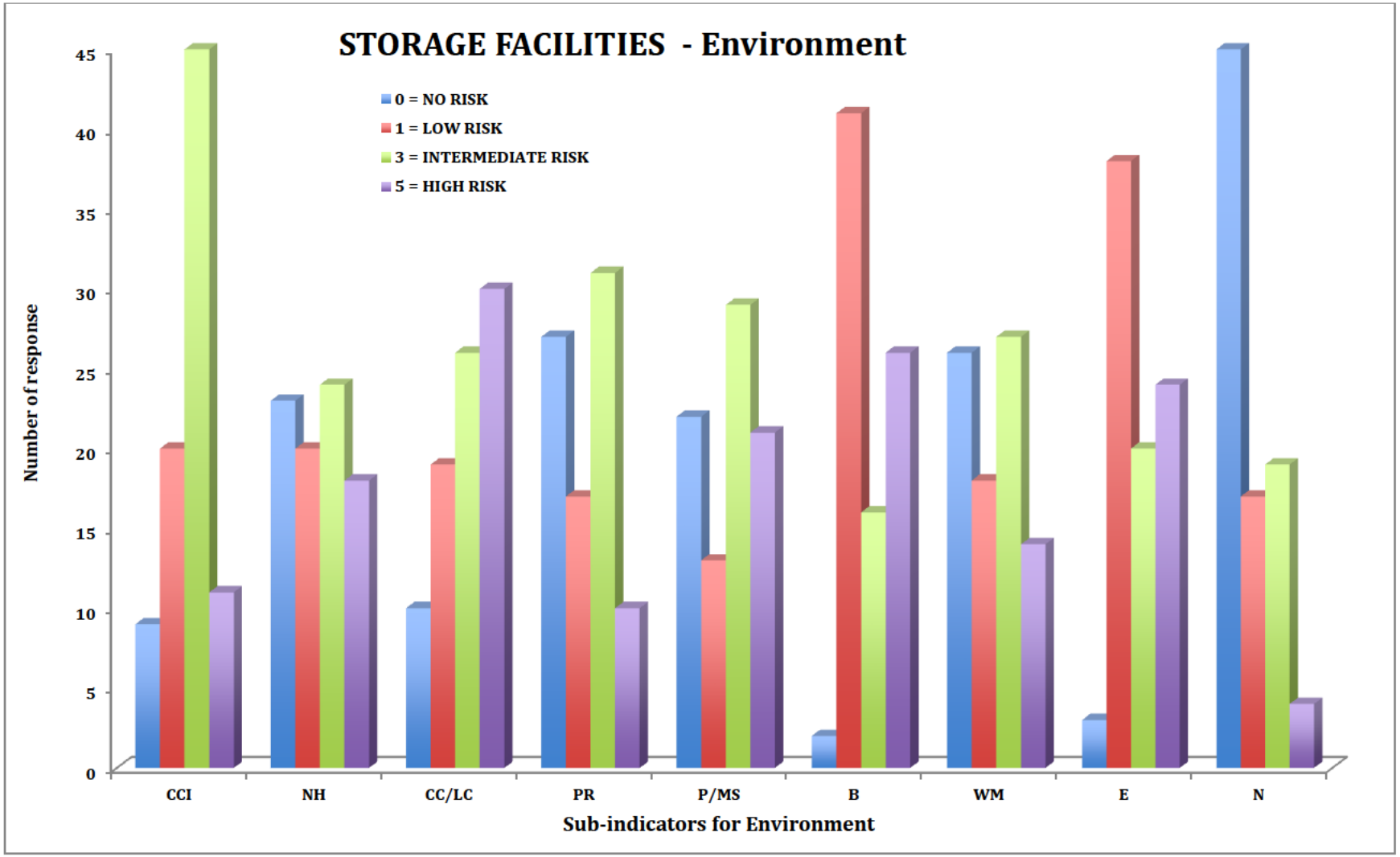


Figure 5.7e Response for Environment

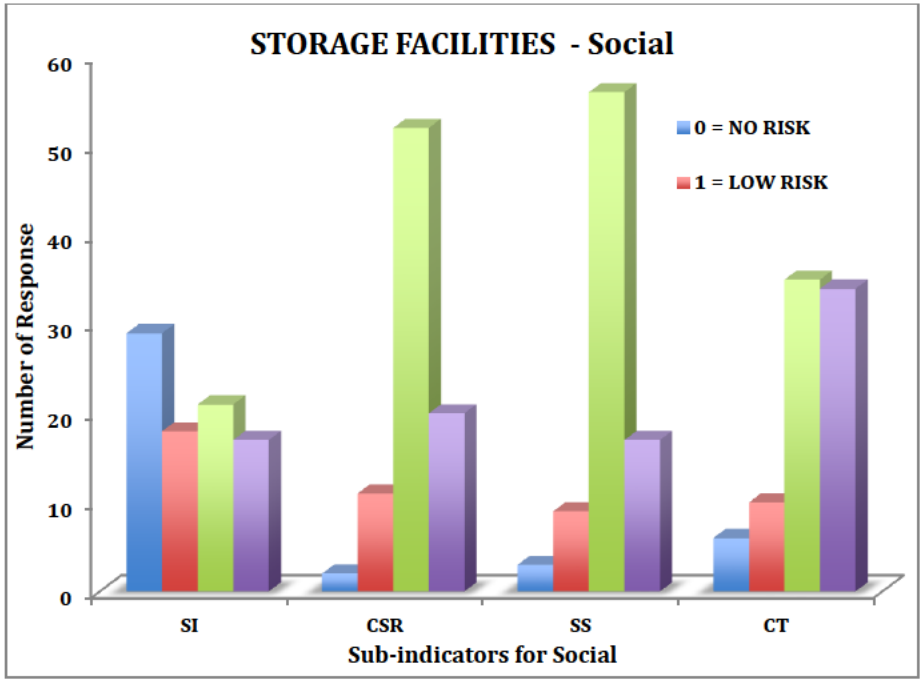


Figure 5.7f Response for Social

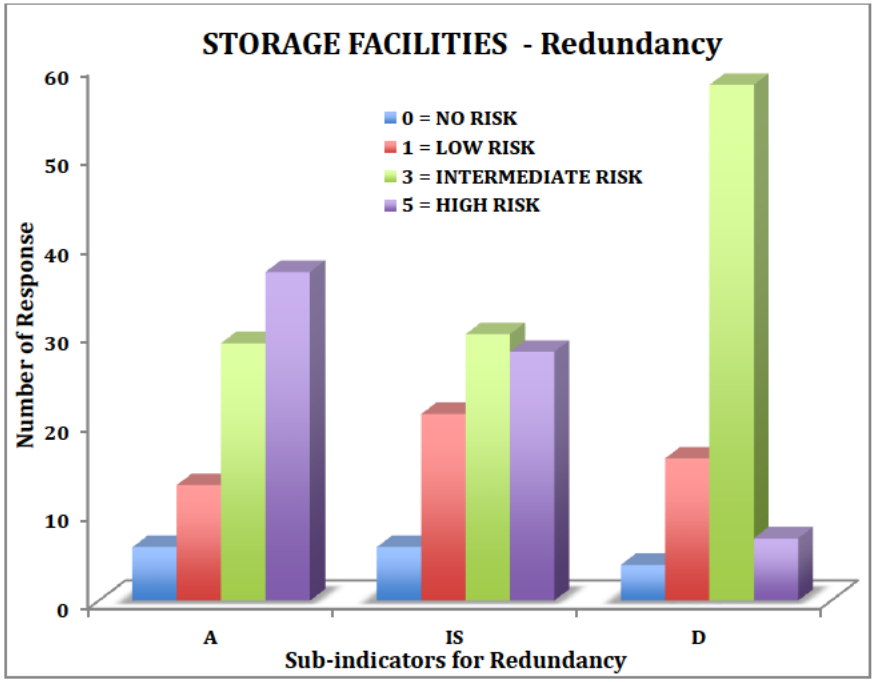


Figure 5.7g Response for Redundancy

Figures 5.7 (a – g): Survey Responses for Storage Facilities

Road Tankers:

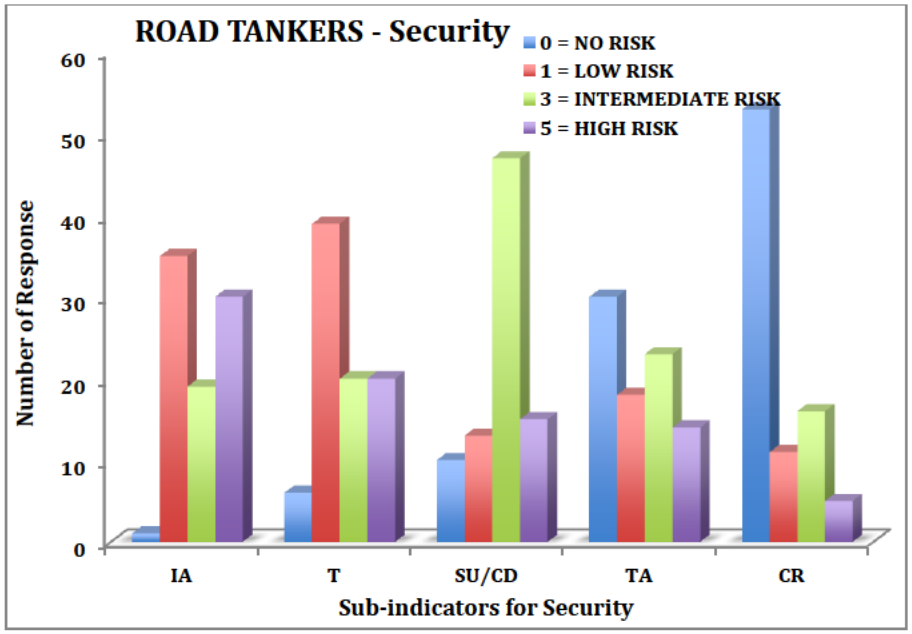


Figure 5.8a Response for security

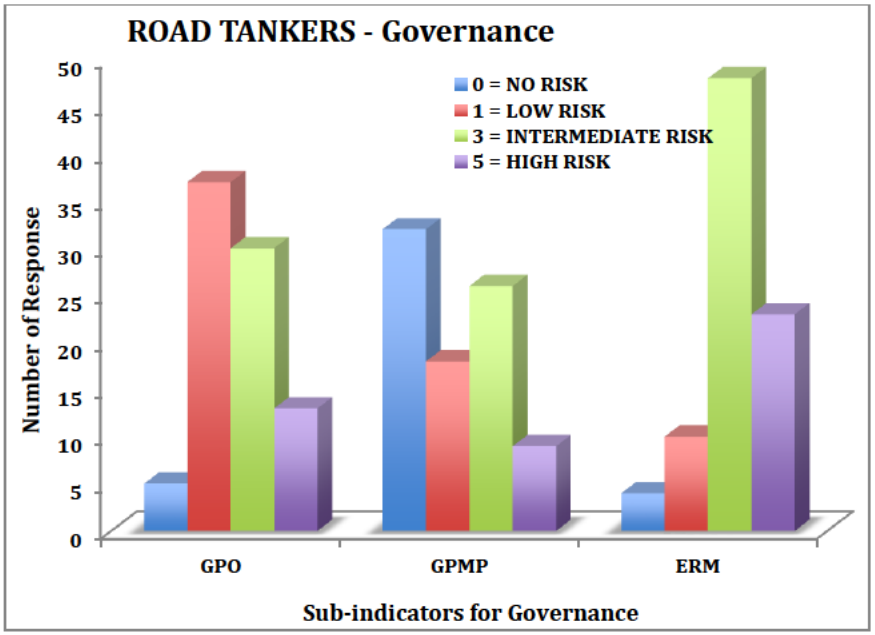


Figure 5.8b Response for Governance

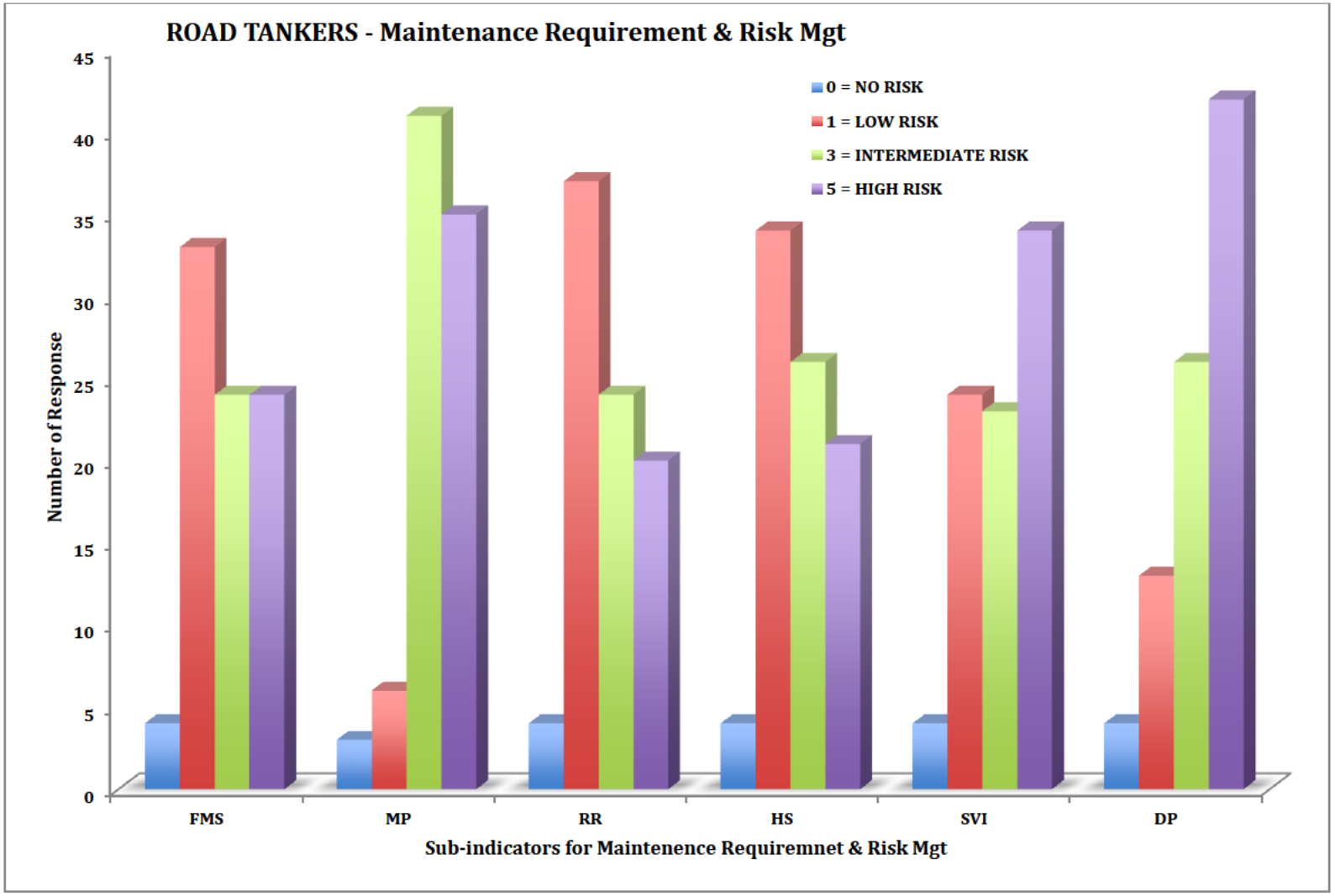


Figure 5.8c Response for Maintenance Req. & Risk Mgt.

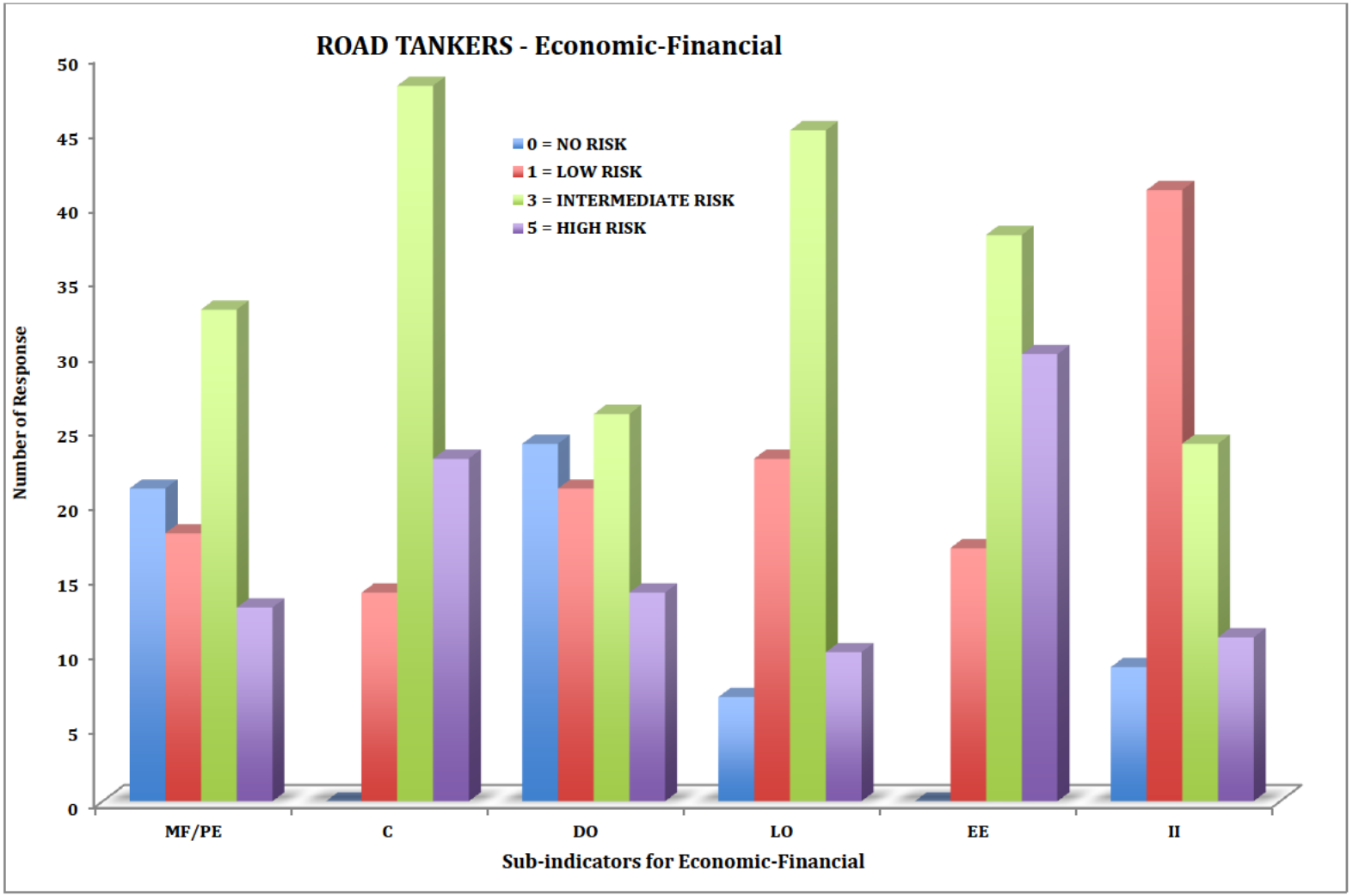


Figure 5.8d Response for Economic-Financial

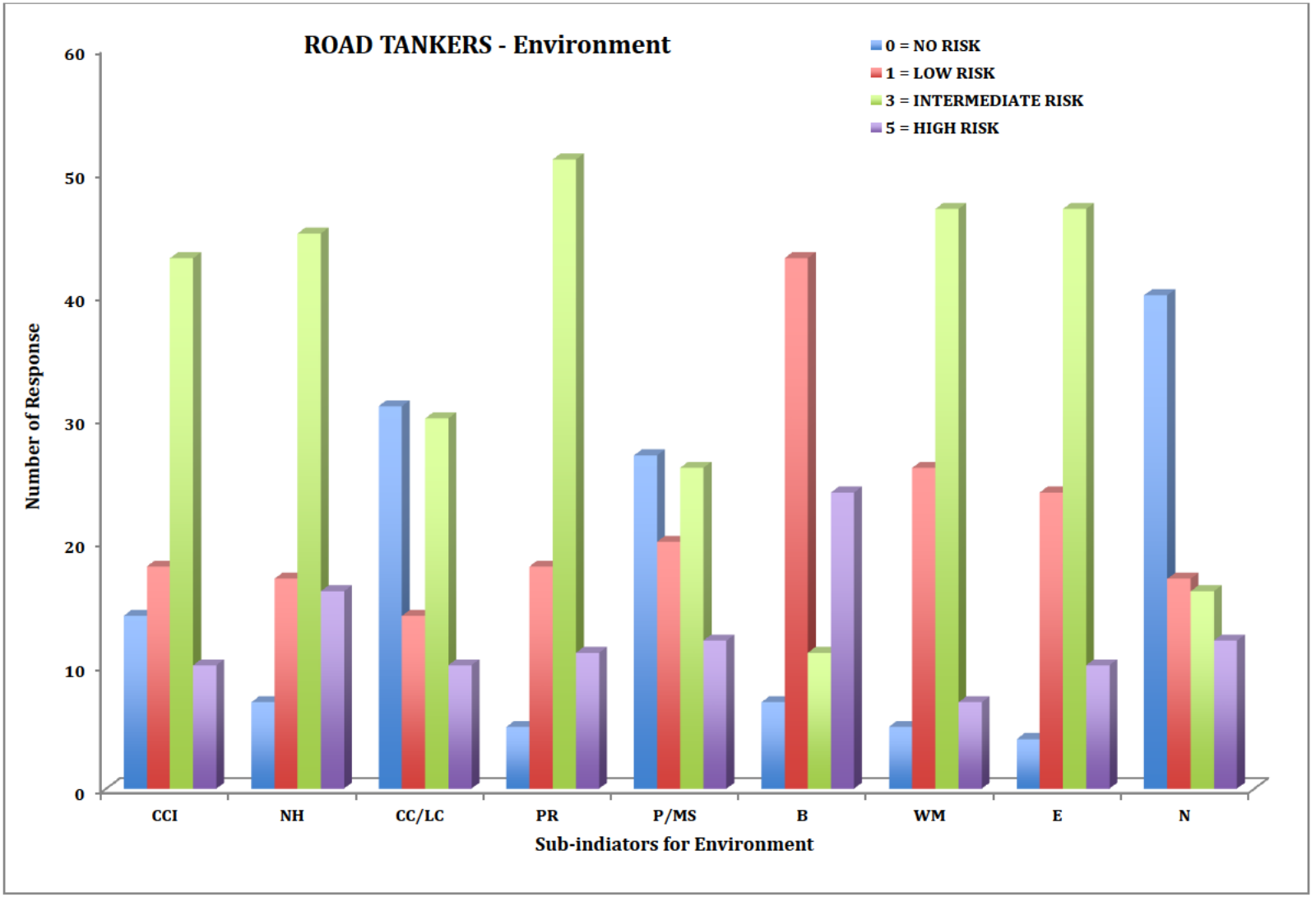


Figure 5.8e Response for Environment

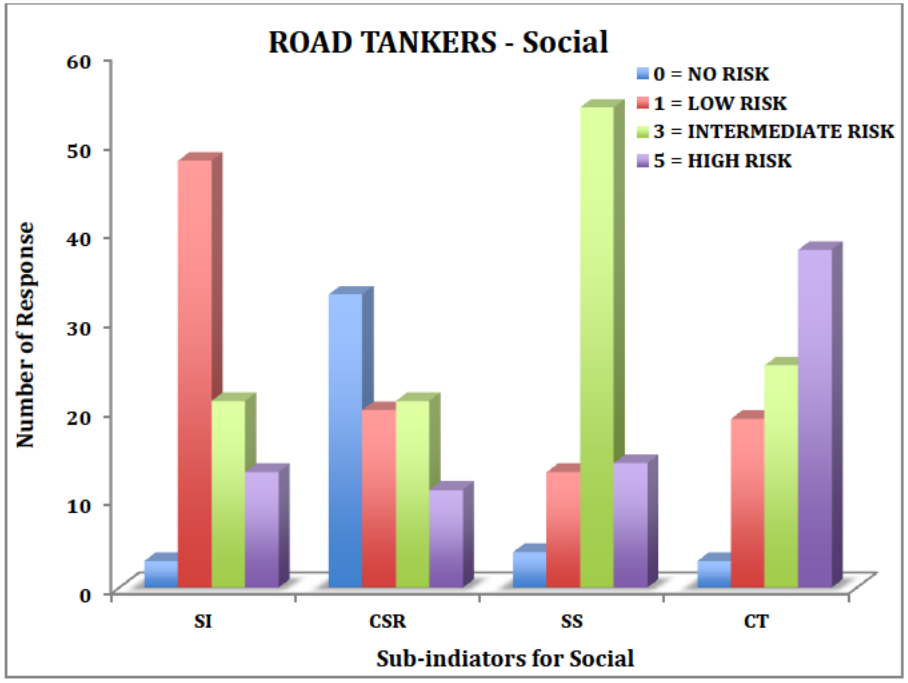


Figure 5.8f Response for Social

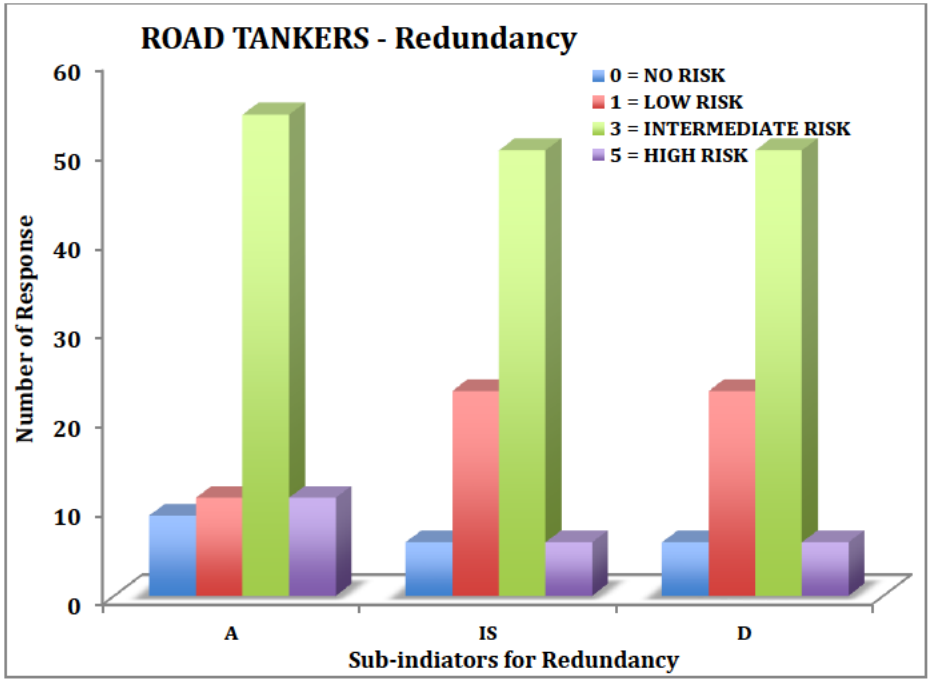


Figure 5.8g Response for Redundancy

Figure 5.8 (a – g): Survey Responses for Road Tankers

Barges and Ships:

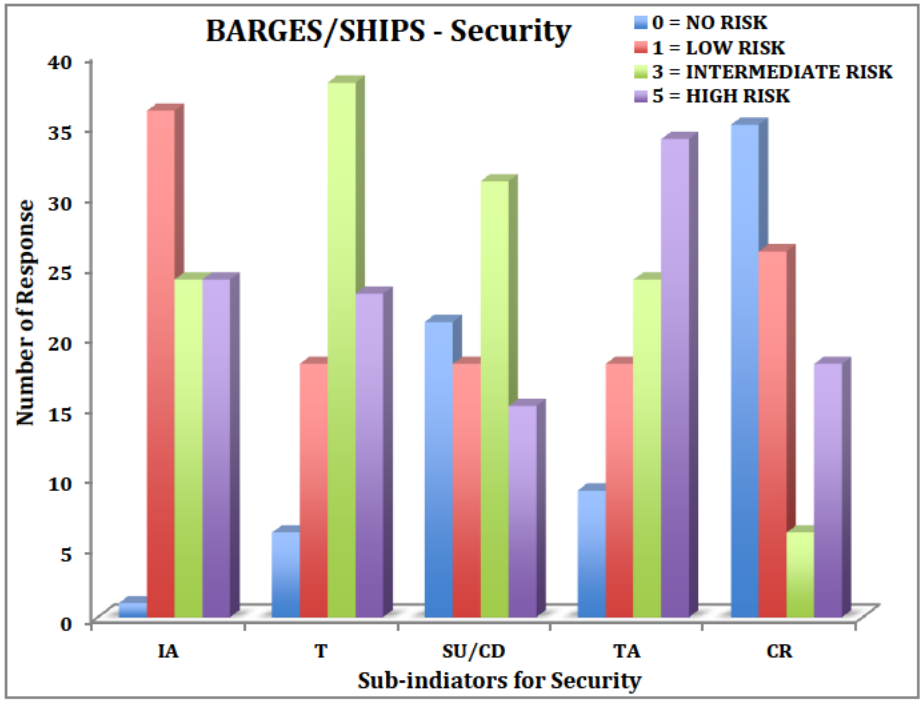


Figure 5.9a Response for security

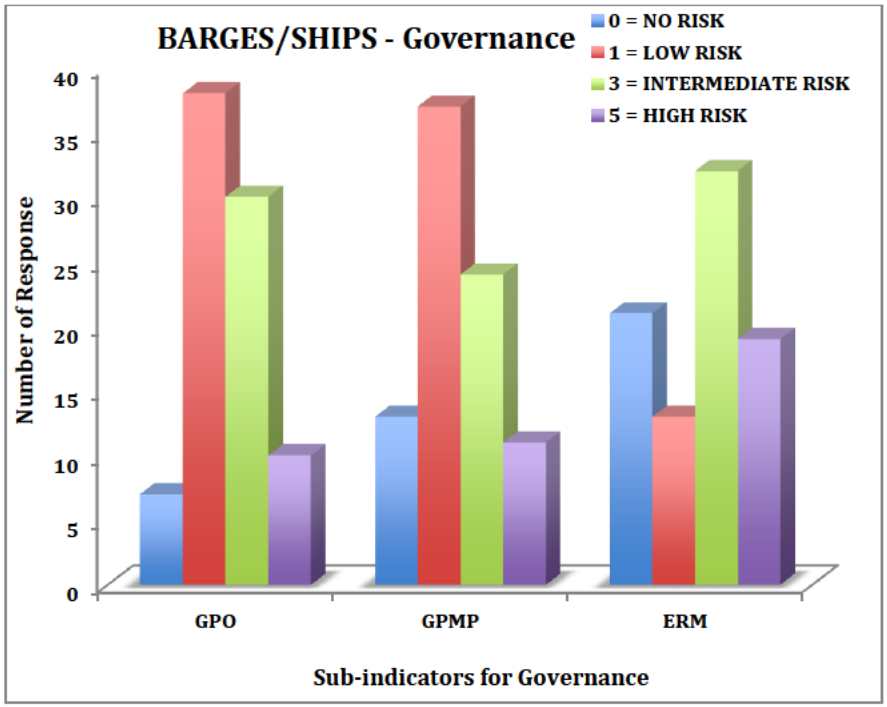


Figure 5.9b Response for Governance

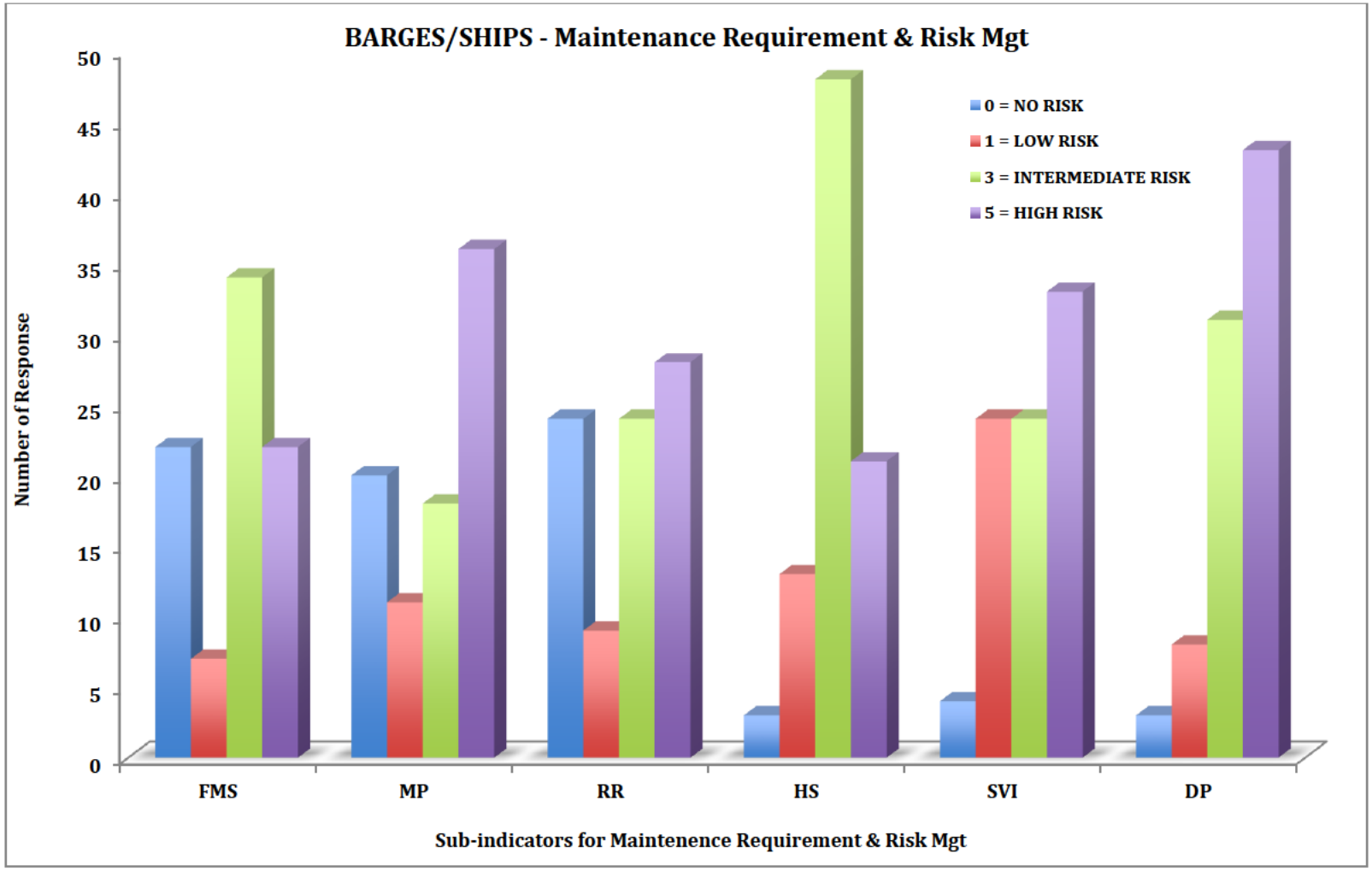


Figure 5.9c Response for Maintenance Req. & Risk Mgt.

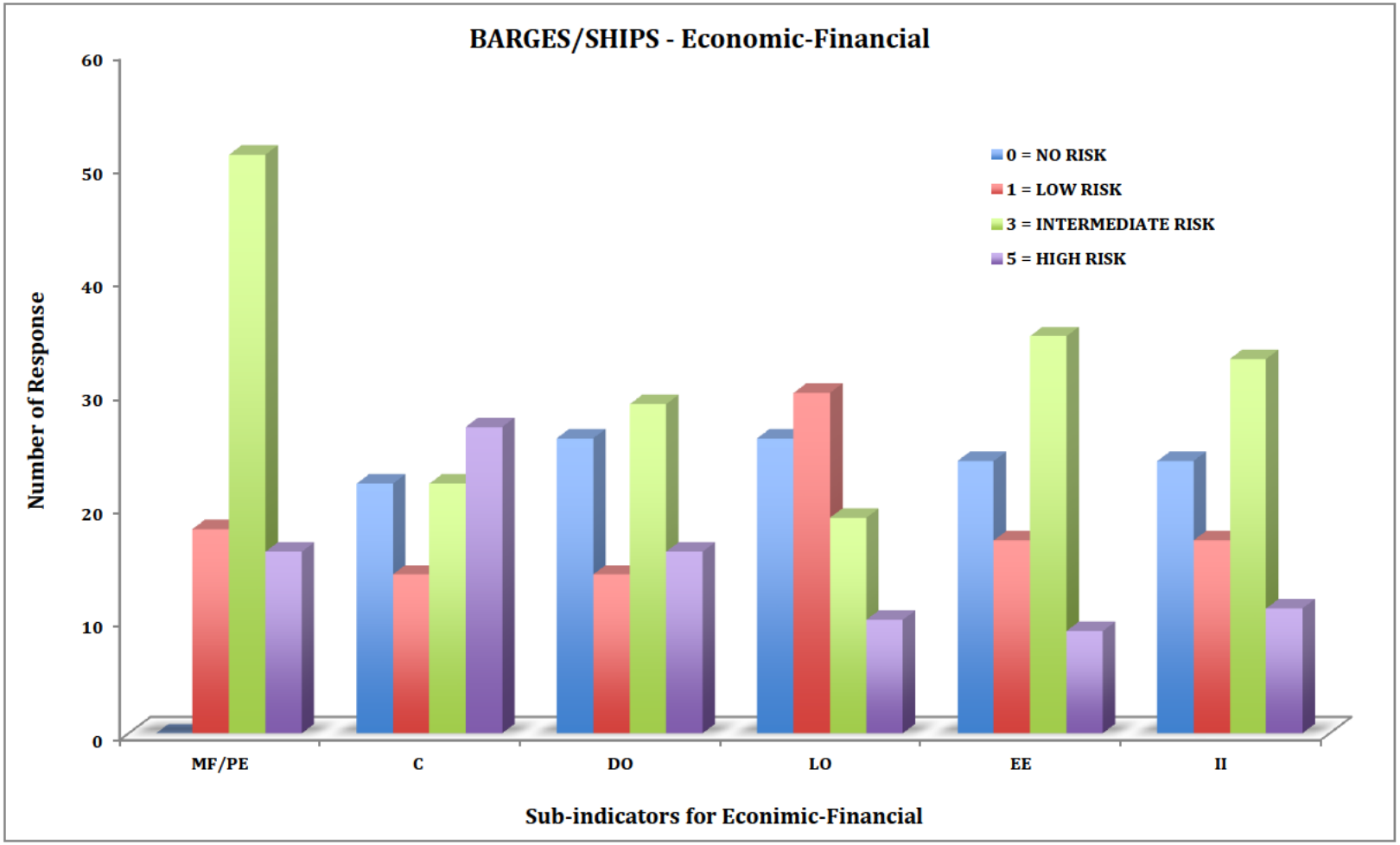


Figure 5.9d Response for Economic-Financial

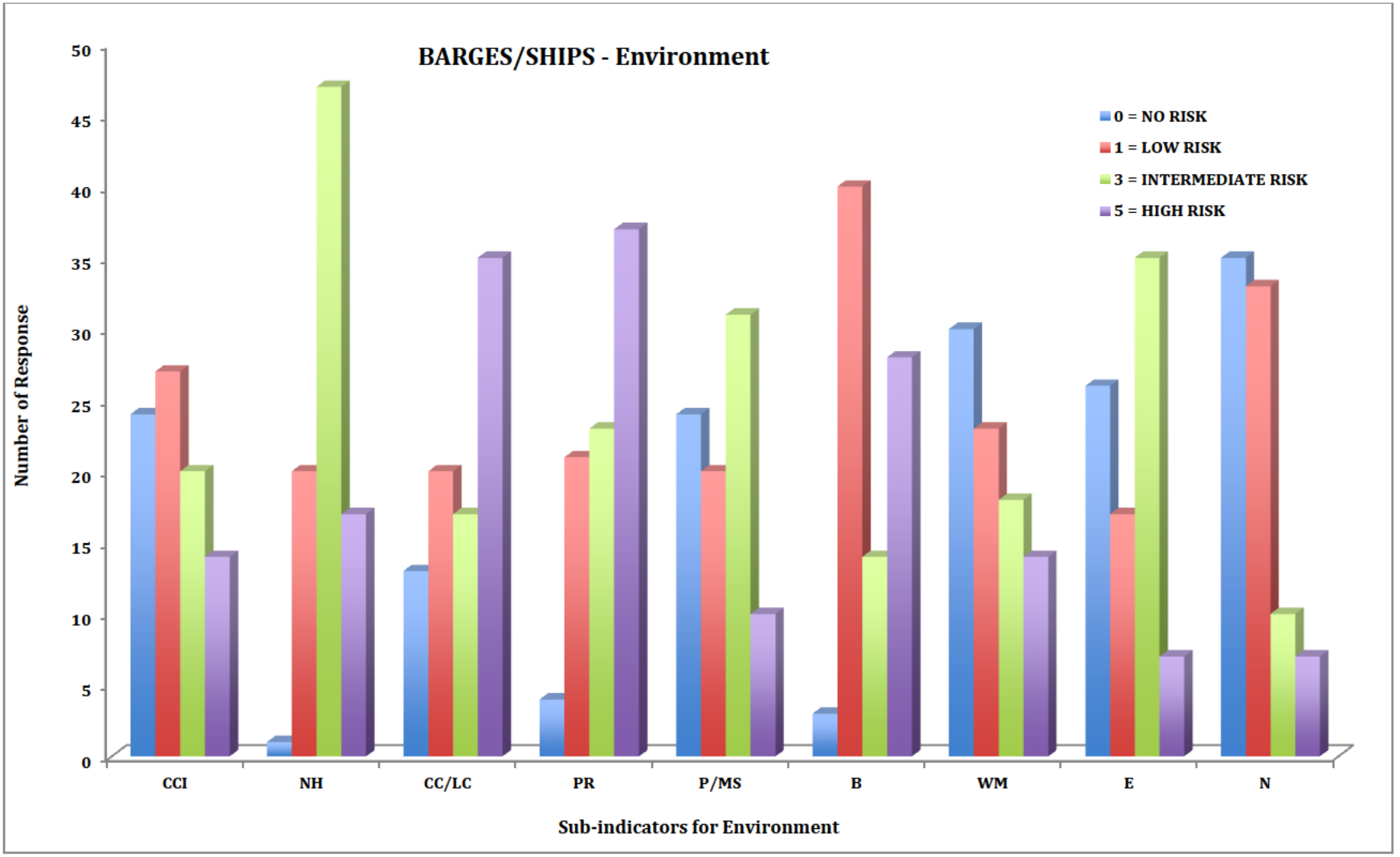


Figure 5.9e Response for Environment

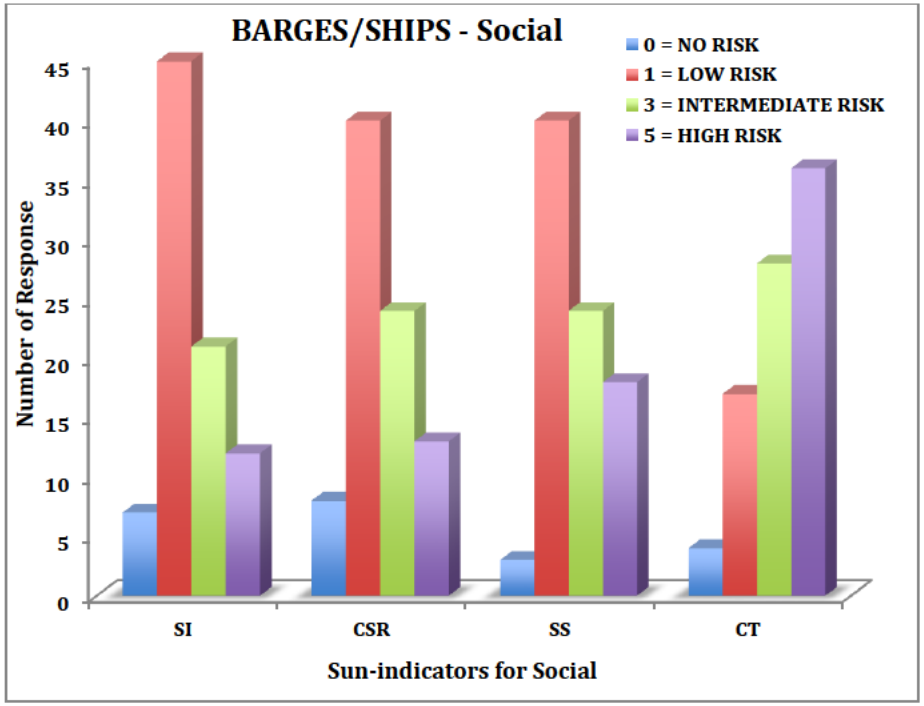


Figure 5.9f Response for Social

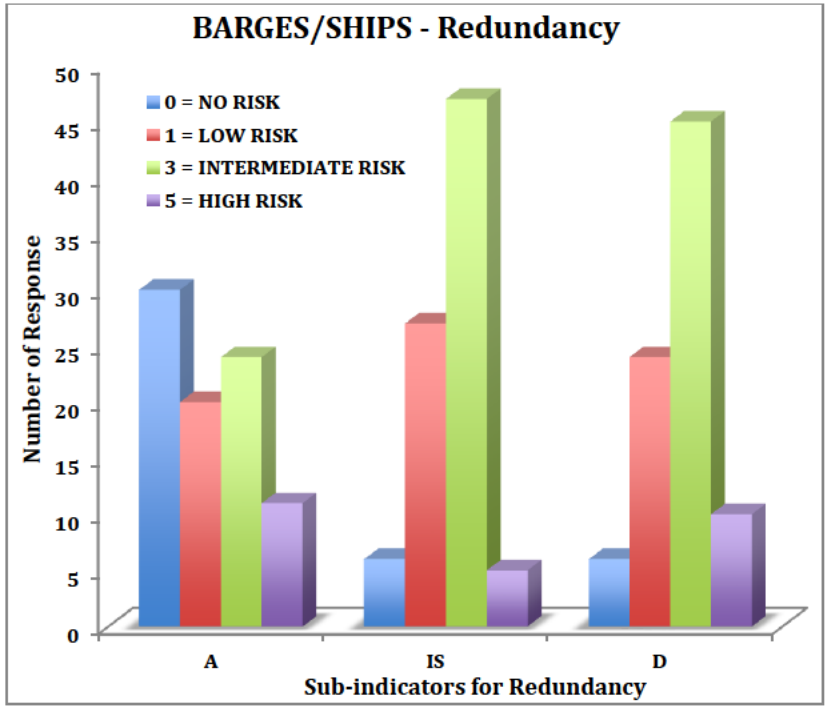


Figure 5.9g Response for Redundancy

Figure 5.9 (a – g): Survey Responses for Barges and Ships

Rail Tankers:

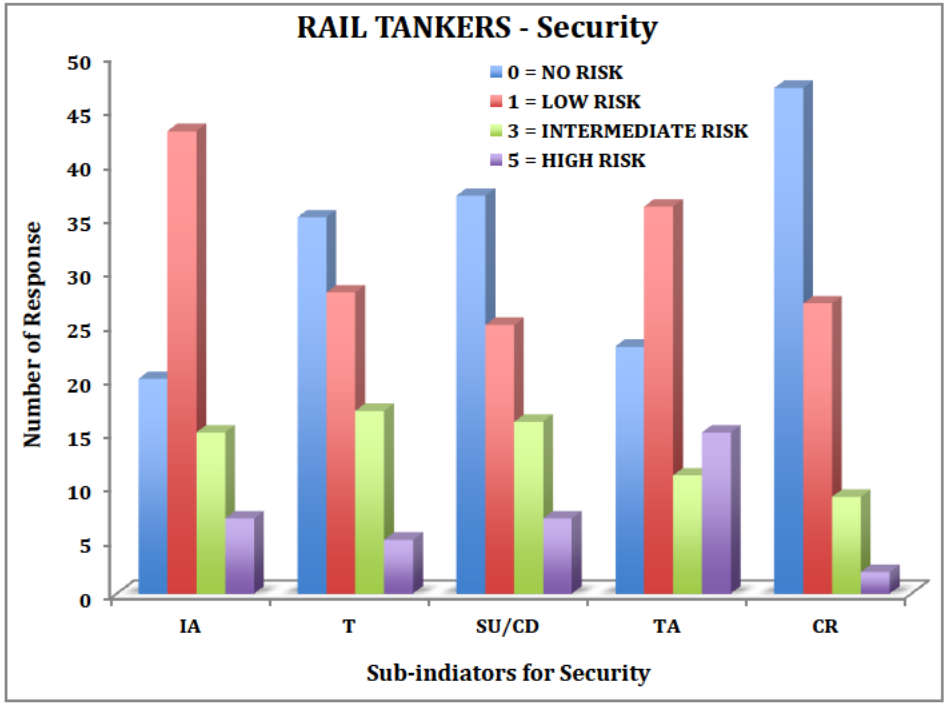


Figure 5.10a Response for security

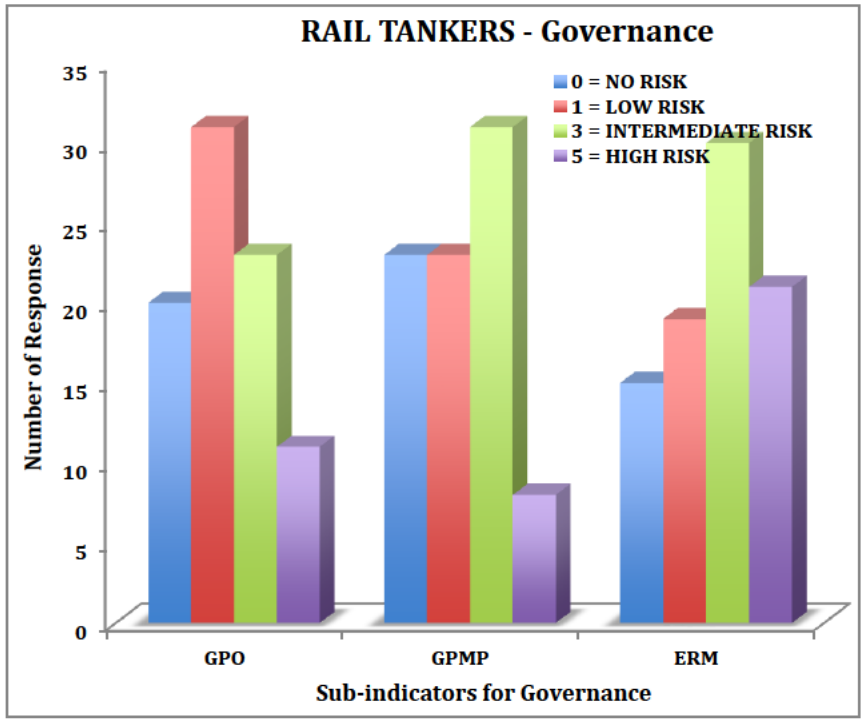


Figure 5.10b Response for Governance

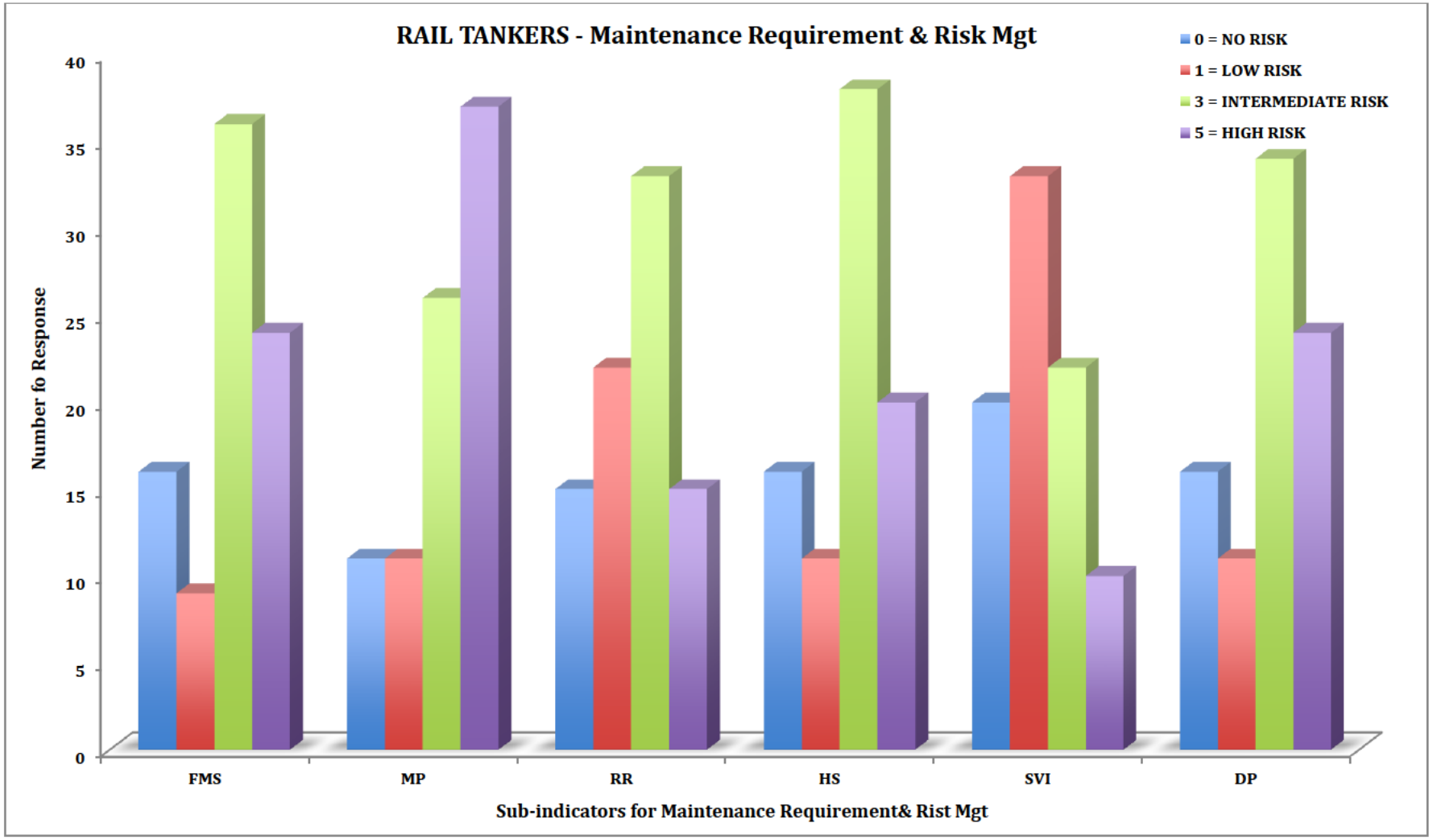


Figure 5.10c Response for Maintenance Req. & Risk Mgt.

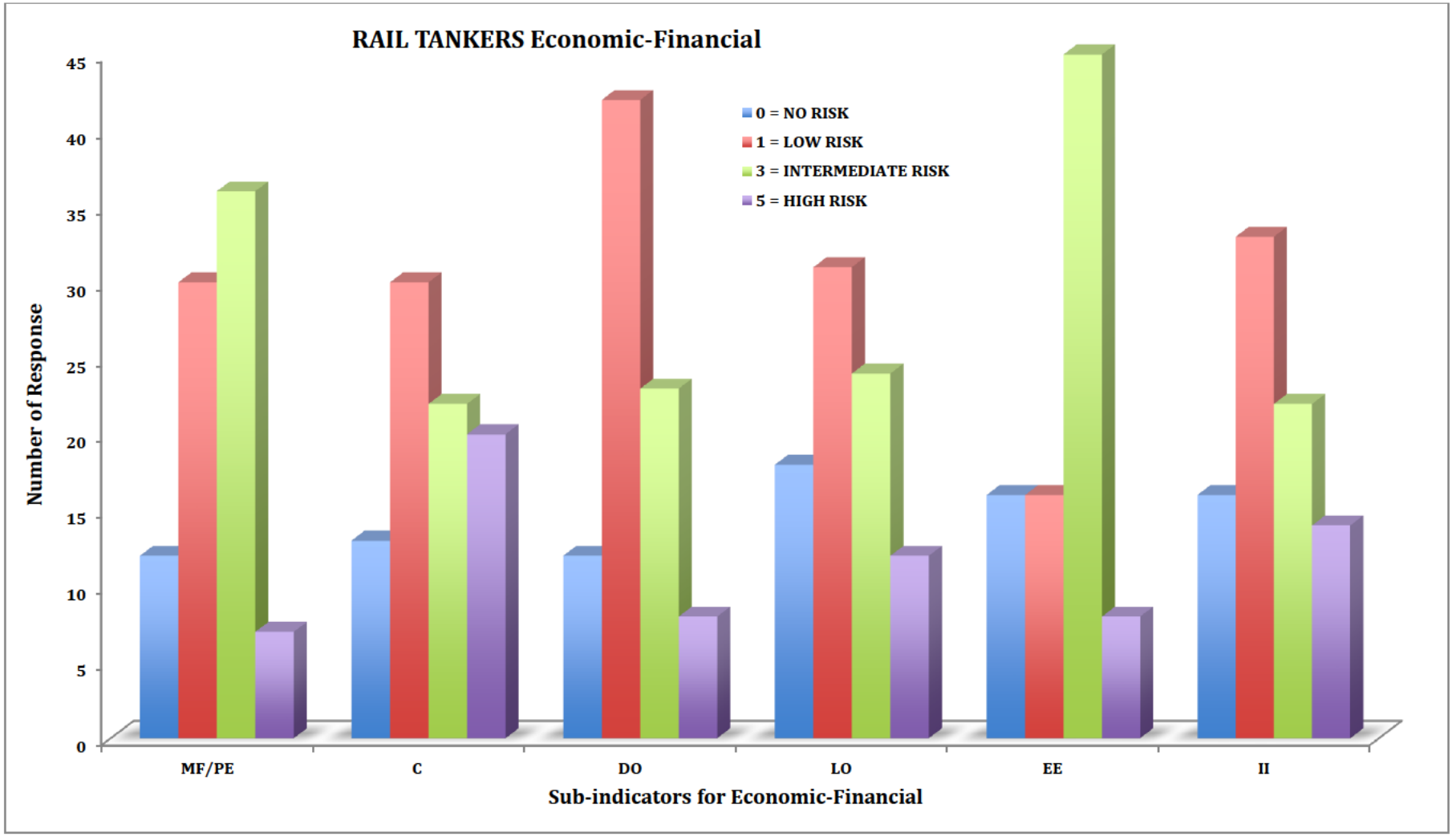


Figure 5.10d Response for Economic-Financial

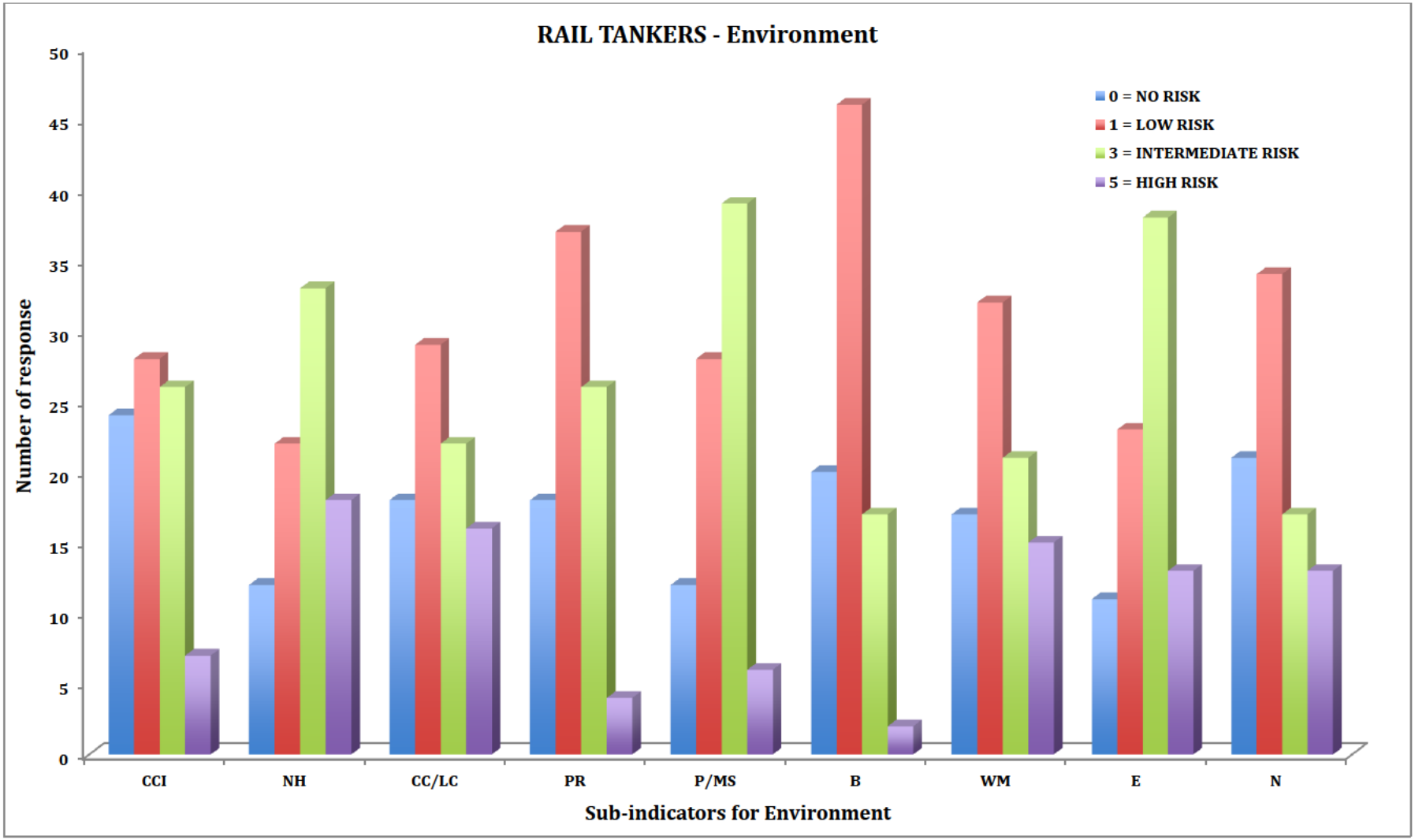


Figure 5.10e Response for Environment

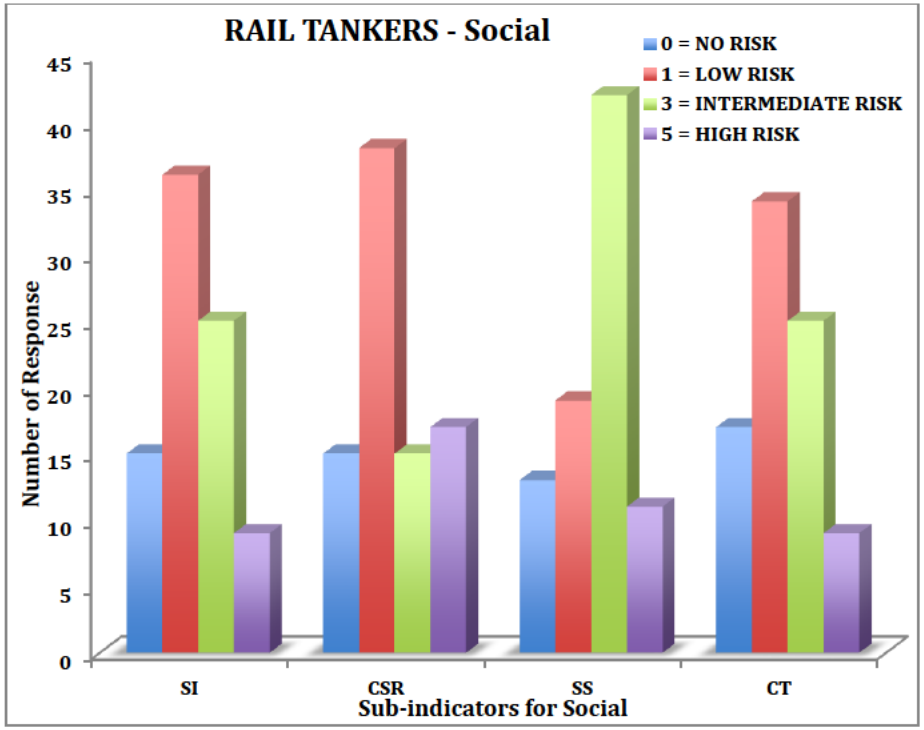


Figure 5.10f Response for Social

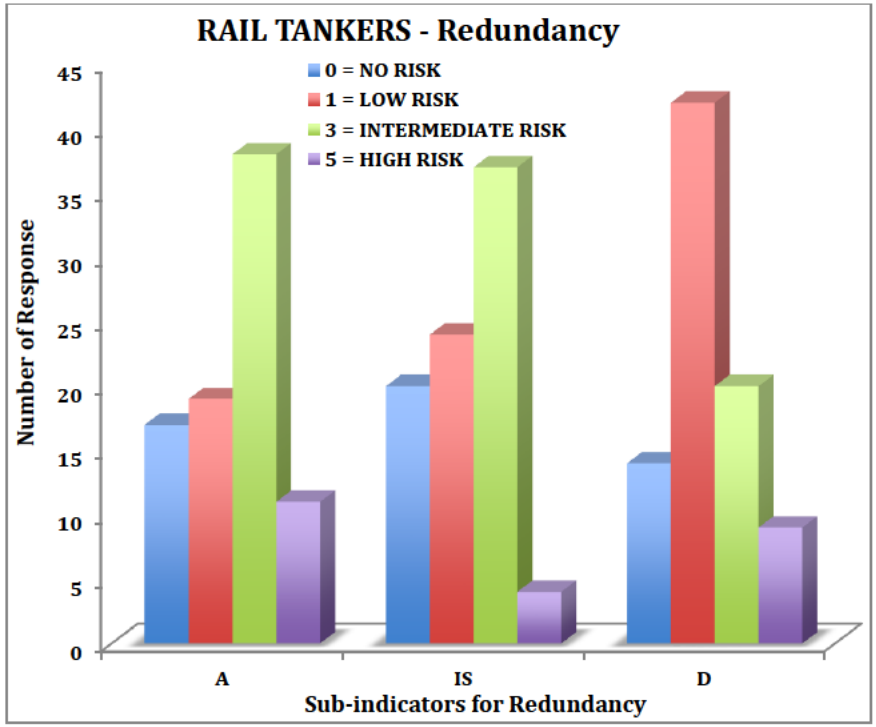


Figure 5.10g Response for Redundancy

Figure 5.10 (a – g): Survey Responses for Rail Tankers

Distribution Nodes or System:

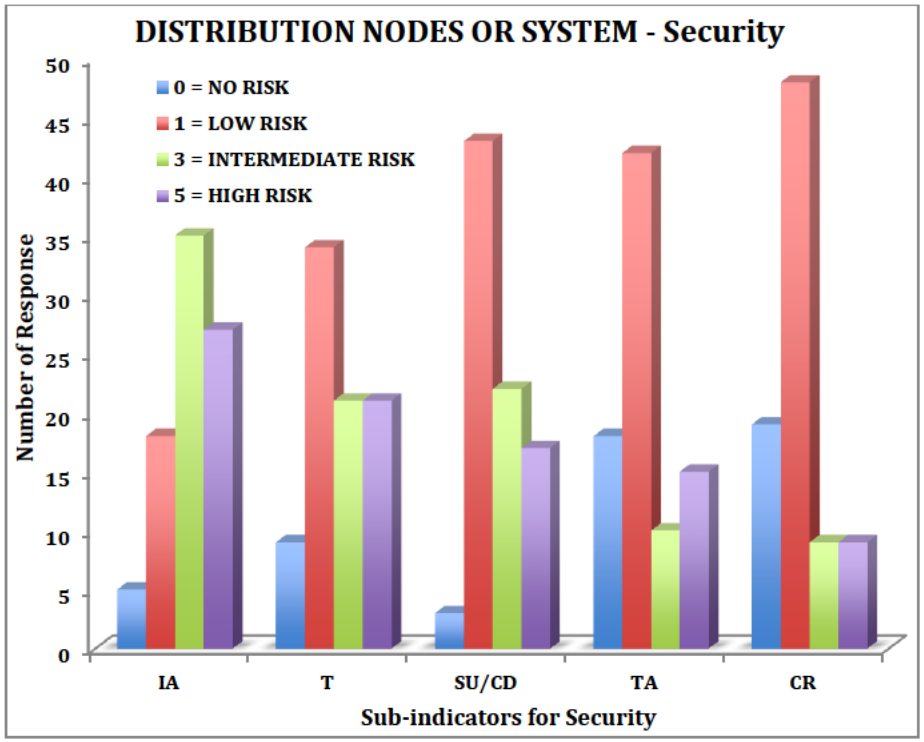


Figure 5.11a Response for security

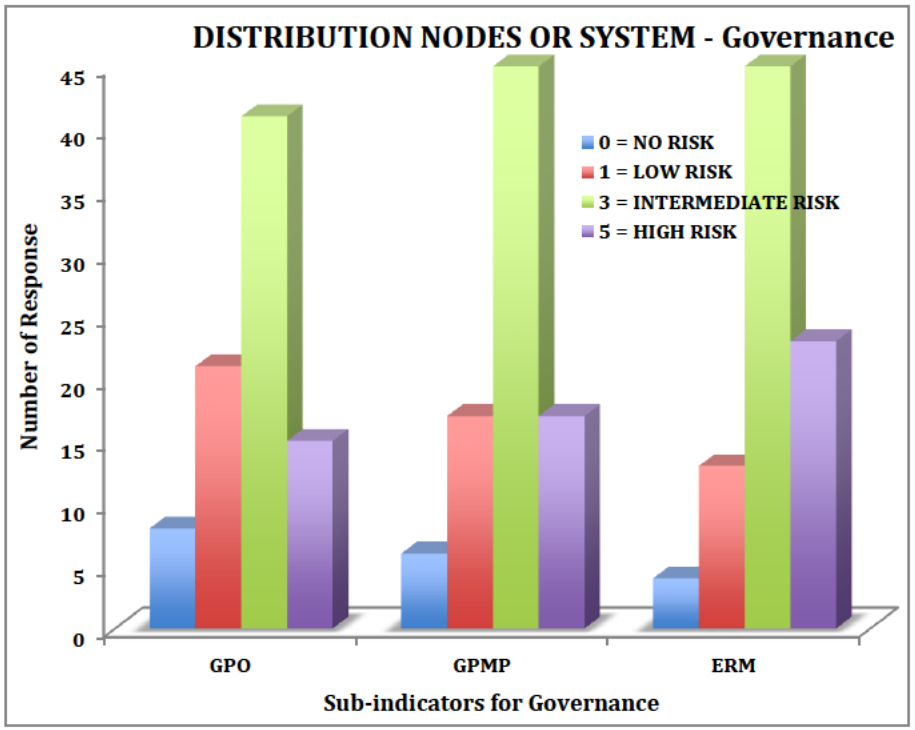


Figure 5.11b Response for Governance

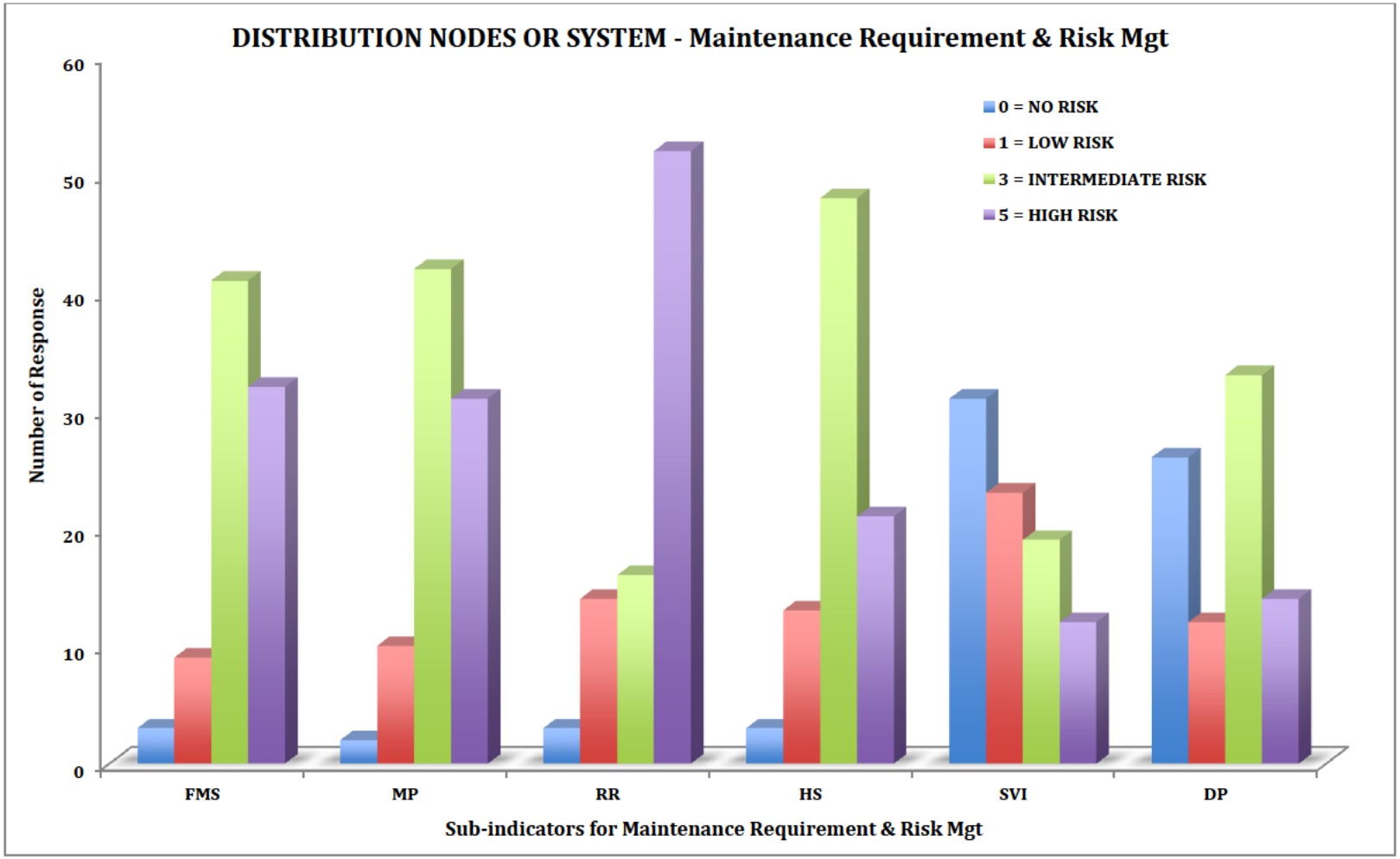


Figure 5.11c Response for Maintenance Req. & Risk Mgt.

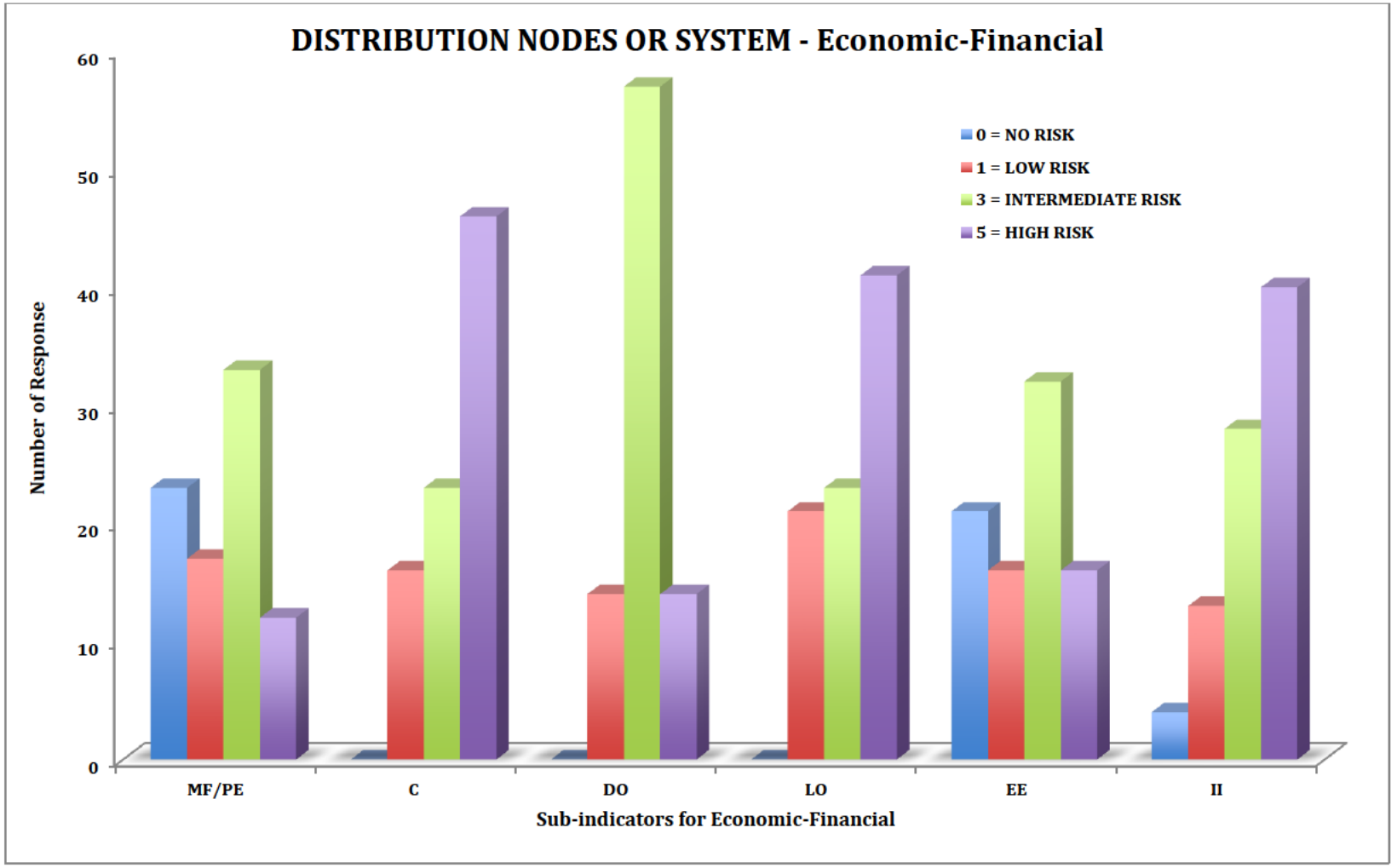


Figure 5.11d Response for Economic-Financial

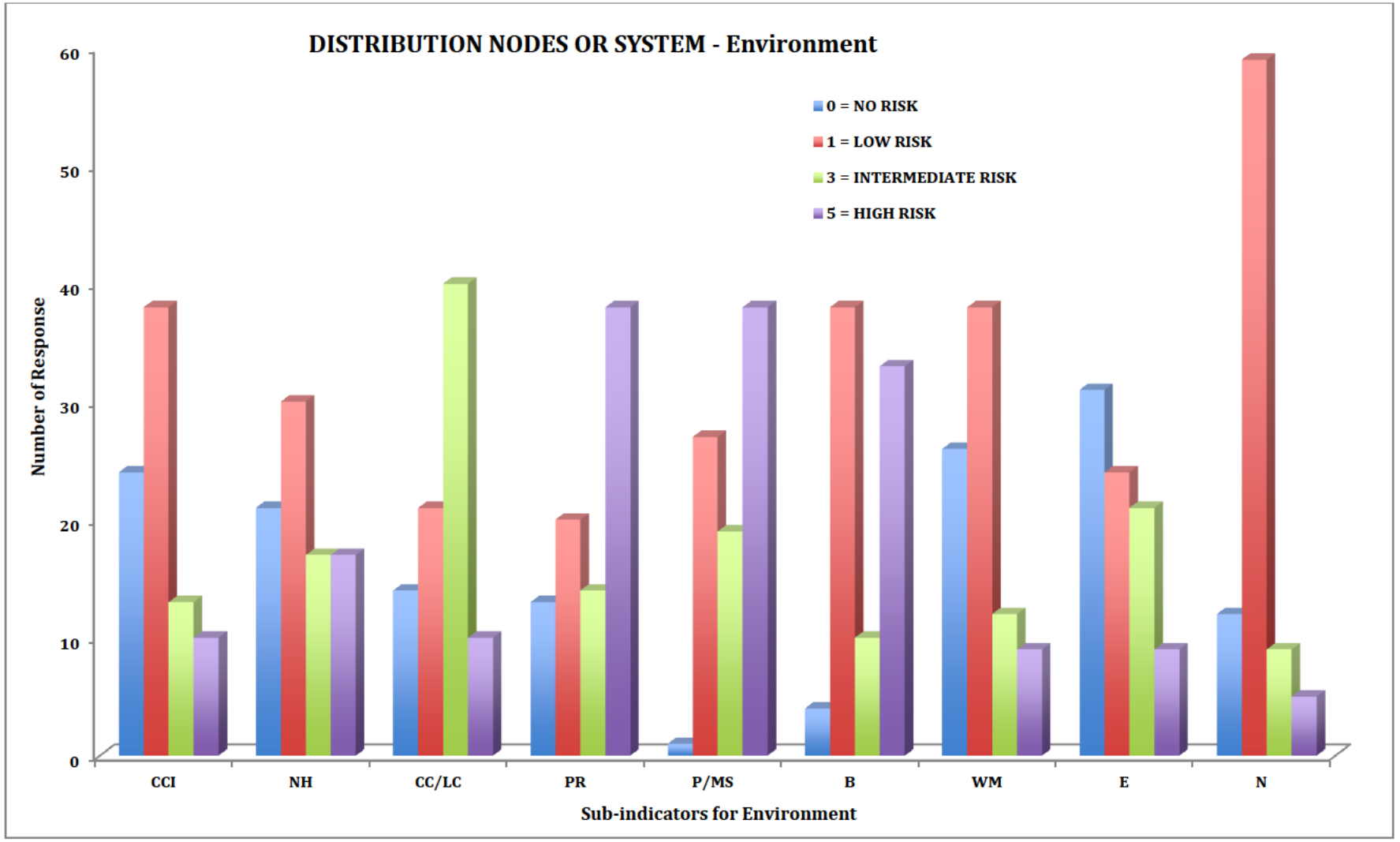


Figure 5.11e Response for Environment

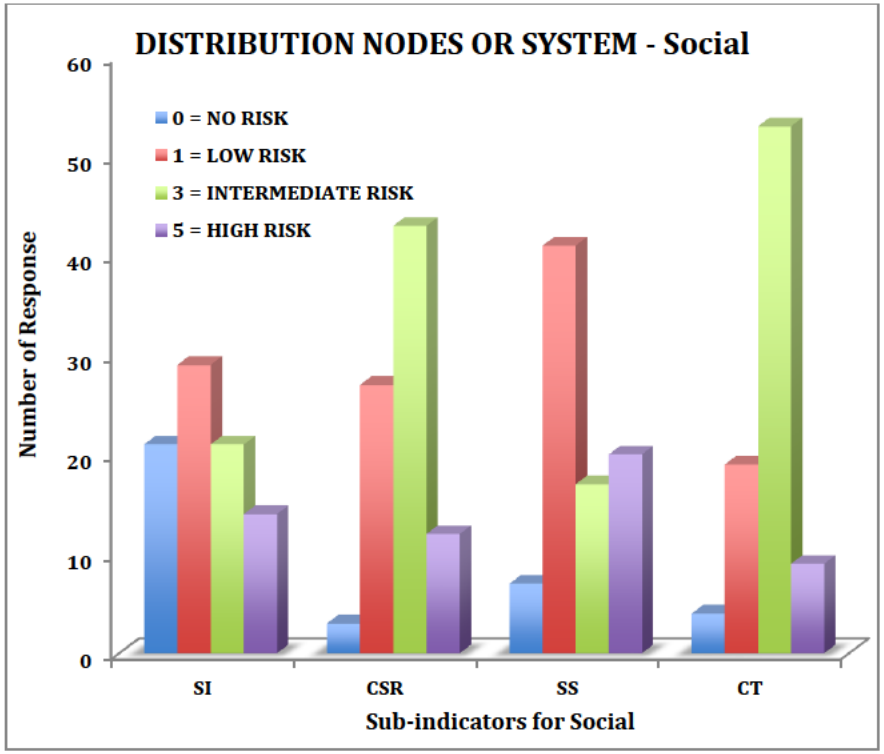


Figure 5.11f Response for Social

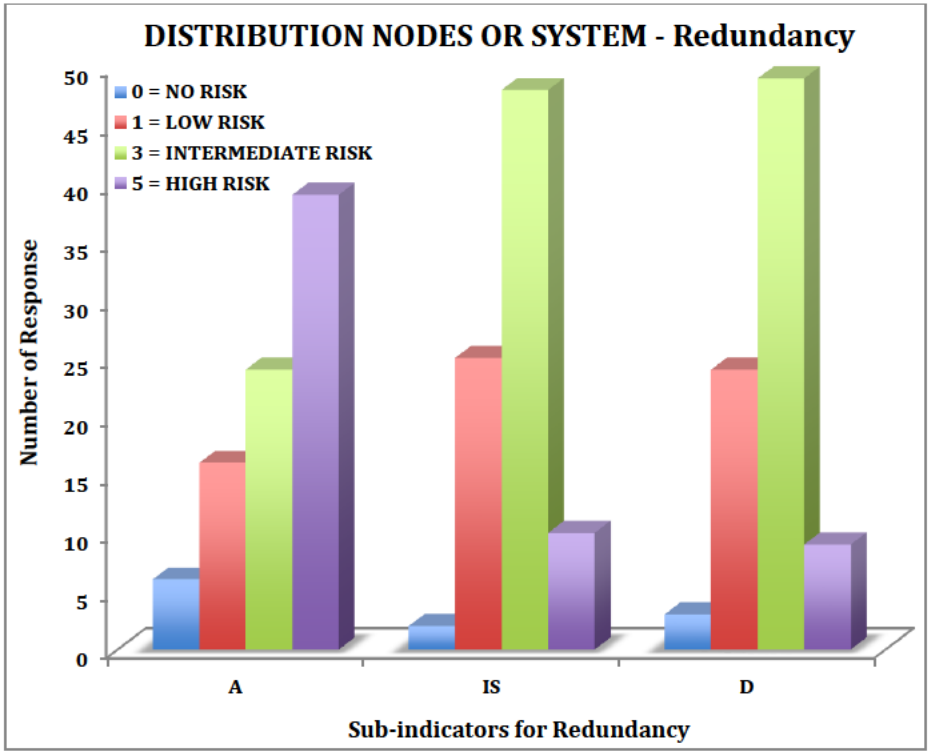


Figure 5.11g Response for Redundancy

Figure 5.11 (a – g): Survey Responses for Distribution Nodes or System

Table 5.17: Criticality Association Between the Hybrid Indicators and Various DCOGIs (source: survey data)

	PIPELINES				STORAGE FACILITIES				ROAD TANKERS				BARGES/SHIPS				RAIL TANKERS				DISTRIBUTION NODES OR SYSTEM			
	NI	LI	II	HI	NI	LI	II	HI	NI	LI	II	HI	NI	LI	II	HI	NI	LI	II	HI	NI	LI	II	HI
IA	1	3	18	63	28	22	17	18	1	35	19	30	1	36	24	24	20	43	15	7	5	18	35	27
T	3	3	15	64	29	15	20	21	6	39	20	20	6	18	38	23	35	28	17	5	9	34	21	21
SU/CD	6	7	38	34	4	18	46	17	10	13	47	15	21	18	31	15	37	25	10	7	3	43	22	17
TA	3	8	28	45	20	14	27	24	30	18	23	14	9	18	24	34	23	36	11	15	14	42	14	15
CR	37	24	17	7	25	34	20	6	53	11	16	5	35	26	6	18	47	27	9	2	19	48	9	9
GPO	4	13	50	18	20	12	37	16	5	37	30	13	7	38	30	10	20	31	23	11	8	21	41	15
GPMP	4	17	30	34	20	20	28	17	32	18	26	9	13	37	24	11	23	23	31	8	6	17	45	17
ERM	3	9	49	24	22	9	30	24	4	10	48	23	21	13	32	19	15	19	30	21	4	13	45	23
FMS	23	1	21	40	21	6	21	37	4	33	24	24	22	7	34	22	16	9	36	24	3	9	41	32
MP	2	25	14	44	21	3	17	44	3	6	41	35	20	11	18	36	10	11	26	37	2	10	42	31
RR	2	10	40	33	4	9	21	51	4	37	24	20	24	9	24	28	15	22	33	16	3	14	16	52
HS	2	32	27	24	4	9	27	45	4	34	26	21	3	13	48	21	16	11	38	20	3	13	48	21
SVI	4	10	49	13	22	22	27	14	4	24	23	34	4	24	24	33	20	33	22	10	31	23	19	12
DP	4	7	26	48	5	6	31	43	4	13	26	42	3	8	31	43	10	11	34	24	26	12	33	14
MF/PE		13	53	19	20	14	37	14	21	18	33	13		18	51	16	12	30	36	7	23	17	33	12
C		10	30	45		10	52	23		14	48	23	22	14	22	27	14	30	22	20		16	23	46
DO		9	33	43		10	32	43	24	21	26	14	26	14	29	16	12	42	23	8		14	57	14
LO	1	7	27	50		17	43	25	7	23	45	10	26	30	19	10	18	31	24	12		21	23	41
EE	3	9	39	34		17	58	10		17	38	30	24	17	35	9	16	16	45	8	21	16	32	16
II	1	16	57	11	3	15	56	11	9	41	24	11	24	17	33	11	16	33	22	14	4	13	28	40
CCI	5	26	38	16	9	20	45	11	14	18	43	10	24	27	20	14	24	28	26	7	24	38	13	10
NH	1	20	47	17	23	20	24	18	7	17	45	16	1	20	47	17	12	22	33	18	21	30	17	17
CC/LC	38	20	20	7	10	19	26	30	31	14	30	10	13	20	17	35	18	29	22	16	14	21	40	10
PR	7	18	23	37	27	17	31	10	5	18	51	11	4	21	23	37	18	37	26	4	13	20	14	38
P/MS	2	17	52	14	22	13	29	21	27	20	26	12	24	20	31	10	12	28	39	6	1	27	19	38
B	25	44	8	8	2	41	16	26	7	43	11	24	3	40	14	28	20	46	17	2	4	38	10	33
WM	7	23	20	35	26	18	27	14	5	26	47	7	30	23	18	14	17	32	21	15	26	38	12	9
E	10	18	44	13	3	38	20	24	4	24	47	10	26	17	35	7	11	23	38	13	31	24	21	9
N	23	21	16	25	45	17	10	4	40	17	16	12	35	33	10	7	21	34	17	13	12	59	9	5
SI	5	18	43	23	29	16	21	17	3	48	21	13	7	45	21	12	15	36	25	9	21	29	21	14
CSR	2	9	24	50	2	11	52	20	33	20	21	11	8	40	24	18	15	38	15	17	3	27	43	12
SS	6	10	45	24	3	9	56	17	4	13	54	14	3	40	24	18	13	19	42	11	7	41	17	20
CT	7	20	20	38	6	10	35	34	3	19	25	38	4	17	28	36	17	34	25	9	4	19	53	9
A	4	13	48	20	6	13	29	37	9	11	54	11	30	20	24	11	17	19	38	11	6	16	24	39
IS	6	20	49	10	6	21	30	28	6	23	50	6	6	27	47	5	20	24	37	4	2	25	48	10
D	7	17	45	16	4	16	58	7	6	23	50	6	6	24	45	10	14	42	20	9	3	24	49	9

IA, Intentional Attacks; T, Theft; SU/CD Social unrest/community disputes; TA, Terrorist attacks; CR, Cyber security risk; GPO, Guiding policy for operation; GPMP, Guiding policy for materials procurement; ERM, Effective regulations and monitoring; FMS, Facilities management system; MP, Maintenance culture/practice; RR, Rapid response system; HS, Health and Safety measures; SVI, Strategies to manage vulnerabilities from interdependencies; DP, Disaster preparedness; MF/PE, Market forces & Politics effect; C, Cost (Direct & Indirect); DO, Design options & value; LO, Location options; EE, Economic effect; II, Informatics & innovation, CCI, Climate change impacts, NH, Natural hazards; CC/LC, Carbon critical design/low carbon emissions; PR, Pollution reduction/mitigation strategy; P/MS, Procurement/materials sourcing, B, Biodiversity; WM, Waste management; E, Energy; N, Noise; SI, Stakeholder/end-user integration & interconnection; CSR, Corporate social responsibilities; SS, Stakeholder satisfaction/product availability; CT, Competitiveness; A, Alternatives; IS, Independent systems, ; D, Diversity; NI, No impact; LI, Low impact; II, Intermediate impact; HI, High impact

Table 5.18: 4-level Scale to Evaluate Criticality of Hybrid Indicators on Various DCOGI

Colour Code	No. Of Response
	No response
	1 - 20
	21 - 40
	41 - 60
	61 - 85

5.6 Development of Hierarchy and Weightings for the Sub-Indicators

It was deemed necessary to derive the weightings for the 36 sub-indicators; similar AHP process used in Section 5.5.6 for deriving headline indicators weights was followed. The results are presented below.

Table 5.19: Security Indicators' AHP Matrix

	IA	T	SU/CD	TA	CR
IA	1	2	4	4	7
T	0.5	1	5	5	7
SU/CD	0.25	0.2	1	1	6
TA	0.25	0.2	1	1	6
CR	**0.14286**	**0.14286**	**0.16667**	**0.16667**	**1**

Table 5.20: Security Indicators' AHP calculations

	IA	T	SU/CD	TA	CR
IA	1	2	4	4	7
T	0.5	1	5	5	7
SU/CD	0.25	0.2	1	1	6
TA	0.25	0.2	1	1	6
CR	0.142857143	0.142857143	0.166666667	0.166666667	1
SUM	**2.142857143**	**3.542857143**	**11.16666667**	**11.16666667**	**27**

Table 5.21: Normalized Relative Weight for Security Indicators

	IA	T	SU/CD	TA	CR
IA	0.46666	0.56452	0.35821	0.35821	0.25926
T	0.23333	0.28226	0.44776	0.44776	0.25926
SU/CD	0.11667	0.05645	0.08955	0.08955	0.22222
TA	0.11667	0.05645	0.08955	0.08955	0.22222
CR	0.06667	0.04032	0.01493	0.01493	0.03704
SUM	**1**	**1**	**1**	**1**	**1**

Table 5.22: Eigen Value Calculations for Security Indicators

	IA	T	SU/CD	TA	CR	EIGEN VECTOR
IA	0.46666	0.56452	0.35821	0.35821	0.25926	0.40630
T	0.23333	0.28226	0.44776	0.44776	0.25926	0.34476
SU/CD	0.11667	0.05645	0.08955	0.08955	0.22222	0.10814
TA	0.11667	0.05645	0.08955	0.08955	0.22222	0.10814
CR	0.06667	0.04032	0.01493	0.01493	0.03704	0.03266
SUM	1	1	1	1	1	
CR = 0.087 < 0.1 ok						

Table 5.23: Governance Indicators' AHP Matrix

	GPO	GPMP	ERM
GPO	**1**	**3**	**0.33333**
GPMP	**0.33333**	**1**	**0.2**
ERM	**3**	**5**	**1**

Table 5.24: Governance Indicators' AHP calculations

	GPO	GPMP	ERM
GPO	1	3	0.33333
GPMP	0.33333	1	0.2
ERM	3	5	1
SUM	**4.33333**	**9**	**1.53333**

Table 5.25: Normalized Relative Weight for Governance Indicators

	GPO	GPMP	ERM
GPO	0.23077	0.33333	0.21739
GPMP	0.07692	0.11111	0.13044
ERM	0.69231	0.55556	0.65217
SUM	**1**	**1**	**1**

Table 5.26: Eigen Value Calculations for Governance Indicators

	GPO	GPMP	ERM	EIGEN VECTOR
GPO	0.23077	0.33333	0.21739	**0.25829**
GPMP	0.07692	0.11111	0.13044	**0.10473**
ERM	0.69231	0.55556	0.65217	**0.63699**
SUM	**1**	**1**	**1**	
CR = 0.037 < 0.1 ok				

Table 5.27: Maintenance Requirement & Risk Management Indicators' AHP Matrix

	FMS	MP	RR	HS	SVI	DP
FMS	**1**	**2**	**0.2**	**4**	**2**	**0.2**
MP	**0.5**	**1**	**0.2**	**3**	**3**	**0.2**
RR	**5**	**5**	**1**	**6**	**5**	**1**
HS	**0.25**	**0.33333**	**0.16666**	**1**	**0.2**	**0.16667**
SVI	**0.5**	**0.33333**	**0.2**	**5**	**1**	**0.2**
DP	**5**	**5**	**1**	**6**	**5**	**1**

Table 5.28: Maintenance Requirement & Risk Management Indicators' AHP calculations

	FMS	MP	RR	HS	SVI	DP
FMS	**1**	**2**	**0.2**	**4**	**2**	**0.2**
MP	**0.5**	**1**	**0.2**	**3**	**3**	**0.2**
RR	**5**	**5**	**1**	**6**	**5**	**1**
HS	**0.25**	**0.33333**	**0.16667**	**1**	**0.2**	**0.16667**
SVI	**0.5**	**0.33333**	**0.2**	**5**	**1**	**0.2**
DP	**5**	**5**	**1**	**6**	**5**	**1**
SUM	12.25	13.6667	2.76667	25	16.2	2.76667

Table 5.29: Normalized Relative Weight for Maintenance Requirement & Risk Management Indicators'

	FMS	MP	RR	HS	SVI	DP
FMS	**0.08163**	**0.14635**	**0.07229**	**0.16000**	**0.12346**	**0.07229**
MP	**0.04082**	**0.07317**	**0.07229**	**0.12000**	**0.18519**	**0.07229**
RR	**0.40816**	**0.36585**	**0.36144**	**0.24000**	**0.30864**	**0.36144**
HS	**0.02041**	**0.02439**	**0.06025**	**0.04000**	**0.01234**	**0.06025**
SVI	**0.04082**	**0.02439**	**0.07229**	**0.20000**	**0.06173**	**0.07229**
DP	**0.40816**	**0.36585**	**0.36144**	**0.24000**	**0.30864**	**0.36144**
SUM	1	1	1	1	1	1

Table 5.30: Eigen Value Calculations for Maintenance Requirement & Risk Management Indicators'

	FMS	MP	RR	HS	SVI	DP	EIGEN VECTOR
FMS	**0.08163**	**0.14635**	**0.07229**	**0.16000**	**0.12346**	**0.07229**	0.10903
MP	**0.04082**	**0.07317**	**0.07229**	**0.12000**	**0.18519**	**0.07229**	0.09225
RR	**0.40816**	**0.36585**	**0.36144**	**0.24000**	**0.30864**	**0.36144**	0.34667
HS	**0.02041**	**0.02439**	**0.06025**	**0.04000**	**0.01234**	**0.06025**	0.03402
SVI	**0.04082**	**0.02439**	**0.07229**	**0.20000**	**0.06173**	**0.07229**	0.07137
DP	**0.40816**	**0.36585**	**0.36144**	**0.24000**	**0.30864**	**0.36144**	0.34667
SUM	1	1	1	1	1	1	
CR = 0.0834 < 0.1 ok							

Table 5.31: Economic-Financial Indicators' AHP Matrix

	MF/PE	C	DO	LO	EE	II
MF/PE	**1**	**0.5**	**0.33333**	**0.33333**	**1**	**2**
C	**2**	**1**	**0.5**	**0.5**	**2**	**3**
DO	**3**	**2**	**1**	**1**	**1**	**3**
LO	**3**	**2**	**1**	**1**	**2**	**4**
EE	**1**	**0.5**	**1**	**0.5**	**1**	**3**
II	**0.5**	**0.33333**	**0.33333**	**0.25**	**0.33333**	**1**

Table 5.32: Economic-Financial Indicators' AHP calculations

	MF/PE	C	DO	LO	EE	II
MF/PE	**1**	**0.5**	**0.33333**	**0.33333**	**1**	**2**
C	**2**	**1**	**0.5**	**0.5**	**2**	**3**
DO	**3**	**2**	**1**	**1**	**1**	**3**
LO	**3**	**2**	**1**	**1**	**2**	**4**
EE	**1**	**0.5**	**1**	**0.5**	**1**	**3**
II	**0.5**	**0.33333**	**0.33333**	**0.25**	**0.33333**	**1**
SUM	10.5	6.33333	4.16667	3.58333	7.33333	16

Table 5.33: Normalized Relative Weight for Economic-Financial Indicators'

	MF/PE	C	DO	LO	EE	II
MF/PE	**0.09524**	**0.07895**	**0.08000**	**0.09302**	**0.13636**	**0.12500**
C	**0.19048**	**0.15789**	**0.12000**	**0.13954**	**0.27273**	**0.18750**
DO	**0.28571**	**0.31579**	**0.24000**	**0.27907**	**0.13636**	**0.18750**
LO	**0.28571**	**0.31579**	**0.24000**	**0.27907**	**0.27273**	**0.25000**
EE	**0.09524**	**0.07895**	**0.24000**	**0.13954**	**0.13636**	**0.18750**
II	**0.04762**	**0.05263**	**0.08000**	**0.06976**	**0.04546**	**0.06250**
SUM	1	1	1	1	1	1

Table 5.34: Eigen Value Calculations for Economic-Financial Indicators'

	MF/PE	C	DO	LO	EE	II	EIGEN VECTOR
MF/PE	**0.09524**	**0.07895**	**0.08000**	**0.09302**	**0.13636**	**0.12500**	0.10100
C	**0.19048**	**0.15789**	**0.12000**	**0.13954**	**0.27273**	**0.18750**	0.17851
DO	**0.28571**	**0.31579**	**0.24000**	**0.27907**	**0.13636**	**0.18750**	0.242167
LO	**0.28571**	**0.31579**	**0.24000**	**0.27907**	**0.27273**	**0.25000**	0.275012
EE	**0.09524**	**0.07895**	**0.24000**	**0.13954**	**0.13636**	**0.18750**	0.144061
II	**0.04762**	**0.05263**	**0.08000**	**0.06976**	**0.04546**	**0.06250**	0.059249
SUM	1	1	1	1	1	1	
CR = 0.030 < 0.1 ok							

Table 5.35: Environmental Indicators' AHP Matrix

	CCI	NH	CC/LC	PR	P/MS	B	WM	E	N
CCI	1	0.33333	1	2	0.25	3	1	0.5	2
NH	3	1	4	2	0.5	4	2	1	4
CC/LC	1	0.25	1	0.33333	0.25	1	0.33333	0.25	0.33333
PR	0.5	0.5	3	1	0.5	3	1	1	3
P/MS	4	2	4	2	1	4	2	2	4
B	0.33333	0.25	1	0.33333	0.25	1	0.2	0.16667	0.25
WM	1	0.5	3	1	0.5	5	1	1	2
E	2	1	4	1	0.5	6	1	1	3
N	0.5	0.25	3	0.33333	0.25	4	0.5	0.33333	1

Table 5.36: Environmental Indicators' AHP calculations

	CCI	NH	CC/LC	PR	P/MS	B	WM	E	N
CCI	1	0.33333	1	2	0.25	3	1	0.5	2
NH	3	1	4	2	0.5	4	2	1	4
CC/LC	1	0.25	1	0.33333	0.25	1	0.33333	0.25	0.33333
PR	0.5	0.5	3	1	0.5	3	1	1	3
P/MS	4	2	4	2	1	4	2	2	4
B	0.33333	0.25	1	0.33333	0.25	1	0.2	0.16667	0.25
WM	1	0.5	3	1	0.5	5	1	1	2
E	2	1	4	1	0.5	6	1	1	3
N	0.5	0.25	3	0.33333	0.25	4	0.5	0.33333	1
SUM	13.33333	6.08333	24	10	4	31	9.03333	7.25	19.58333

Table 5.37: Normalized Relative Weight for Environmental Indicators'

	CCI	NH	CC/LC	PR	P/MS	B	WM	E	N
CCI	**0.07500**	**0.05479**	**0.04167**	**0.20000**	**0.06250**	**0.09677**	**0.11070**	**0.06897**	**0.10213**
NH	**0.22500**	**0.16438**	**0.16667**	**0.20000**	**0.12500**	**0.12903**	**0.22140**	**0.13793**	**0.20426**
CC/LC	**0.07500**	**0.04110**	**0.04167**	**0.03333**	**0.06250**	**0.03226**	**0.03690**	**0.03448**	**0.01702**
PR	**0.03750**	**0.08219**	**0.12500**	**0.10000**	**0.12500**	**0.09677**	**0.11070**	**0.13793**	**0.15319**
P/MS	**0.30000**	**0.32877**	**0.16666**	**0.20000**	**0.25000**	**0.12903**	**0.22140**	**0.27586**	**0.20426**
B	**0.02500**	**0.04110**	**0.04167**	**0.03333**	**0.06250**	**0.03226**	**0.02214**	**0.02299**	**0.01276**
WM	**0.07500**	**0.08219**	**0.12500**	**0.10000**	**0.12500**	**0.16130**	**0.11070**	**0.13793**	**0.10213**
E	**0.15000**	**0.16438**	**0.16666**	**0.10000**	**0.12500**	**0.19355**	**0.11070**	**0.13793**	**0.15319**
N	**0.03750**	**0.04110**	**0.12500**	**0.03333**	**0.06250**	**0.12903**	**0.05536**	**0.04598**	**0.05106**
SUM	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Table 5.38: Eigen Value Calculations for Environmental Indicators'

	CCI	NH	CC/LC	PR	P/MS	B	WM	E	N	EIGEN VECTOR
CCI	0.07500	0.05479	0.04167	0.20000	0.06250	0.09677	0.11070	0.06897	0.10213	0.09087
NH	0.22500	0.16438	0.16667	0.20000	0.12500	0.12903	0.22140	0.13793	0.20426	0.17707
CC/LC	0.07500	0.04110	0.04167	0.03333	0.06250	0.03226	0.03690	0.03448	0.01702	0.04148
PR	0.03750	0.08219	0.12500	0.10000	0.12500	0.09677	0.11070	0.13793	0.15319	0.10693
P/MS	0.30000	0.32877	0.16666	0.20000	0.25000	0.12903	0.22140	0.27586	0.20426	0.23240
B	0.02500	0.04110	0.04167	0.03333	0.06250	0.03226	0.02214	0.02299	0.01276	0.03177
WM	0.07500	0.08219	0.12500	0.10000	0.12500	0.16130	0.11070	0.13793	0.10213	0.11174
E	0.15000	0.16438	0.16666	0.10000	0.12500	0.19355	0.11070	0.13793	0.15319	0.14476
N	0.03750	0.04110	0.12500	0.03333	0.06250	0.12903	0.05536	0.04598	0.05106	0.06298
SUM	1	1	1	1	1	1	1	1	1	
CR = 0.048 < 0.1 ok										

Table 5.39: Social Indicators' AHP Matrix

	SI	CSR	SS	CT
SI	**1**	**0.33333**	**0.5**	**0.5**
CSR	**3**	**1**	**3**	**4**
SS	**2**	**0.33333**	**1**	**3**
CT	**2**	**0.25**	**0.33333**	**1**

Table 5.40: Social Indicators' AHP calculations

	SI	CSR	SS	CT
SI	**1**	**0.33333**	**0.5**	**0.5**
CSR	**3**	**1**	**3**	**4**
SS	**2**	**0.33333**	**1**	**3**
CT	**2**	**0.25**	**0.33333**	**1**
SUM	8	1.91667	4.83333	8.5

Table 5.41: Normalized Relative Weight for Social Indicators

	SI	CSR	SS	CT
SI	**0.12500**	**0.17391**	**0.10345**	**0.05882**
CSR	**0.37500**	**0.52174**	**0.62069**	**0.47059**
SS	**0.25000**	**0.17391**	**0.20690**	**0.35294**
CT	**0.25000**	**0.13044**	**0.06896**	**0.11765**
SUM	1	1	1	1

Table 5.42: Eigen Value Calculations for Social Indicators'

	SI	CSR	SS	CT	EIGEN VECTOR
SI	**0.12500**	**0.17391**	**0.10345**	**0.05882**	0.11208
CSR	**0.37500**	**0.52174**	**0.62069**	**0.47059**	0.50476
SS	**0.25000**	**0.17391**	**0.20690**	**0.35294**	0.24827
CT	**0.25000**	**0.13044**	**0.06896**	**0.11765**	0.13490
SUM	1	1	1	1	
CR = 0.079 < 0.1 ok					

Table 5.43: Redundancy Indicators' AHP Matrix

	A	IS	D
A	**1**	**4**	**4**
IS	**0.25**	**1**	**0.5**
D	**0.25**	**2**	**1**

Table 5.44: Redundancy Indicators' AHP calculations

	A	IS	D
A	**1**	**4**	**4**
IS	**0.25**	**1**	**0.5**
D	**0.25**	**2**	**1**
SUM	1.5	7	5.5

Table 5.45: Normalized Relative Weight for Redundancy Indicators

	A	IS	D
A	**0.66666**	**0.57143**	**0.72727**
IS	**0.16667**	**0.14286**	**0.09091**
D	**0.16667**	**0.28571**	**0.18182**
SUM	1	1	1

Table 5.46: Eigen Value Calculations for Redundancy Indicators

	A	IS	D	EIGEN VECTOR
A	**0.66666**	**0.57143**	**0.72727**	0.66076
IS	**0.16667**	**0.14286**	**0.09091**	0.13111
D	**0.16667**	**0.28571**	**0.18182**	0.20813
SUM	1	1	1	
CR = 0.052 < 0.1 ok				

Table 5.47: AHP Results for the Sub-Indicators

HEADLINE INDICATORS	SUB-INDICATORS	WEIGHTING (w)	CONSISTENCY RATIO
Security	Interdictions / Intentional attacks	0.40630	0.09
	Theft	0.34476	
	Social unrest / community disputes	0.10814	
	Terrorist attacks	0.10814	
	Cyber-security risks	0.03266	
Governance	Guiding policy for operation	0.25829	0.04
	Guiding policy for materials procurement	0.10473	
	Effective regulations and monitoring	0.63699	
Maintenance Requirement & Risk Management	Facilities management system	0.10903	0.08
	Maintenance culture / practice	0.09225	
	Rapid response system	0.34667	
	Health and Safety measures	0.03402	
	Strategies to manage vulnerabilities from interdependencies	0.07137	
	Disaster preparedness	0.34667	
Economic-Financial	Market forces & Politics effect	0.10100	0.03
	Cost (Direct & Indirect)	0.17851	
	Design options & value	0.24217	
	Location options	0.27501	
	Economic effect	0.14406	
	Informatics & innovation	0.05925	
Environment	Climate change impacts	0.09087	0.05
	Natural hazards	0.17707	
	Carbon critical design / low carbon emissions	0.04148	
	Pollution reduction / mitigation strategy	0.10693	
	Procurement / materials sourcing	0.23240	
	Biodiversity	0.03177	
	Waste management	0.11174	
	Energy	0.14476	
	Noise	0.06298	
Social	Stakeholder / end-user integration & interconnection	0.11208	0.08
	Corporate social responsibilities	0.50476	
	Stakeholder satisfaction / product availability	0.24827	
	Competitiveness	0.13490	
Redundancy	Alternatives (multiple distribution routes)	0.66076	0.05
	Independent systems	0.13111	
	Diversity (renewables)	0.20813	

An alternative approach of the AHP has been applied to verify the developed weightings using the weighted average methodology (WAM). With the application of the WAM each of the headline indicators was considered equally based on the WAM process, and the final numbers have been calculated at 14.285 percent of the total for each indicator (Table 5.9). Using the AHP process to derive weightings, it was possible to obtain more precise weightings for the headline indicators as shown in figure 5.5. From the AHP results, security has the highest weighting with 35% importance towards achieving sustainability and resilience in DCOGI. Redundancy, social, governance, maintenance requirement and risk management, economic-financial and environment headline indicators followed with 22%, 21%, 12%, 5%, 3% and 2% respectively. This clearly differs from the WAM results which had equal weightings to the headline indicators. For the sub-indicators, the results are slightly like those derived using the WAM to some degree, with alternatives (Redundancy) e.g., multiple distribution routes having the highest weight of w = 5.13310 (for WAM) and w = 0.66076 (for AHP results). Although they are some similarities between the WAM and AHP results for the sub indicators, the AHP was deemed devoid of assumptions as regard the headline indictors i.e., whereas the WAM assume the headline indicators as equal, the AHP was able to provide the relative importance of the headline indicators. As such, it is considered that the AHP results will enable ease of judgement and decision making given the importance of each headline indicator towards achieving sustainability and resilience, and consistent with the overall aim of this study. Hence, the AHP results have been used for the RESOGI.

5.7 The RESOGI Outlook and Rating System

The section presents the final outlook of the RESOGI and rating method for end-users. At the core of the development of the RESOGI was to produce an assessment framework that is easy to use, and every stakeholder understands the thinking behind it, also a framework that is readily available in the public space. The process of developing the RESOGI involved all the major stakeholders to the DCOGI industry; in so doing the RESOGI is free of bias, this distinguishes the RESOGI from other assessment frameworks. The chosen method of display is a visual display dart and is presented in figure 5.12. Scoring is done using a rating system developed for the RESOGI. The rating system consist of the RESOGI scoring key, and the RESOGI outlook colour code. The scores range from 5 (which is worst case) to 1 (which is the optimum). A DCOGI system where a hybrid indicator is scored 1 will mean the hybrid indicator for the

infrastructure system does not require improvement, if scored 2 the hybrid indicator for the infrastructure system requires minor improvement. If scored 3, the hybrid indicator for the infrastructure system requires moderate improvement. If score 4, the hybrid indicator for the infrastructure system requires major improvement. If scored 5, the infrastructure system may require re-engineering. A detailed scoring key accompanying the RESOGI outlook is presented in table 5.48. For visual clarity, a colour code, which compliments that of the criticality association table (see table 5.49), is assigned to the RESOGI scores.

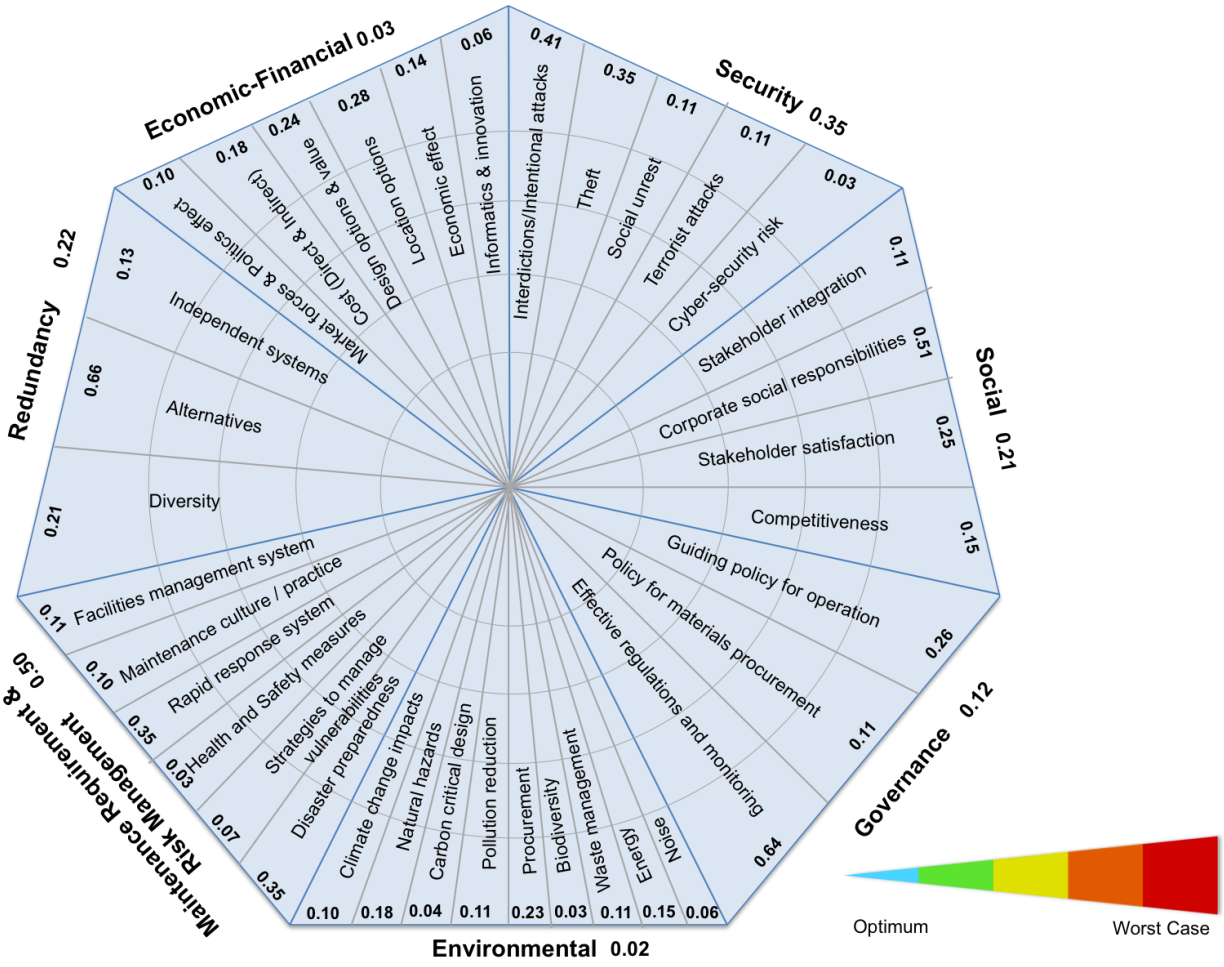


Figure 5.12: The RESOGI Outlook

Table 5.48: RESOGI Scoring key

Levels on the chart	Description
1	The indicator has been implemented at optimum, no improvement is required
2	The indicator is rated as good because it has been implemented but requires minor improvement
3	The indicator is rated as fair because it has been implemented but requires moderate improvement
4	The indicator is rated as poor, because it has been inadequately implemented and requires major improvement
5	The indicator is rated as very poor, because it has not been implemented and requires re-engineering

Table 5.49: RESOGI Outlook Colour Code

Colour Code	Key
	1
	2
	3
	4
	5

5.8 Summary

This Chapter presented the survey and responses that were mainly required to achieve objective 5 and 6 of the research. The results include those from the focus groups, interviews, and questionnaires. It was possible to verify the relevance, and usefulness of the hybrid indicators presented to the stakeholders. One of the key strengths of the developed RESOGI indicators is that they are constituted in collaboration with an array of stakeholders to the DCOGI industry, although with different inclinations which is beneficial to cover the different dimensions of sustainability and resilience. The diversity in responses is aimed to ensure the proposed framework is devoid of bias. The responses from the survey are being incorporated into the indicators best suited. For the interviews it was possible to agree with the respondents which indicators their inputs best fitted. The author, using their knowledge and experience within this field, incorporated the responses from questionnaires and focus groups into their relevant indicator (e.g., see table 5.4). The significance table developed revealed that cyber security risk (Security) and noise (Environment) are considered as less significant to achieving sustainable and resilient DCOGI. This finding was however not expected considering that cyber security risk has been an increasing concern globally, with many countries' government e.g., United Kingdom and United States have recently increased spending to curb cyber security attacks on their national assets.

CHAPTER 6: TESTING THE RESOGI FRAMEWORK – CASE STUDIES

6.1 Introduction

The previous chapter produced the Beta version of the RESOGI framework (i.e., the validated version) following inputs from DCOGI stakeholders through the survey. The theoretical and empirical aspect of this study so far has identified a shortfall in both spheres for an integrated and holistic sustainability and resilience assessment frameworks for DCOGI, the proposed RESOGI assessment framework is a core knowledge contribution to the broader field of study. However, a further empirical process is needed to add more relevance to the proposed framework and ensure that the framework is complete and useful (McLachlin, 1997; Labaka et al., 2016). The primary purpose of this chapter is to road test the RESOGI and demonstrates how the RESOGI is applied through two case studies, both of which are gas distribution infrastructures. Consideration is given to confidentiality agreements; because of this some case study project information may not be included in the thesis.

Case study 1 is a gas distribution Infrastructure system located in Nigeria, a critical national asset developed to meet increased demand for domestic use of gas (Details in section 6.3.1). Case study 2 is a gas distribution system development project in Nigeria, proposed to expand domestic supply of gas to the northern part of the country and for export services to the European markets through the trans-Sahara network (Details in section 6.3.2). In section 6.4 of the chapter, application of the RESOGI in both case studies and results are presented. The discussions of the application results, and an attempt to validate the results using the SPeAR® assessment framework and the Resilience Assessment framework by Francis and Bekera are presented in section 6.5 of the chapter. The following section (6.2) will detail the implementation and rating method for the RESOGI.

6.2 Implementing the RESOGI

As highlighted in the literature review and survey results, it is vital for the DCOGI industry and its stakeholders that sustainable and resilience in DCOGI systems are assessed all through the DCOGI developmental phases. The wider benefit therein includes those along the lines of the energy trilemma (i.e., Economic Competitiveness, Environmental Sustainability, and Energy Security). The RESOGI, as presented, constitutes a robust array of hybrid indicators tailored

specifically to cover broadly issues that disrupt the sustainability and resilience of DCOGIs, including associated weightings to aid the sustainability and resilience evaluation of DCOGIs. An added contribution to this field of study is the development of weightings and the associated criticality table of derived significance for six identified DCOGIs which are pipeline, storage facilities, road tankers, barges and ships, rail tankers, and distribution nodes or system (Table 5.18). One of the core advantages of the RESOGI is it can be used globally, considering the global perspective incorporated during its development process e.g., derived global views from the literature review and broad array of survey stakeholders' input. And so, the RESOGI is deemed applicable to DCOGI in any developed and developing country context. To demonstrate the implementation of the RESOGI, the next section shows the methodology used to assess the case studies.

6.2.1 Implementation System

The RESOGI implementation system was developed in two parts. First, the developmental stages of the case studies for application of the RESOGI are derived. This refers to the developmental stages of a DCOGI to which the implementation system is applicable, where the hybrid indicators would have more impact. Four industry professionals within the case studies project that are familiar with the case study infrastructure system attended a group model development exercise with the author in order to undertake the REOSGI assessment (Details in chapter 3), during which they professionals made considerations of practices associated with DCOGI systems whole life stages, civil engineering projects life cycle, using considerable engineering knowledge and project management experience by the professionals. The outcome was also assessed by a sustainability professional before concluding (Table 6.1), thus:

Stage 1 – Planning (includes feasibility, design, award, mobilisation).

Stage 2 – Construction (Includes actual development stage or acquisition in some cases).

Stage 3 – Demobilisation (includes removal of construction equipment, machinery, manpower).

Stage 4 – Operation (during active functioning of DCOGI systems).

Stage 5 – Decommission (Includes end of life of DCOGI systems).

The aim is to ensure a systematic consideration of the vital stages that require careful attention throughout the developmental phases of a DCOGI system. The key feature of the process is to allow for identification of indicators, where it does matter the most, which could thwart the continuous delivery of service of DCOGIs and other cascading impacts. However, for flexibility of use, users of the RESOGI framework can extend the application to other stages of DCOGI phase if deemed necessary.

Table 6.1: Indicators Implementation for Case Studies Developmental Stages

HD Indicators	Indicators	Stages				
		1st	2nd	3rd	4th	5th
Security	Interdictions / Intentional attacks				◆	
	Theft		◆		◆	
	Social unrest / community disputes		◆		◆	
	Terrorist attacks				◆	
	Cyber-security risks				◆	
Governance	Guiding policy for operation				◆	
	Guiding policy for materials procurement	◆				
	Effective regulations and monitoring	◆	◆	◆	◆	◆
Maintenance Requirement & Risk Management	Facilities management system				◆	
	Maintenance culture / practice				◆	
	Rapid response system				◆	
	Health and Safety measures	◆	◆	◆	◆	◆
	Strategies to manage vulnerabilities from interdependencies	◆				
	Disaster preparedness	◆				
Economic-Financial	Market forces & Politics effect	◆			◆	
	Cost (Direct & Indirect)	◆	◆	◆	◆	◆
	Design options & value	◆				
	Location options	◆				
	Economic effect		◆		◆	◆
	Informatics & innovation				◆	
Environmental	Climate change impacts		◆		◆	
	Natural hazards	◆			◆	
	Carbon critical design / low carbon emissions	◆	◆		◆	
	Pollution reduction / mitigation strategy	◆	◆	◆	◆	◆
	Procurement / materials sourcing	◆	◆			
	Biodiversity	◆	◆			
	Waste management		◆		◆	◆
	Energy		◆		◆	◆
	Noise		◆		◆	◆
Social	Stakeholder / End-user integration & interconnection	◆	◆		◆	◆
	Corporate social responsibilities	◆			◆	
	Stakeholder satisfaction / product availability				◆	
	Competitiveness				◆	
Redundancy	Alternatives (multiple distribution routes)	◆	◆		◆	
	Independent systems	◆	◆		◆	
	Diversity (renewables)		◆		◆	

The second part of the implementation system is the process implementation, which refers to the step-by-step guide for the RESOGI end-users. Using the study outcomes from chapter 5 and the previous section of this chapter, testing the RESOGI requires a four-step process. Thus, to apply the RESOGI, the following steps should be followed:

- Step 1: Using the criticality association table (Table 5.17 - Pg198), identify DCOGI and familiarise with levels of associated impact derived for the DCOGI. This is helpful particularly for end-users not familiar with the industry and a good starting point for the assessment process. The derived table 6.1 is equally helpful to professionals; its viability for use is justified in that the table is a direct input from industry professionals. Following this, define boundaries for the assessment e.g., geographical locations and boundaries, the communities and other stakeholders involved.
- Step 2: Using the implementation table (as shown in table 6.1), identify targeted DCOGI developmental stages as described i.e., planning, construction, demobilization, operations, or decommissioning. End-users should be flexible with their application to the stages in the table. If the user feels a hybrid indicator assessment is needed in addition to the pre-identified ones can include one.
- Step 3: Using the RESOGI scoring key (Table 5.48 – Pg214) and the assigned colour code (Table 5.49) as described in section 5.7 of chapter 5, the DCOGI is assessed for each indicator within the RESOGI in detail. The steps may require involvement of other players depending on who is the assessor. E.g., in a case were the assessor lacks the engineering knowledge or a case the assessor requires access to a DCOGI facility or where several facilities require assessment. It could also depend on organisational arrangements (in the case of the operators or government agencies).
- Step 4: Lastly, using the RESOGI outlook (Figure 5.12 – Pg213), the scores are recorded, allowing for a visual judgement of the sustainability and resilience levels of the chosen DCOGI. Where a hybrid indicator requires improvement; the level of improvement would also be determined based on the score assigned to the hybrid indicator and boundary conditions as described in step1.

A brief background overview of the case studies infrastructure systems is presented in the next section and the results and conclusions are presented thereafter.

6.3 Overview of Case-Study Infrastructure System

6.3.1 Case Study 1 - Gas Distribution Infrastructure system:

Case study 1 gas distribution system is a key gas infrastructure system developed by the Nigerian National Petroleum Corporation (NNPC) designed to distribute gas from the Oben / Obrikom (South-Nigeria) to the western, eastern and northern region of the country and to double the volume of the Escravos Lagos gas distribution system (ELPS) line. Figures 6.1 and 6.2 show the oriental view of the case study location and distribution route respectively on the map of Nigeria. The primary purpose of the gas distribution infrastructure system is to meet the Nigerian gas demand for domestic power generation and industrial use that includes methanol, cement, manufacturing etc. As a critical national infrastructure, there is emphasis on operational safety, efficiency and flexibility with a view to providing industry standard, remote supervision and control. The distribution infrastructure also feeds other gas infrastructure systems; it supplies the West African gas pipeline with gas. Bit A of case study 1 infrastructure system includes the pipeline network, which covers over 64.65km, and includes having the pipeline cross under the River Niger with Horizontal Directional Drilling (HDD). HDD is a minimal impact trenchless method of installing underground utilities (Oil & gas report, 2020). Case study 1 LOT A covers a terrain of land, swamp and seasonal swamp, as well as rivers (including River Niger), creeks and road crossings.



Figure 6.1: Case study 1 gas infrastructure system (Source: Robert Brelsford)

The River site has a 716m river crossing under the river using the Horizontal Directional Drilling method and accessible by speedboat. In general, the infrastructure system covers three major river crossings, three minor river crossings through swampy terrain, twelve road crossings through hills and valleys and includes 18 pressure vessels at the custody transfer metering station in the south, including a control building, generator house & sheds, isolation valves, line break valves, etc. Case study 1 gas distribution system generally involves an Engineering, Procurement, Construction (EPC) of 127km x 48inch diameter class 600 trunk gas supply pipeline project and Gas Processing and Pressure Reduction Facilities with designed capacity of 2 billion Standard Cubic Feet per day (scf/d). The pipeline size is described as the largest in West Africa. The infrastructure transverses two States from Obiafu-Obrikom in Rivers States south-south of Nigeria and terminates at Oben Node in Edo State southeast of the country. The revised estimate total cost for the Engineering, Procurement and Construction of the case study 1 gas distribution infrastructure system was $700 million.



Figure 6.2: Map of Nigeria showing distribution route of case study 1 (Source: Petroleum Economist)

6.3.2 Case Study 2 - Gas Distribution System Project:

Case study 2 gas distribution infrastructure system is a major gas distribution infrastructure of the Federal Ministry of Petroleum Resources Nigeria (Figures 6.3 and 6.4). Figure 6.3 shows the distribution route of the gas infrastructure system as it cuts across the length and breadth of the country (North, South, East and West). Figure 6.4 shows the distribution locations within the map of Nigeria. The gas distribution infrastructure system was developed for two primary purposes. To further develop for the country's domestic consumption and with sufficient capacity built into the system, it will supply a future trans-Saharan gas pipeline for export to the European markets. The system is designed to supply quality gas at a minimum pressure of 1000 psig from source and deliver at same pressure of 1000 psig. The estimated total cost for the engineering, procurement and construction of Case study 2 gas distribution system is $2.8 billion.

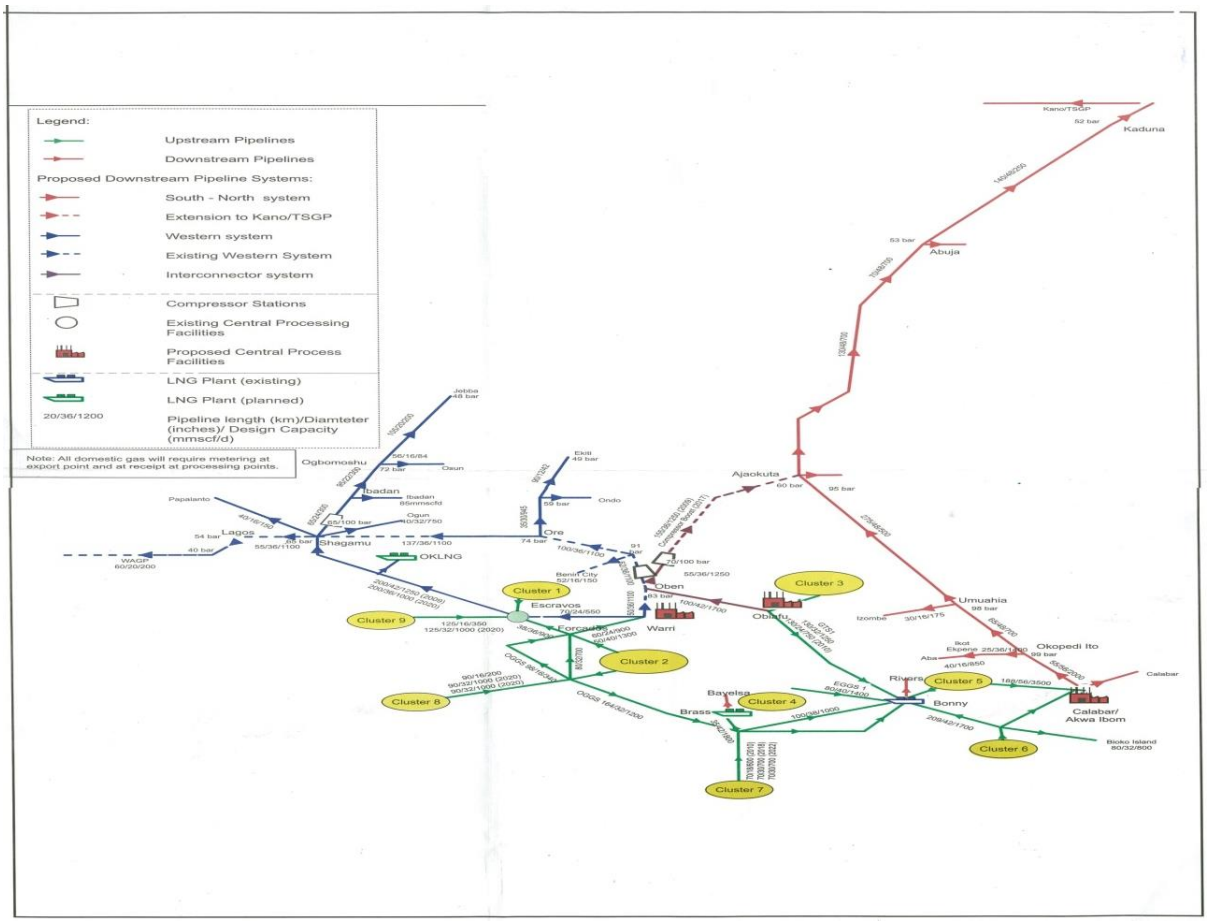


Figure 6.3: Case study 2 gas distribution route (Source: Master plan document)

The gas distribution system includes a 614km pipeline network, terminal gas stations and distribution nodes, compressor booster stations with compressor power equipment, has eight major river crossings and ten major road crossings, depressurizing valves and other valves, scraper launcher / receiver stations, control and monitoring systems, communication systems, security systems, instrumentations, fired heaters, pressure let-down stations, consumer metering etc. Utilities include fuel gas, service water, drains etc. The design flow capacity at various points ranges from 500 mm scf/d to 3000 mm scf/d with expected future capability of supplying up to 2000 mm scf/d onward transmission into the sub-Saharan route. The pipeline has a conservative design temperature of 100℃ and design pressure of 9320 kPa (1352 psig) based on the American Society of Mechanical Engineers standard B16.5 (2003) with a rating of 600♯.

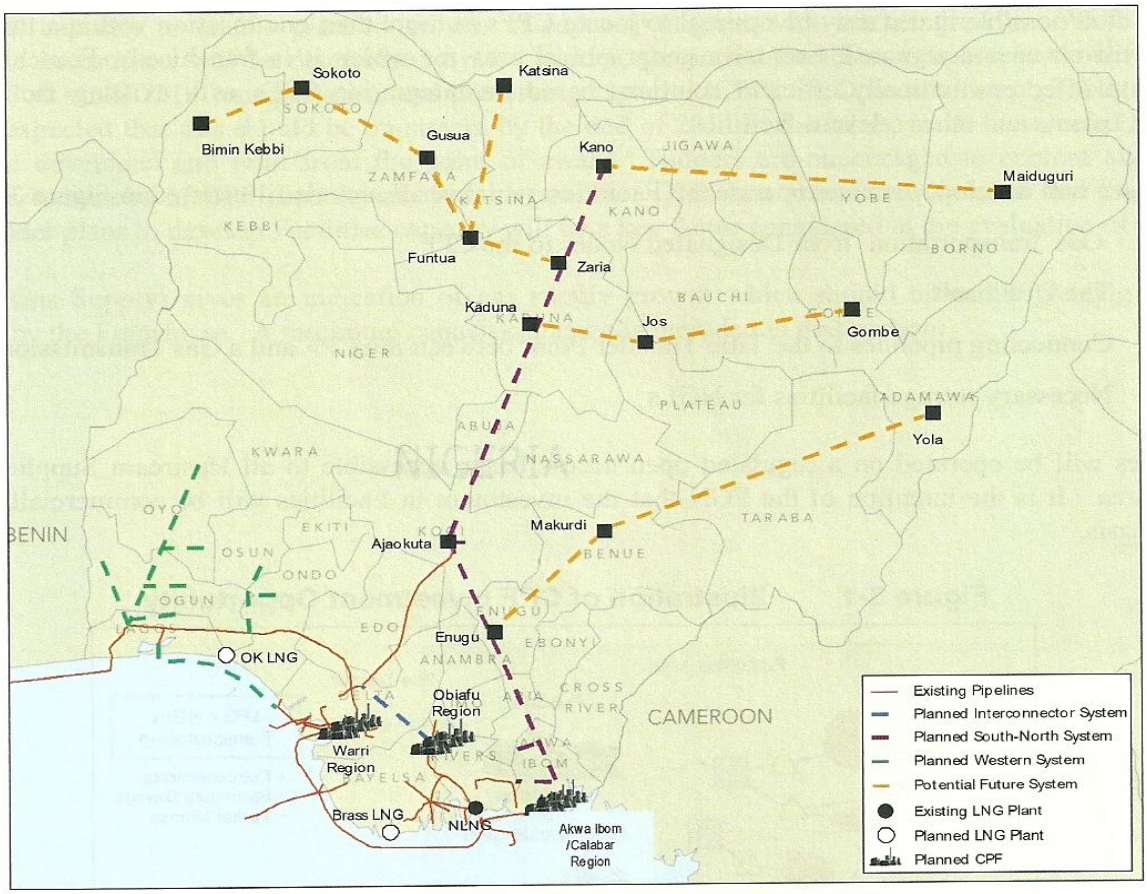


Figure 6.4: Map of Nigeria showing case study 2 distribution locations (Source: Master plan document)

6.4 Application of the RESOGI framework to Case Study

As mentioned in chapter 3, the performance assessments of the two case study infrastructure systems were done during meetings held with four industry professionals / experts who had knowledge of the project (including director and deputy director of MPR Downstream unit, two members of the NNPC Gas infrastructure technical team). Having been part of the study's survey respondent, the four experts were familiar with step 1 of the RESOGI implementation process.

The experts were familiar with the levels of associated impact derived for the DCOGI using the criticality table (5.17). For the case studies, they included mainly indicators in the security pillar of the RESOGI i.e., theft, vandalism, intentional attacks. Also, maintenance requirement and risk management indicators e.g., rapid response systems, health safety measures and the indicators in the social pillar e.g., stakeholder integration i.e., involving the community indigenes, relevant government agencies e.g., Department of Petroleum Resources (DPR Nigeria), National Oil Spill Detection and Response Agency (NOSDRA). For step 2 of the RESOGI implementation process, the developmental stages considered for case study 1 and 2 were planning, construction and operation. Following this, the step 3 of the implementation process, which is the scoring of the case study 1 and 2. Indicator's performance was discussed and reviewed by the assessors in the meetings and evidence provided. Using the RESOGI scoring key, scoring of the case studies was done from 1 to 5 (or optimum to worse case) based on the RESOGI scoring key.

Details of the indicator analysis for case study 1 and 2 are provided in tables 6.1 and 6.2 respectively. After scoring was done, the complimenting colour codes (Table 5.49) for the scoring key applied on the RESOGI outlook (shown in figures 6.5 and 6.6). The scoring and justifications given in the tables contain information collected during these meetings, based on the assessors' knowledge of the infrastructure systems during planning, construction, and operations. And, from planning, design and operations documents for the case studies infrastructure systems.

Table 6.2: Assessment and Scoring for case study 1 Gas Distribution Infrastructure system

HEADLINE INDICATORS	SUB INDICATORS (And Weights)	SCORE	JUSTIFICATION
Security (0.353)	Interdictions / Intentional attacks (0.406)	4	There is rampant vandalization of existing infrastructure. Insecurity has delayed the project for six years, attacks on workers by unknown persons.
	Theft (0.344)	3	Theft of welding machine and electrode, cutting and grinding machines.
	Social unrest / Community disputes (0.108)	4	Blockage on right of way, refusal of access to project sites, request to stipends regularly.
	Cyber-security risks (0.032)	2	Contracted cyber security agency is employed to manage cyber activities.
Governance (0.115)	Guiding policy for materials procurement (0.104)	1	Close to 100% completed, knock out drum - like separators or scrubbers, flow metering unit, floater, custody transfer metering station. All based on ASME. All in line with specifications.
	Effective regulations and monitoring (0.636)	2	Factory acceptance test – sign off before dispatch sites. Visit to factory – leak test conducted, x-ray of joints (x-ray film/sheet).
Maintenance Requirement & Risk Management (0.046)	Facilities management system (0.109)	2	Delegated to the NGC, required to meet international standards. Adoption of cathodic protection. Facilities managers will be on site to trouble shoot and resolve mechanical failures.
	Maintenance culture / practice (0.092)	2	As part of the project plan, long-term routine maintenance requirements for the infrastructure have been identified in line with relevant standards and budgeted for. Maintenance responsibilities are assigned. There are preventive and corrective activities in place.
	Rapid response system (0.346)	3	There are several defined operating and organizational procedures to know how to respond when an incident occurs. There is an established information system to track incidents and collate lessons learnt. It was agreed that collaborations with external responders e.g. fire fighters, police, military and civil protection workers require some improvement.
	Health and Safety measures (0.034)	3	There are pieces of emergency equipment and health & safety materials on sites to ensure safety of workers.
	Disaster preparedness (0.346)	4	Essential external crisis response equipment are not reliable to absorb impact and recover efficiently e.g. with the local first responders and local government's external relations department.
Economic-Financial (0.031)	Market forces & Politics effect (0.101)	2	Existing strategies in place by the NNPC for all national DCOGI assets are good.

	Cost (Direct & Indirect) (0.178)	2	Funds made readily available, Well funded although few concerns e.g. issues with design concerns regarding topography of the right of way (swampy areas, across rivers), also misappropriation of funds by funding body.
	Design options & value (0.242)	2	Minor variations from initial sum value – compromise by external contractors due errors made from planning stage.
	Location options (0.275)	3	Pipelines are not on existing right of way. Although adequate vital considerations are given, swampy terrains would require more security measures.
Environmental (0.024)	Climate change impacts (0.090)	1	System proofed against impacts – included in the EIA process.
	Natural hazards (0.177)	3	System has proof against impacts based on pipeline specifications. Geographically, not much is expected regarding occurrence of major natural disaster. However, considerations are to be given to impacts in the swampy terrains and ensure products retain required conditions.
	Procurement / Materials sourcing (0.232)	2	Compressor station facilities, gaskets, bolts all sourced sustainable.
	Biodiversity (0.317)	1	Covered under Environmental Impact assessment – considerations made before commencement of constructions – liaison with communities and government agency – certification obtained as proof.
	Waste management (0.111)	3	Waste management plans in place. Most materials are kept for re-use e.g. offcut, toxic waste are disposed adequately.
Social (0.207)	Stakeholder / End-user integration & interconnection (0.112)	1	All stakeholders are duly involved.
	Competitiveness **(0.134)**	1	Top NNPC management have shown full commitment to the success of the project in line with the benefits and revenue expected. Top management have affirmed that the continuous operations of the infrastructure, safety of workers and the infrastructure are its top priority.
Redundancy (0.222)	Alternatives - Multiple distribution routes **(0.660)**	5	There is no alternative routing.
	Independent systems **(0.131)**	2	Redundancies have been provided for equipment e.g. filter separators, gas coolers, pressure reduction systems etc.

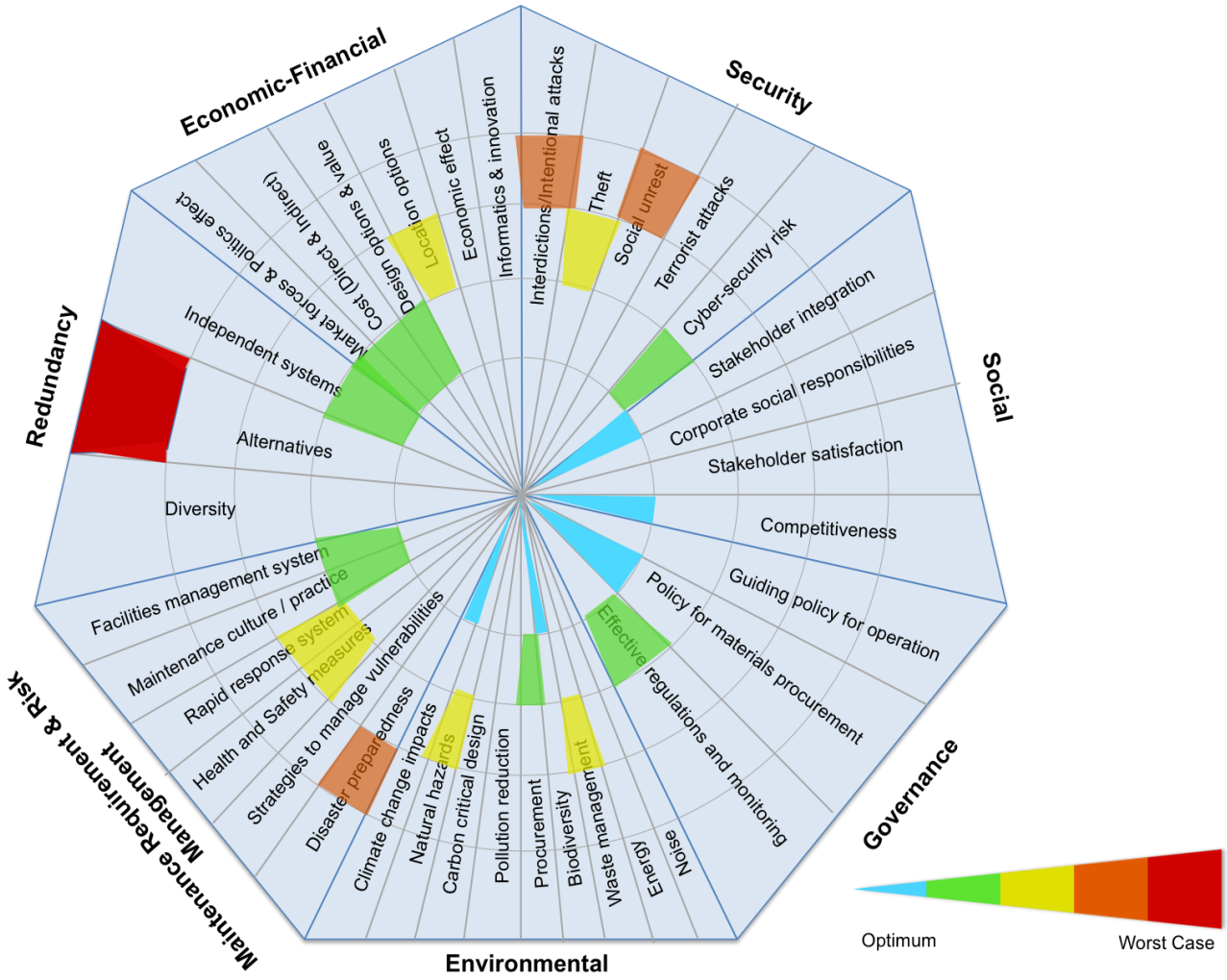


Figure 6.5: RESOGI Results for Case Study 1

Table 6.3: Assessment and Scoring for case study 2 Gas Distribution Infrastructure system

HEADLINE INDICATORS	SUB INDICATORS	SCORE	JUSTIFICATION
Security (0.353)	Interdictions / Intentional attacks (0.406)	3	Measures for protection of pipeline, pipeline support plants, consumer equipment and other distribution facilities are in place, by continuous monitoring of the feed streams, instrumented alarm systems and shut-in of incoming feed streams. The pipeline routes have routed through existing rights of way wherever possible.
	Theft (0.344)	3	Security measures have been put in place to guide against theft of equipment. Focus is more on equipment, as gas cannot be stolen. Armed security personnel are on constant patrol around facilities.
	Social unrest / Community disputes (0.108)	3	This indicator has been addressed, although most of the pipeline routes are away from major communities, the stations and distribution outlets are within reach. Community leaders and indigenes in those areas have been actively involved in monitoring and securing facilities.
	Terrorist attacks (0.108)	3	As a critical national infrastructure, the federal ministry of petroleum are partnering with the military to provide security and put in place counter measures against terrorist attacks on installations.
Governance (0.115)	Guiding policy for operation (0.258)	2	The following codes and standards are in place for operation: ISO Standards, EN Standards, IEC Standards, ISO Communication standards, American Petroleum Institute (API), American Gas Association (AGA). Also existence of in-house control and operations philosophy.
	Guiding policy for materials procurement (0.104)	2	All through the construction period they was strict adherence to national and international standards for procurement. The American Society for Mechanical Engineers (ASME), American Petroleum Institute (API), National Association of Corrosion Engineer (NACE) codes and standards were used for procurement of materials.
	Effective regulations and monitoring (0.636)	2	Arrangements for regular regulatory checks for compliance to regulations and laws by the Department of Petroleum Resources, a regulatory agency under the ministry of petroleum resources is in place.
Maintenance Requirement & Risk Management (0.046)	Facilities management system (0.109)	2	Facilities management procedures are in place, allowing for routine reporting and maintenance scheduling. All access arrangements have been provided and visible to all above ground facilities. Operating and inspection points are all accessible from operating aisles and not requiring auxiliary platforms and ladders. Intermediate scraper receiver / launcher stations are installed to facilitate smooth intelligent and conventional pigging operations.
	Rapid response system	2	All the stations have been laid-out in a manner that

	(0.346)		meets requirement for normal vehicle and personnel traffic, emergency / security evacuation, firefighting and accessibility for walkovers.
	Health and Safety measures (0.034)	2	This indicator requirement has been met. There are health and safety awareness and procedures in place at all stations and MPR commitment to averting disruptions and incidents in the consciousness of a catastrophic nature of gas infrastructure incidence e.g. explosion. Confirm compliance to HAZOB and HSE procedures.
	Strategies to manage vulnerabilities from interdependencies (0.071)	2	For such a strategically important installation, vulnerabilities from all interdependent equipment / points are in place. This has also warranted adequate budgetary allocations are made for strategic alternatives, replacement equipment including open link with suppliers and embedded independent systems. E.g. for this facility is the installation of ring main that allows for up to six alternative valve / pump openings in the events of failure or maintenance requirement.
	Disaster preparedness (0.346)	3	Proper positioning of critical equipment and valves are in place – firewater pumps, depressurizing valves, ventilation inlets & outlets and vents, emergency response system, exits. However, are no formal alliance with external first responders,
Economic-Financial (0.031)	Market forces & Politics effect (0.101)	1	At the moment demand for gas is at peak and there is a gap in meeting supply requirements. The infrastructure is strategically developed to meet the demand of both national (Domestic and Industrial) needs and international market's demand. There is genuine backing and sincerity of purpose by governments, politicians' nationally and around the sub-Saharan region as well as the European market.
	Cost (Direct & Indirect) (0.178)	1	Adequate budgeting and budgetary plans has been in place. This includes for both corrective and preventive maintenance, plans for emergency responses. Installation cost savings were made e.g. initial decision between either a single 60' or dual 48' pipeline option and number of booster compressor stations.
	Design options & value (0.242)	1	Installation of dual pipelines 42" gas transmission pipelines, the design to accommodate multiple booster compressor stations along with pipeline length to compensate for unavoidable pressure losses and disruptions. This design option was decided upon and expected to add value despite the high installation cost. A trade-off for cost was made to ensure value and avoid future disruptions in the case of plant failure or pipeline damage.
	Location options	1	Locations of various facilities for this gas distribution

	(0.275)		system have been strategically positioned, because it is a highly critical national infrastructure. Stations, facilities, Pipelines have been aligned with existing right of ways with adequately reinforced security. It was deemed vital that all considerations to location including waterways, major roads, isolated areas etc.
	Economic effect (0.144)	2	Economic effect is positive both externally and internally to the gas distribution infrastructure. The local gas economy supply has been boosted particularly with the increase demand for gas for industrial and domestic use nationally. It is expected that with the commencements of the trans-Sahara distribution of supply, this will generate more revenue for the country.
Environmental (0.024)	Natural hazards (0.177)	2	Geographically, not much is expected regarding occurrence of major natural disaster. Identified issues are with temperature effects on gas products. However, are extreme high temperatures when effects are expected on gas products, measures are in place to intermittently swap systems and ensure products retain required conditions.
	Pollution reduction / Mitigation strategy (0.106)	2	Based on review of the project information, there is a potential for contamination / pollution in all phases of the development. There is a pollution management plan in place for construction to operations of the infrastructure that covers all natural resources e.g. soil / land contamination, water, air.
	Procurement / Materials sourcing (0.232)	1	There is a project specific procurement strategy that covers all design and operational functions (e.g. Carbon management policy for carbon critical design and low carbon emissions), and supports sustainability guidance, goals and targets. This includes cost with respect to global and local sourcing, impacts of material on the environment at source and the project infrastructure requirement specifications.
	Biodiversity (0.317)	2	There is a strategy to manage biodiversity incorporated at the planning phase under the principle of sustainability in the EIA. This includes the adopted national and international environmental policies, that provides considerations for protecting and replacing of existing / affected species and their natural habitats particularly for the construction phase of the development.
	Waste management (0.111)	2	There is a waste management plan / strategy in place for waste management during construction and operations. Waste management complies with local, regional and international standards and processes including provision for storage, collection, reuse where possible and recycling.
	Energy	3	Fuel gas is used to for the Indirect Fired Heaters, this

	(0.145)		is considered as efficient. However, diesel is used to generate power for uninterrupted power supply at the terminal gas stations. All backup and emergency generators are also diesel powered. This requires improvement, as there is an opportunity to provide power from solar systems considering abundant sun in the region. Also, hydro sources. Good energy saver indoor lightings and outdoor lighting systems.
Social (0.207)	Stakeholder / End-user integration & interconnection (0.112)	2	The review of the project shows the involvement of all-relevant stakeholders (including Government agencies and parastatals, local communities, state Government) to the infrastructure development have been involved.
	Stakeholder satisfaction / product availability (0.248)	2	The project is particularly initiated and designed to meet increased domestic demand for gas and to increase export capacity of the country.
	Competitiveness (0.134)	2	NNPC management and the Nigerian Government have shown full commitment to the success of the project in line with the benefits and revenue expected. Top management have affirmed that the continuous operations of the infrastructure, safety of workers and the infrastructure are its top priority
Redundancy (0.222)	Alternatives - Multiple distribution routes (0.660)	1	Dual pipeline installation for distribution to stations and for domestic and industrial consumers. Each station has two turbo compressor trains in operation with one spare train. The trains are lined up to either pipeline in the event of a problem occurring with one of the normally operating trains. Sufficient booster's compressors are provided to ensure steady delivery at required pressure.
	Independent systems (0.131)	1	Appropriate redundancy has been provided for the following equipment – filter separators, gas coolers, fuel gas system, pressure reduction systems etc.

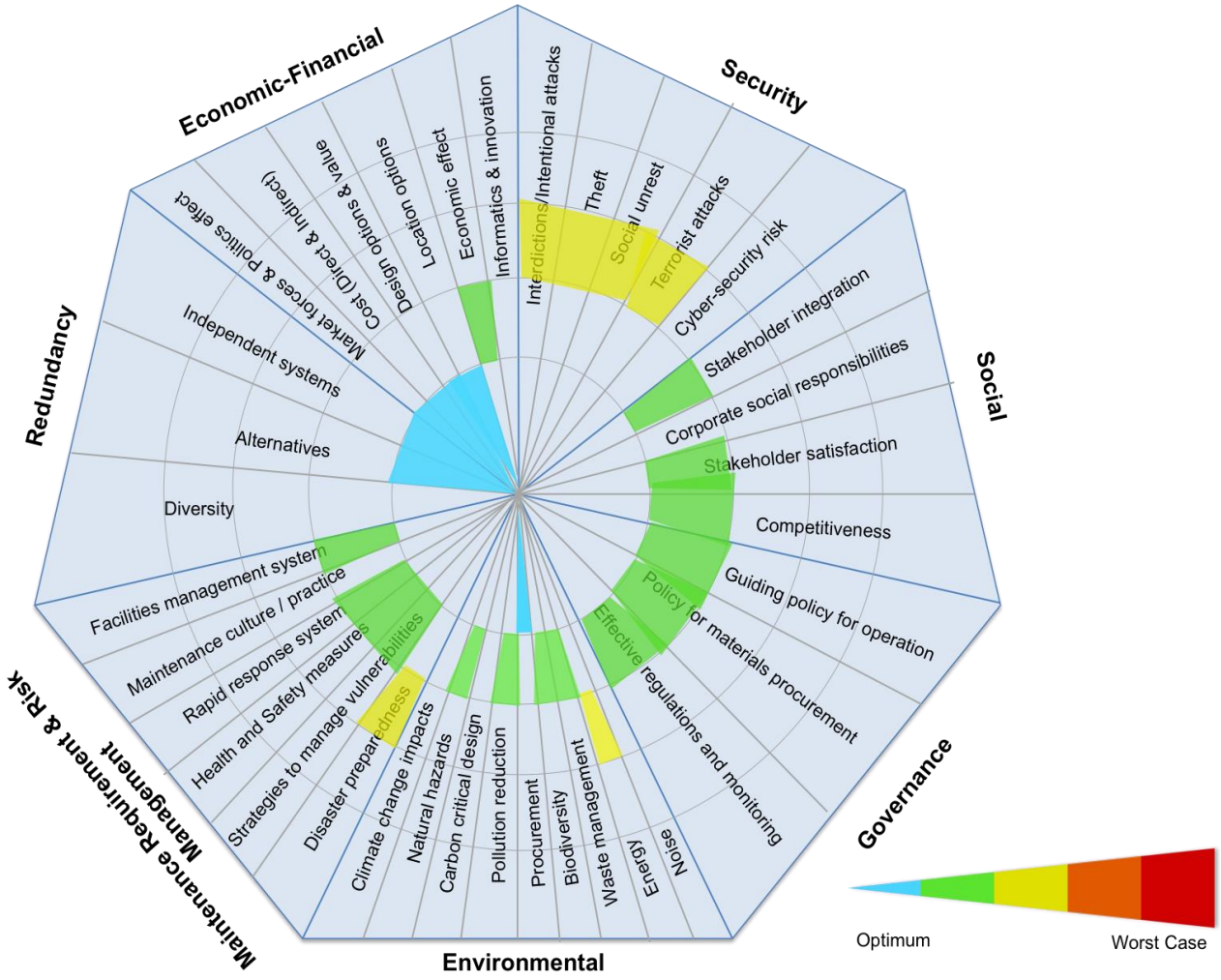


Figure 6.6: RESOGI Results for Case Study 2

6.5 Discussion and validation of Case Study Assessment Results

To road test the RESOGI assessment framework and evaluate the value it adds, an application of the framework to two downstream critical gas distribution infrastructure systems has been carried out. Gas distribution infrastructures operate in high-risk conditions and require high level of resilience. Case studies 1 and 2 were selected to assess the usefulness of the RESOGI towards improving the resilience and sustainability of DCOGIs. Case studies as described in chapter 3 are useful in investigating new ideas and theories within a real-life context, to clarify the boundaries between the idea and context using multiple sources of evidence (Bell, 2010). It is expected that through this road testing process the relevance of the hybrid indicators and the completeness of the framework will be reached, to achieve one of the key objectives of this study. The RESOGI aims to help decision making by identifying which hybrid indicator requires improving or is critical to achieve a sustainable and resilient DCOGI. To further validate the usefulness of the RESOGI, the case study results obtained above are compared with two other assessment frameworks simultaneously. The SPeAR® sustainability assessment framework and a resilience assessment framework (RAF) developed by Francis & Bekera (2014). The SPeAR® framework and application process has been discussed in chapter 2. Before presenting the case study results, the RAF is briefly presented in the next section.

6.5.1 Resilience Assessment Framework (RAF)

The RAF was developed specifically to enable the resilience analysis of engineered and infrastructure systems. According to Vugrin et al., (2011); Francis & Bekera, (2014) the RAF summarizes the diversity of factors and dimensions that have been linked to the concept of resilience into three capacities namely absorptive capacity ("The degree to which a system can absorb the impact of system perturbations and minimize consequences with little effort"), adaptive capacity ("The ability of a system to adjust to understand situations by undergoing some changes in response to adverse impacts") and restorative capacity (The rapidity of return to normal operations and system reliability). The framework consist of five components as follows (Vugrin et al., (2011); Francis & Bekera, (2014)):

1. System Identification: The process of understanding and identifying the characteristics of the infrastructure system e.g., spatial, physical.
2. Vulnerability Analysis: The process of determining the disruptive event of a system's normal functions.

3. Resilience Objective Settings: refers to the process of delegating a set of resilience actions based on the vulnerability analysis outcome.
4. Stakeholder Engagement: In this stage, relevant stakeholders come together to coordinate recovery strategy for the identified disruptions.
5. Resilience Capacities: Refers to solutions that are based on the three capacities described above.

Similar to other resilience frameworks, where attempts have been made to address resilience related issues particularly as it affects socio-ecological systems; important challenges and disagreements have not been addressed. The RAF fails to address issues that are external to an infrastructure system, it is mainly focused on technical issues yet little or no consideration to social-economic and environmental dimensions of an infrastructure system (Labaka et al., 2015). Another major gap with the RAF is that the resilience metric is only useful when a disruption occurs because the parameters are identified based on the system's performance level (Labaka et al., 2015,). The RAF can hardly assess the level of resilience improvement without the occurrence of a disruption. This implies that the RAF is reactive in approach to prevent disruptions in any critical infrastructure system, whereas the RESOGI framework supports a proactive approach. To further validate the efficacy of the RESOGI, the case study results from the RESOGI are compare with the results using the RAF and SPeAR® in the following section.

6.5.2: Case Study Results

Within the RESOGI, security is a highly weighted indicator (w = 0.35), between the case study 1 distribution infrastructure system and case study 2 distribution infrastructure system the RESOGI results show that security needs to be enhanced within the case study 1 distribution infrastructure system. Compared to case study 2 distribution infrastructure system where security is at the core with armed security personnel on constant patrol with aerial support and the alliance of the operators with the military to resist terrorist attacks. With the case study 2, the involvement of the indigenes in monitoring facilities through job creation and social support is a proactive approach to long-term stability for the business. Whereas security is explicitly addressed by the RESOGI with five sub-indictors based on stakeholder survey responses and literature review findings, and in fact a core indicator (highest weighting) of the RESOGI for DCOGI. Security is not addressed this way in the SPeAR® framework, security is only mentioned in the context of form and space and therefore the SPeAR® is deemed not suitable for assessing security aspects of DCOGI. A

holistic and proactive approach is encouraged by RESOGI, ensuring decision makers embed security measures from the design phase of development to during operations to avoid disruptions, it is mainly an external factor to the DCOGI apart from cyber security issues that could have internal dimensions and therefore the RAF is considered not suitable for assessing the security aspects of DCOGI. This is because the RAF is reactive and would only identify security lapses after an incident and is focused on internal technical issues only.

Redundancy (w = 0.22) is the second highest for the RESOGI, and therefore highly vital to achieving resilience and sustainability of DCOGIs. With case study 2 redundancy measures were taken very seriously and from the planning stage of the development. Design for dual pipeline routing and provision of multiple turbo compressor trains and booster compressors were efforts made to ensure continuous delivery of service in the event of a failure for example. With case study 1, there was only one pipeline route for distribution and the case study lacked sufficient information regarding other support facilities and redundancy measures. The score was based on available information. However, it was not possible to assess the resilience level of the case studies with the SPeAR® framework either at system-level, subsystem-level, and component-level. There are no considerations for redundancy of DCOGI systems within the SPeAR® framework, making SPeAR® unsuitable for assessing DCOGI. The RAF does not address redundancy explicitly and this is a vital indicator for DCOGI resilience. However, because it takes a reactive approach to decision making, it is possible that issues relating to redundancy are identified and addressed after a disruption would have occurred. For these reasons the RAF is deemed not fully suitable for assessment of DCOGIs.

The Social indicator has a weight (w = 0.20), for case study 2 the competitiveness indicator was optimum. This is because the distribution infrastructure system was strategically developed as the flagship, as the only system transporting gas product from the source. The pipeline has also been designed as the biggest gas distribution infrastructure system within the region, with embedded capacity to meet current high demands. However, the stakeholder integration and interconnection impact was scored 4 requiring a major improvement with this indicator. This is also evidence with high level of security issues and dispute with host communities. Case study 1 is scored 2 with the competitiveness indicator considering it has met its optimum service at the moment. The distribution infrastructure system was design to supply to sub-Saharan region and into Europe but at the moment this service is not being delivered. With stakeholder's integration and interconnection, measures were in place to liaise with stakeholders like government regulatory

agencies, consultations with the host communities, security services and emergency responders, hence the high score of 2. The SPeAR® tool does have the social dimension of sustainability but in the context of DCOGI, this only address the stakeholder integration and interconnection issues, other vital indicators relevant to DCOGI like competitiveness, product availability cannot be assessed using the SPeAR®. RAF also does not consider social related aspects of DCOGIs for assessment and is not suitable for use in these case studies.

The Governance indicator (w = 0.11) was considered for both infrastructure systems, for case study 2 was generally scored 2 in all its sub-indicators, which is a high score. This is because policies were adhered to with relevant standards and codes used when procuring equipment and materials for construction and operations. There were measures to ensure compliance to regulations and laws and regular compliance checks by regulators. For case study 1 this was slightly different because the information about guiding policy for operation was not available, procurement of equipment and materials were done in accordance with relevance standards and industry codes. Corporation for regulatory checks requires moderate improvement, which means the operators will have to liaise with DPR to ensure operations within legal standards. SPeAR® does address an aspect of governance as applicable to the case studies above, which is monitoring and evaluation as well as procurement partially. It fails to address other key indicators for the case studies above as applicable to DCOGIs in general. RAF is not explicitly designed to address issues relating to governance and is not suitable for assessing the above case studies.

For maintenance requirement and risk management (w = 0.04), case study 1 had adequate measures for facilities management – routine maintenance reporting, maintaining high reliability levels of the components of systems, plans for efficient repairs of failures or incorrectly functions components or system. Relevant standards for health and safety are in place, as well as strategy to manage vulnerabilities e.g., budgetary allocations are made for strategic alternatives, replacement equipment including open link with suppliers and embedded independent systems. Rapid response facilities are strategically positioned in the events of an incidence. For case study 2, most of the indicators required major improvements, suggesting the need for major improvement except the Health and safety measures that require moderate improvement. SPeAR® can assess facilities management indicator, operation and maintenance and whole-life-flexibility. If used in assessing the case studies, are assigned the similar scores relatively. Health and safety issues are addressed by SPeAR® as it considers the indicator from design, construction and operation that could utilize for assessing the case studies above. The RAF is not useful for addressing

maintenance requirement and risk management issues from design, construction to operations developmental phases of DCOGI.

6.6 Summary

As discussed in the methodology chapter, the purpose of the road-testing process is to demonstrate the application of the RESOGI framework to a case study and add real life context. The chapter has presented and demonstrated the process of applying the RESOGI framework to two case studies. It was anticipated that the outcome of the road test would assess the completeness, usefulness, and relevance of the RESOGI framework to DCOGI systems. Following this was the validation of the road test results aimed at further highlighting the efficacy of the RESOGI for assessing and improving sustainability and resilience of DCOGI systems, by attempting to assess the case studies with chosen assessment frameworks to compare the results. An attempt to validate the results of the case studies by assessing with SPeAR® and the RAF revealed that the RESOGI framework is best fit for assessing DCOGI systems specifically. Also, another key benefit of the RESOGI framework is the ease of use by any DCOGI stakeholder globally. Industry professionals were involved in the road-testing process, the assessors did not find any other aspects within the case study infrastructure system that could not be assessed by the RESOGI framework. Consequently, as there was no aspect that could not be assess within the case studies, the completeness of this framework is confirmed. Furthermore, during the case study assessments the assessors acknowledged that the RESOGI had prompted their considerations of broader aspects not commonly considered particularly the role of external players to DCOGI sustainability and resilience. Albeit this may vary with different DCOGI in different parts of the world. It is expected that further application of the RESOGI other DCOGIs may yield improvement opportunities or highlight limitations of the RESOGI. Nevertheless, the ability to assess the sustainability and resilience levels of the two case studies with the involvement of industry professionals also confirms the hybrid indicators and sub-indicators were relevant. The RESOGI framework can add value to DCOGIs and improve the sustainability and resilience levels of DCOGI systems.

CHAPTER 7: CONCLUSIONS

7.1 Introduction

Within the confines of the chosen research area, limitations exist with respect to the hybrid (integrated) assessment of critical infrastructures and more specifically DCOGI systems and proof of concept, coupled with the increasing global focus on achieving the energy trilemma and the need to satisfy the demands of the various stakeholders of DCOGIs. The integration of the concepts of sustainability and resilience and their subsequent use in decision-making is an emerging field, still at a relatively early stage. Also, several research findings report that too few empirical case studies on the implementation of both concepts in critical infrastructures exist. This research is a comprehensive advancement in the implementation of sustainability and resilience in critical infrastructures. The thesis has presented the methodology for the development of a novel and robust hybrid framework for assessing both sustainability and resilience of downstream critical oil and gas distribution infrastructure systems, the RESOGI (Resilient and Sustainable Oil and Gas Infrastructure). The research as a test of the hypothesis, attempts to resolve the debate between practitioners of whether sustainability and resilience could be assessed together or which should take prominence over the other, and goes further to proof that both concepts are better tackled and achieved together. The hybrid approach and the application to downstream critical oil and gas distribution infrastructures as a proof of concept, is the first of its kind, albeit different methods and approaches of evaluating sustainability and resilience distinctively exist. The hybrid assessment framework takes cue from a socio-ecological systems approach to evaluation, a nexus of sustainability science and resilience theory that constitutes a robust array of indicators, actors (internal and external) and dimensions; whereby the development of indicator criteria were validated and supported with empirical data from surveys. By obtaining baseline data from a range of stakeholders and expert knowledge, covering various downstream critical oil and gas distribution infrastructures; the empirical nature of the research aimed to achieve an assessment framework that does not reflect bias. The RESOGI presents a one-stop guide for achieving a sustainable and resilient DCOGI system. The outlook of the RESOGI has also been designed to make it user friendly with an illustrative appeal to all stakeholders, to make project planning, forecasting, decision-making and identification of areas of weakness and strength an easy task i.e., in relation to DCOGI. This research has shown the benefits for developing the RESOGI assessment framework, such as to facilitate strategic

decision-making that can add value and improve the quality of DCOGI system; DCOGI continuous delivery of service; and contribution to achieving energy security.

7.2 The Need for a DCOGI Assessment Framework

In the context of increasing disruptions to DCOGIs and energy security needs, this study identifies that the DCOGI industry requires a proactive sustainability and resilience strategy to remain in operation long term. Currently, there are numerous sustainability and resilience assessment tools that cover an array of civil engineering projects. Sustainability as a concept has been in existence for over three decades. Of the many sustainability frameworks that exist, the literature review reveals a shortfall, as none is applicable for the assessment of DCOGI (Yusuf et al., 2013; Lima et al., 2016; Ahmad et al., 2016; Martîsauskas et al., 2018; Roostaie et al. 2019). The literature review indicates that resilience has been a subject of discourse within the oil and gas industry in very recent times (BEIS, 2018). However, of the very few resilience assessment metrics for oil and gas infrastructures (shown in chapter 2), none of them holistically considers DCOGI specifically and its sustainability dimensions. As discussed in chapter 2 of the thesis, existing resilience assessment metrics either considers individual aspects and dimensions of resilience with regards to DCOGI e.g., technical or engineering resilience; or the lack of comprehensive indicator sets fully applicable to DCOGIs. Moreover, the literature also reveals the need for empirical and case studies, and quantitative approach to the implementation of sustainability and resilience in DCOGI specifically (Yusuf et al., 2013; Lima et al., 2016; Labaka et al., 2016). This research presents advancement in the implementation and improvement of sustainability and resilience in DCOGI specifically, by developing the RESOGI, based on theoretical and empirical findings and expert knowledge. The surveys involving industry practitioners conducted during this research also reveals no indication that an established sustainability and resilience assessment tool exist amongst practitioners in the DCOGI industry. Existing industry procedures (e.g., downtime monitoring) are deemed for improvement in line with changing realities. The RESOGI aims to provide DCOGI stakeholders with a tool to improve the sustainability and resilience levels of DCOGI, to detect improvement opportunities and to project future actions or policies to enhance DCOGI systems.

In a recent study and consultation carried out by the Energy Resilience and Emergency Response unit of the UK Department of Business, Energy and Industrial Strategy, the lack of industry-wide holistic resilience assessment framework for the downstream oil and gas industry was widely

acknowledged (BEIS Report, 2018). A gap within the legislative framework abounding the industry was also highlighted. Current procedures that exist (e.g., downtime monitoring) are mainly reactive, where measures only come in place after a disruptive event has occurred. As such, this presents a shortfall both within the literature and in practice. The consultation called for inputs in the areas of monitoring, protection and insurance as follows:

- Monitoring – "to enable BEIS to collect information from the downstream oil sector to better understand the impact of potential disruptive events, and to use the information to support industry in improving fuel resilience" (BEIS Report, 2018).
- Protection – "to align this sector with protections that apply in other critical service sectors, by enabling Government to ensure that new owners of critical fuel infrastructure are financially sound and operationally capable; and to take a Government spending power to enable Government to support supply resilience improvements and schemes" (BEIS Report, 2018).
- Insurance – "to enable industry to create and operate collective, sector-wide industry-led schemes to maintain fuel supply in case normal supply arrangements are seriously disrupted; and a power to direct individual companies to participate in such schemes and take other action that may be necessary to ensure resilience" (BEIS Report, 2018).

This does not however provide a comprehensive and integrative assessment currently required to achieve sustainability and resilience of DCOGIs.

7.3 Summary of Overall Findings

It is possible to draw the following findings and contributions from the research:

Chapter 2 - The critical review of the current state-of-the art, as presented in chapter 2, introduces the current understanding of energy security issues, and explores the roles of oil and gas to the society globally. The chapter then draws light on key related subject areas vital to the energy industry such as, governance, infrastructures, redundancy, environment and societal effect, critical infrastructures and asset management and the interdependencies. Chapter 2 presents the literature review of factors and impacts that affect the DCOGI industry. The chapter also introduces an overview of comprehensive approaches to assessing sustainability and resilience to establish their application to DCOGI. It features existing sustainability and resilience assessment frameworks with foci for an application to DCOGI systems. Chapter 2 points to the fact that at present there is a knowledge gap with regards to an integrated sustainability and resilience

assessment framework for DCOGI. It is established that to address the shortfall, it is necessary to investigate required parameters and ascertain the meaning in the context of DCOGI using existing assessment frameworks. Conclusions from this chapter sets the approach and methodology required to meet the aim and objectives of the study (e.g., by identifying the Top-Down and Bottom-Up approaches to indicator development), it presents the preliminary hybrid indicator aspects and dimensions relevant for assessing DCOGI as a preliminary step for development of the RESOGI and interpretations of sustainability and resilience in the context of DCOGI.

In chapter 4, it was possible to carry out the initial hybrid indicator selection process. The SPeAR® assessment framework was selected as the most appropriate tool used as a baseline provided a comprehensive list of generic indicators, to guide and inform indicator selection process in a Top-Down approach involving expert opinion. This enabled the development of a conceptual framework of hybrid indicators selected for DCOGI assessment. It was possible to construct the narratives for the hybrid indicators specifically for DCOGI. The relevance of each indicator was considered against relevant criteria during a review process involving an engineering sustainability expert, as also suggested by the SPeAR®. The resulting conceptual RESOGI assessment framework consists of seven headline hybrid indicators and 36 sub-hybrid indicators (Table 4.4), integrating the dimensions of and actors for achieving sustainability and resilience of DCOGI. The outcome of this chapter set the stage to further validate the developed conceptual framework through the surveys with experts and other key stakeholders of DCOGI industry.

Chapter 5 - The survey process was largely involved in this chapter, where it was deemed necessary to canvass stakeholder's opinion to determine the significance, weightings and criticality of each headline and sub-indicator for the proposed RESOGI as well as to validate preliminary findings from literature review. Opinion canvassed confirmed diverging perception and interpretation of sustainability and resilience amongst stakeholders. It was largely agreed that both concepts are best assessed together and combing them in indicator sets was a practical approach. The survey also validated all the indicator sets identified from the literature review, and contributions were made to the underlying narratives for each sub-indicator. The interviews and focus groups responses help recognize key factors relevant to achieving sustainability and resilience with the DCOGI industry e.g., communication problems between governments agencies – infrastructure owners - end-user, security, lack of sincerity of purpose, poor

governance, ageing legacy facilities etc. However, sub-indicators like cyber security risk and noise were considered of least significance to sustainability and resilience of DCOGI despite being topical aspects of critical infrastructure security and societal well-being. As well as facilitating empirical findings, the survey also enabled a quantitative approach that provided weightings for the developed RESOGI hybrid indicators. The results of derived weightings for headline and sub-indicators show stakeholders suggested that security was of more weight with w = 0.35399, and the alternatives (multiple distribution routes) w = 0.66076 was suggested as highest weight respectively. In addition, a criticality table of 6 vital DCOGI was developed. The criticality table identifies risk and impact levels of each of the sub-indicators associated to the six vital DCOGI. which is a vital finding of this research. With this, it is possible to carry out a correlation analysis between the DCOGIs that is capable of informing decision-making.

Chapter 6 - In this chapter, two case studies based on gas distribution infrastructure systems were assessed using the RESOGI assessment framework. The road testing was carried out with a panel of industry practitioners. The case study application allowed for assessing the relevance, completeness, and usefulness of the RESOGI to real life DCOGI. Case study two had a higher resilience level than case study one, although both case studies presented several improvement opportunities. Indicators for improvement for case study one was disaster preparedness, alternative (multiple distribution routes), social unrest and community disputes and security against intentional attacks. Prior to the road-testing process, the management approach was mainly based on risk management and trade-offs are made for cost considerations. Disaster preparedness was mainly viewed from internal crisis like fire incidents and did not consider external crisis from e.g., natural disasters are not considered. The second case study had lesser areas for improvement, in all indicators in the security group required improvements. The application of the RESOGI framework allowed the practitioners involved to recognize the areas of weakness giving a broad picture of what needs improving. The road-testing implementation process also derived the relevant DCOGI development cycle phases most applicable to the RESOGI indicators, although the RESOGI allows for flexibility of use. A validation process was carried out with the RAF to further demonstrate the usefulness of the RESOGI; it was impossible to fully assess both case studies with the RAF. Generally, in both case studies, it was observed that more effort was concentrated on internal factors and dimensions of sustainability and resilience. It was not possible to judge if this was the case globally or isolated to the two case studies, recommendations were made for this aspect to be improved. The practitioners, who are all experts in the DCOGI industry, judge the RESOGI framework to be relevant, complete, and

useful to the industry. Based on the outline in sections 8.1 and 8.2, it can be concluded that the aim and objectives of this research work as stated in chapter 1 of this thesis has been addressed with the development of the RESOGI assessment framework.

7.4 Potential End-users and Framework Transferability

Taking everything into account, it is necessary to outline the advantages of the research. The RESOGI assessment framework is designed to be applicable to DCOGIs globally by a host of end-users that include:

- Government policy makers, planners, and regulators
- Non-governmental organisations and interest groups
- Decision makers in the downstream oil and gas industry
- Insurance companies
- Civil and construction engineering companies

and thus, it presents indicator sets for all dimensions of sustainability and resilience. To achieve this, the hybrid indicators were selected with a global context in view. The research process reflects this. The survey participants considered global context in their responses, and participants included individuals across the globe. Furthermore, to ensure global applicability of the RESOGI assessment framework, efforts were made to road test the RESOGI assessment framework with case studies across the globe. The framework implementation model developed, supports the universal and typical flow steps of DCOGI project life cycle. The methodology used in this research to develop the integrated sustainability and resilience assessment framework for DCOGI is considered adaptable and transferable to other critical infrastructure domains.

7.5 Research challenges

Some challenges were encountered during the research and this was not limited to the inter-displinary nature of the research. The exploration of new approaches to research comes with challenges of developing a methodology involving disparate methods of investigation. Harmonizing these methods in theory and in practice was quite time consuming with several meetings with supervisors, experts, colleagues to ensure coherence and consistency in the research approach. Delving into different discipline of study requiring consultation with statistician, social scientist particularly when developing the interview questionnaires and selection of method for analysis required much mental elasticity, of which some of what was

learnt may not have been utilised during the study. Embarking on the field study to conduct interviews and case study data created much burden and took far longer than planned. Access to chosen government agencies and industry personnel proofed very difficult and costly, with numerous disappointing encounters to mention a few. The amount of data obtained and the need to streamline the scope and methods used was mainly dictated by timeline of the thesis. Nevertheless, this did not impair the robustness of the research. The amount of time spent with experts, academics, and industry personnel yielded fruitful exchanges.

7.6 Recommendation for future work

To further improve the completeness, usefulness and relevance of the framework to stakeholders and decision makers, the following is recommended for future study:

- Further application of the RESOGI tool to different case studies could be carried out and feedback from new users could be used to update the indicators and their weightings. This could yield an opportunity to modify the framework by applying more real-world examples and obtaining feedback from users with different experiences and needs, and ultimately enforcing more empirical studies currently lacking in this area of research.

- The implementation of frameworks like this would inevitably involve a degree of trade-off. An exploration of trade-offs is beyond the scope of this study; the use of trade-off between indicators could be explored in future. This could be incorporated into the RESOGI tool for scoring and ranking the indicators and could allow a wider range of benefits from this framework.

- The framework may require more in-depth quantitative methodology for implementing the hybrid indicators (e.g., for direct and in-direct costing considerations) and for precisely estimating the sustainability and resilience levels of DCOGI. Given this limitation, future research should include the development of more quantitative methodology.

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APPENDICES

Appendix 1. Survey Questionnaire

Interview Questions 1

Dear Sir/Madam,

SUSTAINABILITY AND RESILIENCE INDICATORS AND NECESSARY CONDITIONS, WEIGHTS AND IMPACT RANKING.

This survey is part of a PhD study whose case studies will be conducted in and around UK and Nigeria. The purpose of the study is to develop approaches for assessing sustainability and resilience of downstream critical oil and gas distribution infrastructures, that consider all indicators/necessary conditions e.g., Technical, Socio-Economic, Environmental, and political impacts.
The questions are designed to enable the researcher obtain opinion on assessing sustainability and resilience, identify risks, impacts as well as existing and prospective mitigation strategies and to rank weights for indicators and necessary conditions based on the impacts on sustainability and resilience of downstream critical oil and gas distribution infrastructures. It is in that respect that I kindly request you to provide your opinion on the aforementioned aspects. Please if you feel that some useful concern has been left out of the questionnaire, the interviewer will be happy to record your comments.

It is worthy to note that the outcome of this research could be of benefit to you/your organization. Participation in this survey is voluntary and the researcher will do everything possible to ensure participants identity remain anonymous, but general information is required to enable the researcher to organize the data more logically and more usefully.

If you have any concerns or questions about this questionnaire, please feel free to contact the researcher, Dianabasi Akpan on +447532356500 or [redacted]

The following themes used in the questionnaire are briefly described:

INDICATORS – Refers to the sustainability and resilience indicators adapted for this research e.g., Social, Environmental, and Economic-Financial sustainability indicator.

RESILIENCE – Refers to the existence of four strategic components (i.e., adaptability, reliability, resistance, response & recovery), aiming to ensure continuous delivery of service in the face of short-term shocks and disruptions.

NECESSARY CONDITIONS – Refers to the requirements to achieve sustainability and resilience, proposed for this research e.g., Security, Governance, Maintenance Requirement & Risk Management, and Redundancy.

DOWNSTREAM – Refers to the distribution and marketing sectors of the oil and gas industry i.e., storage, transport of oil and gas to refineries and processing plants as well as storage, transport of refined and processed products.

SECTION ONE: Personal data

Which of the following best describes your status (Tick)

Government agency staff [] Oil/Gas industry staff [] Construction/Infrastructure industry worker []
Interest group member / NGO [] Planner [] Engineer [] Other (Please specify) []

Please state your organization –
What is your role in the organization? -
Please state your duration on the role –

SECTION TWO

The following questions are about your opinion on sustainability and resilience relating to downstream critical oil and gas distribution systems specifically. (Considering case studies in UK and Nigeria)

(1) Are you familiar with the concept of resilience in the context of downstream critical oil and gas distribution systems? YES [] NO []
If is **yes**, please briefly describe your understanding?

(2) Do you think resilience and sustainability are related issues? YES [] NO [ ]
Please state any further comments

(3) Do you think resilience could (and should) be integrated into assessment tools as an indicator or rating codes? YES [] NO []
Please state any further comments

(4) Do you think resilience is a familiar concept in the planning, design, development and operation of downstream critical oil and gas infrastructures? YES [] NO [ ]
If yes, please how do you think it is currently interpreted?

(5) Which of the following do you think describes the current notion of resilience for downstream critical oil and gas infrastructures? (Please indicate if more than one)
Longevity/Flexibility of Physical Structure []. Uninterrupted Distribution of Oil or Gas and their products [].
Adequate Organizational/Management system []. Economic Competitiveness of Infrastructure Owner []. Others [].
Please state any further comments

(6) Achieving sustainability and resilience of downstream critical oil and gas infrastructures requires the collaboration of every stakeholder including end users and host community indigenes. Strongly Agree [] Agree [] Disagree [] Strongly disagree [ ]
Please state any further comments

(7) In your view, what factors are most capable of disrupting the operations of downstream critical oil and gas infrastructure systems?

(8) In your view, what measures can be put in place to prevent disruptions of downstream critical oil and gas infrastructures?

(9) Based on your experience, please state potential vulnerable components/factors that are capable of causing disruptions to the operation of downstream oil and gas distribution systems.

(10) Based on your answer above, please state how disruptions of critical oil and gas distribution infrastructures are currently prevented and mitigation strategies if any.

(11) Briefly state the role host communities can play to ensure oil and gas infrastructure safety and energy security?

(12) In your view, do you think cost considerations by infrastructure owners can influence the achievability of sustainability goals or resilience of downstream critical oil and gas infrastructures? Very likely [ ] likely [ ] Not sure [ ] Unlikely [ ]
Please state any further comments

(13) Do you think the nature of resilience changes depending on the scale of infrastructure? Very likely [ ] likely [ ] Not sure [ ] Unlikely [ ]

(14) Please state, if any, known ways of assessing sustainability and resilience of downstream critical oil and gas distribution systems.

(15) How would you rate the current methods of assessing sustainability and resilience of downstream oil and gas distribution systems?
Excellent [ ] Good [ ] Fair [ ] Poor [ ]
Please state any further comments

(16) In your view, is the application of a set of principles or guidelines useful in achieving long-term effectiveness of sustainability and resilience that can inform the operation of oil/gas infrastructures? YES [ ] NO [ ]
Please state any further comments

(17) In your view, do you think a value based/quantitative approach (e.g. establishing performances of the infrastructure that should be sustained over the life time of the service delivery), is rather useful in achieving the long-term effectiveness of sustainability and resilience. YES [ ] NO [ ]
Please state any further comments

SECTION THREE: **Scoring the different indicators / necessary conditions (NC):**

From your experience, please rate the significance of the following indicators/necessary conditions to achieving sustainability and resilience of downstream critical oil and gas infrastructures. (Considering oil and gas infrastructures in both developing and developed countries)

Core Indicator/NC	**Sub Indicator/NC**	Rate each on a scale of 1 (very low) to 4 (very high), please tick a box on each row below			
		VL ←----------→ VH			
		1	2	3	4
Security	Interdictions/Intentional attacks				
	Theft				
	Social unrest/community disputes				
	Terrorist attacks				
	Cyber-security risks				
Governance	Guiding policy for operation				
	Guiding policy for materials procurement				
	Effective regulations and monitoring				

Maintenance Requirement & Risk Management	Facilities management system				
	Maintenance culture/practice				
	Rapid response system				
	Health and Safety measures				
	Strategies to manage vulnerabilities from interdependencies				
	Disaster preparedness				
Economic-Financial	Market forces & Politics effect				
	Cost (Direct & Indirect)				
	Design options & value				
	Location options				
	Economic effect				
	Informatics & innovation				
Environment	Climate change impacts				
	Natural hazards				
	Carbon critical design/low carbon emissions				
	Pollution reduction/mitigation strategy				
	Procurement/materials sourcing				
	Biodiversity				
	Waste management				
	Energy				
	Noise				
Social	Stakeholder/end-user integration & interconnection				
	Corporate social responsibilities				
	Stakeholder satisfaction/product availability				
	Competitiveness				
Redundancy	Alternatives (multiple distribution routes)				
	Independent systems				
	Diversity (renewables)				

SECTION FOUR: **Indicators / necessary conditions (NC) Weights:**

With respect to achieving sustainability and resilience of downstream critical oil and gas infrastructures, based on your experience what is the relative importance of the indicators/NC on the left to the indicators/NC on the right of the table using the scale in the middle.

Indicators/necessary conditions	9= **extremely important**; 7= **very strongly important**; 5= **moderately important**; 3= **slightly important**; 1= **equally important**; 1/3= **slightly not important**; 1/5= **moderately not important**; 1/7= **very strongly not important**; 1/9= **extremely not important**. **Please circle one option on each row below.**									Indicators/necessary conditions
SECURITY	9	7	5	3	1	1/3	1/5	1/7	1/9	GOVERNANCE
SECURITY	9	7	5	3	1	1/3	1/5	1/7	1/9	MAINTENANCE REQUIREMENTS & RISK MANANGEMNT
SECURITY	9	7	5	3	1	1/3	1/5	1/7	1/9	ECONOMIC-FINANCIAL
SECURITY	9	7	5	3	1	1/3	1/5	1/7	1/9	ENVIRONMENT
SECURITY	9	7	5	3	1	1/3	1/5	1/7	1/9	SOCIAL
SECURITY	9	7	5	3	1	1/3	1/5	1/7	1/9	REDUNDANCY
GOVERNANCE	9	7	5	3	1	1/3	1/5	1/7	1/9	MAINTENANCE REQUIREMENTS & RISK MANANGEMNT
GOVERNANCE	9	7	5	3	1	1/3	1/5	1/7	1/9	ECONOMIC-FINANCIAL
GOVERNANCE	9	7	5	3	1	1/3	1/5	1/7	1/9	ENVIRONMENT
GOVERNANCE	9	7	5	3	1	1/3	1/5	1/7	1/9	SOCIAL
GOVERNANCE	9	7	5	3	1	1/3	1/5	1/7	1/9	REDUNDANCY
MAINTENANCE REQUIREMENTS & RISK MANANGEMNT	9	7	5	3	1	1/3	1/5	1/7	1/9	ECONOMIC-FINANCIAL
MAINTENANCE REQUIREMENTS & RISK MANANGEMNT	9	7	5	3	1	1/3	1/5	1/7	1/9	ENVIRONMENT
MAINTENANCE REQUIREMENTS & RISK MANANGEMNT	9	7	5	3	1	1/3	1/5	1/7	1/9	SOCIAL
MAINTENANCE REQUIREMENTS & RISK MANANGEMNT	9	7	5	3	1	1/3	1/5	1/7	1/9	REDUNDANCY
ECONOMIC-FINANCIAL	9	7	5	3	1	1/3	1/5	1/7	1/9	ENVIRONMENT
ECONOMIC-FINANCIAL	9	7	5	3	1	1/3	1/5	1/7	1/9	SOCIAL
ECONOMIC-FINANCIAL	9	7	5	3	1	1/3	1/5	1/7	1/9	REDUNDANCY
ENVIRONMENT	9	7	5	3	1	1/3	1/5	1/7	1/9	SOCIAL
ENVIRONMENT	9	7	5	3	1	1/3	1/5	1/7	1/9	REDUNDANCY
SOCIAL	9	7	5	3	1	1/3	1/5	1/7	1/9	REDUNDANCY

SECTION FIVE: **Impact ranking:**

Based on your experience, with respect to the various downstream oil and gas distribution infrastructures please rate the impact of each indicator/NC on sustainability and resilience. (Considering oil and gas infrastructures in both developing and developed countries)

	Please rate using the scale of **0=no risk, 1=low risk**, **3=intermediate risk, 5=high risk**					
	PIPELINE	**STORAGE FACILITIES**	**ROAD TANKERS**	**BARGES/SHIPS**	**RAIL TANKERS**	**DISTRIBUTION NODES OR SYSTEM**
Security						
Interdictions/Intentional attacks						
Theft						
Social unrest/community disputes						
Terrorist attacks						
Cyber-security risks						
Governance						
Guiding policy for operation						
Guiding policy for materials procurement						
Effective regulations and monitoring						
Maintenance Requirement & Risk Management						
Facilities management system						
Maintenance culture/practice						
Rapid response system						
Health and Safety measures						
Strategies to manage vulnerabilities from interdependencies						
Disaster preparedness						
Economic-Financial						
Market forces & Politics effect						
Cost (Direct & Indirect)						
Design options & value						
Location options						
Economic effect						
Informatics & innovation						
Environment						
Climate change impacts						

Natural hazards						
Carbon critical design/low carbon emissions						
Pollution reduction/mitigation strategy						
Procurement/materials sourcing						
Biodiversity						
Waste management						
Energy						
Noise						
Social						
Stakeholder/end-user integration & interconnection						
Corporate social responsibilities						
Stakeholder satisfaction/product availability						
Competitiveness						
Redundancy						
Alternatives (multiple distribution routes)						
Independent systems						
Diversity (renewables)						

Please feel free to state any more indicators or necessary conditions and further comments you may like to add, in support of your answers above.

The researcher would like to contact you again, would you like a follow up? Yes [] No [ ]

Thank you very much for making out valuable time to partake in this survey!

Interview Questions 2

Dear Sir/Madam,

SUSTAINABILITY AND RESILIENCE INDICATORS AND NECESSARY CONDITIONS

This survey is part of a PhD study whose case studies will be conducted in and around Nigeria and the UK. The purpose of the study is to develop approaches for assessing sustainability and resilience of critical downstream oil and gas distribution infrastructures, that consider all indicators/necessary conditions e.g., Technical, Socio-Economic, Environmental, and political impacts.

The questions are also designed to enable the researcher to identify barriers to the integration of, and communication between host communities, infrastructure owners and government regarding security of oil and gas infrastructures, and to seek your suggestions for improvement. It is in that respect that I kindly request you to provide your opinion on the aforementioned aspects.

Please if you feel that some useful concern has been left out of the questionnaire, the interviewer will be happy to record your comments.

It is worthy to note that the outcome of this research could be of benefit to you/your community. Participation in this survey is voluntary and the researcher will do everything possible to ensure participants identity remain anonymous, but general information is required to enable the researcher to organize the data more logically and more usefully.

If you have any concerns or questions about this questionnaire, please feel free to contact the researcher, Dianabasi Akpan on +447532356500 or [redacted]

PARTICIPANTS QUESTIONNAIRE

SECTION ONE: Personal Data

Q1. Please select your age group: - 18-20[ ] 21-30[ ] 31-40[ ] 41-50[ ] 51-60[ ] 61-70[ ]

Q2. Please select your gender: - I am male [ ] I am Female [ ]

Q3. Please state your occupation –

Q4. How long have you lived in your community? –

Q5. What is your highest level of education: - No formal education [ ] Primary school [ ] Secondary school [ ] Tertiary [ ] Higher degree [ ]

SECTION TWO

Answer the question below using the following scale. (3=strongly agree; 2=agree; 1=disagree; 0=strongly disagree)

I feel that the community through its leaders is properly informed about the activities/operation of the oil and gas pipelines/infrastructure owners from inception. [ ]

I feel there is harmony between the community, the government, and the oil or gas pipelines /infrastructure owners. [ ]

I feel it is the Government's responsibility to liaise with the oil or gas pipelines/infrastructure owners in protecting community's interest. [ ]

I believe more can be done to ensure effective communication between the community, the government, and the oil or gas infrastructure owners? [ ]

Please suggest solutions to improve communication.

I am happy with the location of the oil or gas pipelines/infrastructure in my community. [ ]

I feel a sense of ownership of the oil or gas pipelines/infrastructure in my community. [ ]

I am committed to ensuring the protection of the oil or gas pipelines /infrastructure in the community. [ ]

The benefit of the oil or gas pipelines/infrastructure in my community to my welfare out-weighs the detriment. [ ]

I am concerned about the impacts from the operation of the oil or gas pipeline /infrastructure in my community on **ANY** or **ALL** the following:

ECONOMIC ACTIVITIES [] SOCIAL WELFARE [] ENVIRONMENT [] NATURAL RESOURCES []

Please specify and give details.

The following aspect of my community could be impacted most by the construction of new oil or gas pipelines/infrastructures in my community:
THE ECONOMY [] NATURAL RESOURCES [] ENVIRONMENT [] SOCIETAL WELLBEING []

Please write in the box below any further comments you may like to add, in support of your answers above.

The researcher would like to contact you again, would you like a follow up? YES [ ] NO[ ]

Thank you very much for making out valuable time to partake in this survey!