Identifying uncertainties in the development of Oil Sands in Nigeria: An exploratory SD Model

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Abstract:

The rapid increase in attention and interests in unconventional resources have been attributed to their vast occurrences across the globe; the dwindling reserves of conventional resources, and improvements in technology making their extraction more profitable. The occurrence of oil sands in Nigeria has been known for close to a century with estimated reserves of about 43 billion barrels of recoverable crude oil. This resource however is still not commercially developed despite several attempts made by the government. It is therefore presumed that there are myriad of uncertainties surrounding this development as is the case with fossil fuel resources especially unconventional like oil sands. The uncertainties may be due to certain factors including technological, environmental and political.

In this exploratory study, firstly these uncertainties associated with the development of oil sands in Nigeria are identified and categorized. Secondly, the system dynamics approach is employed to explore cause-and-effect relationships among the uncertainties in relation to oil sands development.

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***Key Words**: Uncertainties, Oil (Tar) Sands, Nigeria, System dynamics, causal loop diagram, exploratory study*

1. Introduction

Energy is the underpinning of all aspects of our "Global Economy" (Hall *et al.*, 1986; Bassi *et al.*, 2010); it is also central to crucial world issues such as climate change, food security, international trade and economics, national security and geopolitics (Ate and Nwoke, 1998; Smil, 2003 and Odell, 2004). Without adequate actions aimed at maintaining energy availability, the well-being of our increasingly urbanized, industrialized and growing world population faces the prospects of a number of severe concerns such as; reduced standard of living, declining access to food (Pimentel, 2008) and clean water supplies (Gleick *et al.*, 2006), and the contraction of global trade and GDP (IPCC, 2007a,b,c). A nation that can competently tackle its energy development concerns, and equally manage essential global energy resources is bound to play a prominent role in international markets (Odell, 2004; IEA, 2010).

Nigeria as a nation can be referred to as "energy rich" because of the presence of several mineral resources widely distributed in various states of the nation; this is aside her crude oil which is responsible for about 95 percent of her foreign earnings (Sambo, 2009; Mbasuen & Darton, 2012b). However, the country still faces difficulties in tackling her energy demand issues, coupled with the fear of dwindling crude oil reserves (Oketola, 2014). Besides, it has been put forward that unconventional hydrocarbon resources especially Oil Sands (OS) have the potentials to generate more royalty and tax revenues for the Nigerian government, as well as cost reduction and foreign exchange reservation on a long-term basis (Adedimula, 2000; Ayodele, 2011; and Falebita, 2014).

The desire to increase foreign earnings, spread out energy sources as well as diversify the economy through the development of other energy sources, spurred the attention on the Nigerian OS, especially with its various applications in several industries. In addition, other potential benefits include increased foreign earnings for the nation, reduction of importation of bitumen, asphalt and other derivatives of OS; in addition to increase in oil reserves of the nation to combat the fear and challenge of dwindling conventional oil reserves.

Yet the energy system is a very dynamic system and its developments such as that of the OS are bedevilled by myriad of uncertainties such as technological, resource, political, and environmental. This study is therefore aimed at developing capabilities for identifying the uncertainties associated with the development of OS in Nigeria with the aid of system dynamics methodology. The paper is consequently structured as follows: first we attempt to introduce OS, its occurrence and associated uncertainties; and then the definition of uncertainty; followed by techniques for identifying uncertainties and the SD approach to uncertainties. Lastly we present the findings and conclusions.

2. Oil Sands: Availability and Usefulness, Economy, Uncertainty in its Development

Oil sands is a naturally occurring mixture of sand, clay or other minerals, water and bitumen, which is heavy and extremely viscous oil that requires treatment before it can be extracted and put to use by refineries for the production of usable fuels such as gasoline and diesel. Bitumen is soluble organic matter derived from degradation of oil either as seeps that come to surface or within shallow subsurface reservoirs (EMD Report, 2013) Bitumen is so viscous that at room temperature it behaves like cold molasses. A variety of treatment methods are currently available to OS producers and new methods are put into practice as more research is completed and new technology is developed (EMD Report, 2013; Alberta Energy, 2014a). Over the last twenty years, the increase in non-conventional oils has contributed largely to the renewal and increase seen in global reserves (World Energy Council, 2013).

OS resources are found in various nations across the globe including Venezuela, US, Russia, former Soviet Union, Cuba, Indonesia, Brazil, Trinidad and Tobago, Jordan, Madagascar, Colombia, Albania, Romania, Spain, Portugal, Nigeria and Argentina (Isaacs, 2011; Alberta Energy, 2014b); with the major deposits in Canada and Venezuela.

Canada: The Athabasca deposit in Alberta is the largest commercial deposit, most developed and makes use of the most advanced technological processes for production. Alberta’s oil reserves play a vital role in the Canadian and global economy, through providing steady, dependable energy to the world. The OS of Alberta have been described as "Canada's greatest buried energy treasure" (Alberta Energy, 2014a). In terms of proven reserves, Alberta OS contains proven crude oil reserves of about 173 billion barrels (bbl) making it the third-largest proven crude oil reserve in the world (**Table 1**) subsequent to Saudi Arabia and

Venezuela; 97 percent (168 bbl) of those reserves recoverable with today's technology are in the OS (World Energy Council, 2013).

Total investment in Alberta OS projects should be greater than $514 billion; generating revenues more than $2,484 billion (2013 Canadian dollars). Each dollar put in the OS creates about $8 worth of economic activity; where 25 percent of that economic value is produced outside Alberta that is in Canada, US and around the world (Alberta Energy, 2014b; CERI, 2014). Projected revenues for federal and provincial government on inflation-adjustment basis; from OS-related investment is $79.4 billion between 2012 and 2035 (Conference Board of Canada Report, 2012).

In addition to all these benefits that are being derived from Canadian oil sands, others are (CERI, 2014);

1. Employment and job creation of about 121, 500 Albertans are employed in Alberta's mining, and oil and gas industries;
2. Huge federal and provincial revenues through taxes amounting to about $574 billion and $302 billion (2013 Canadian dollars) respectively, and through
3. Carbon capture Storage, (CCS is a technology that can be used in a number of industries to reduce CO_2 emissions) carbon emissions have been reduced to between 26 and 50 percent per barrel since 1990 (Alberta Energy, 2014b).

Venezuela: The oil resource base of this country is very enormous, with remarkable increase from proven reserves estimates of around 99.4 bbl in 2009 to about 211bbl in 2011; and then to an approximate value of 298.4 bbl as of 2014. The recent estimates dwarfs that of Canada; making it presently the largest in the world and the increase has been traced to massive reserves inclusion from Orinoco's OS deposits. Hence, she currently represents the principal contributor (**Table 1**) to OPEC oil (Oil and Gas Journal, 2013; World Energy Council, 2013; and OPEC, 2014). As at 2009 Venezuela produced over half a million barrels of oil per day from four OS development projects: Petroanzoategui, Petromonagas, Petrocedeno and Petropiar (Energy Information Administration, 2009a).

At least 10 percent of the annual investment in these deposits goes into social programmes such as the provision of free health care, discounted food for poor neighbourhoods, job creation programmes, education, and indigenous land-tilling and discounted oil prices for exports to neighbouring Caribbean countries (Alvarez and Hanson, 2009).

The exploitation of OS in Canada and Venezuela OS (168 bbl and 220 bbl of reserves respectively; details in **Table 1**) have contributed very extensively to available reserves in these two countries by an increase of a factor of four since the 1990s. Venezuela leads the world in terms of oil reserves, followed by Saudi Arabia and Canada (World Energy Council, 2013 and OPEC, 2014). This however is not to say that these developments do not have their downsides such as environmental impacts on water, land, and air among others; contributing to existing uncertainties as well as creating new ones.

Table 1: Contributory Oil reserves in billion barrels (bbl)

(Source: Modified after Oil and Gas Journal, 2013, and OPEC, 2014).

Countries	*Proven Crude Oil reserves (bbl)*	*Percentage (%)*	*Notes*
Venezuela	298.4	24.7	220 bbl is from OS
Saudi Arabia	265.8	22.0	
***Canada**	173.0	Not Applicable	168 bbl is from OS
IR Iran	157.8	13.1	
Iraq	144.2	12.0	
Kuwait	101.5	8.4	
UAE	97.8	8.1	
Libya	48.4	4.0	
Nigeria	37.1	3.1	Presently no contribution from OS
Qatar	25.2	2.1	
Algeria	12.2	1.0	
Angola	9.0	0.7	
Ecuador	8.8	0.7	

***Canada is a Non-OPEC Country**

Nigeria

Nigeria presently has the second largest proved oil reserves in Africa with about 37.1 bbl (from her conventional crude) after Libya (World Energy Council, 2013 and OPEC, 2014; see **Table 1** for details). According to existing sources the country has about 43 billion barrels of recoverable crude oil within the coastal region of Ondo State (Geological Consultancy Unit (GCU), 1980), and probably twice this amount for the entire OS belt of 120 by 4-6 kilometres which is yet to be developed (GCU), 1980). The OS belt (Ekweozor, 1990; and Enu, 1990) extends from parts of Edo State through Ondo, Ogun and Lagos States and its outcroppings have been known to be present in Western Nigeria for about a century (Adegoke, 1974, (Ministry of Solid Minerals Development (MSMD), 2006; (Ministry of Mines and Steel Development (MMSD), 2010).

The distinctiveness of Nigerian OS such as; medium to good sorting of the sand grains, low clay content, higher bitumen content and low heavy metal content give it significant advantage over the Canadian OS (Coker, 1990). This deposit also possesses the following potential for easy development; amenability to gravity assistance, potential for steam assistance, amenability to open cast mining similar to and in some cases better than the Canadian OS; in addition to its technological, economic and environmental benefits to the nation are some of the inherent advantages of the development of this resource.

Based on studies carried out on Nigerian OS, its characteristics such as; water-wet nature of the sand grains, textural parameters, oil saturation, general chemical properties and facies and age relationship compare favourably with Athabasca OS (Oluwole *et al.,* 1985 and Ekweozor and Nwachukwu, 1989).

Tar sands, oil sands or bituminous sands are all names for a combination of clay, sand, water, and bitumen which is viscous extra-heavy crude oil. It describes sandstones or friable sands (quartz) impregnated with bitumen (a hydrocarbon soluble in carbon disulfide). Bitumen is just one of the many products derivable from OS (Adegoke *et al*., 1974; Oblad *et al.*, 1987; Meyer, 1995 and Speight, 1997). However, despite all these advantages and potential benefits derivable from the development of this resource, it is yet to undergo commercial exploration and exploitation. The question is why? It is safe to say that there are uncertainties associated with this development; responsible for its present state. What are they? Where are they located? What types of uncertainties are they? What are their effects on this resource development? These are some of the questions to be explored in this study.

3. Uncertainty Definition, Identification and Methodology

A number of authors have attempted to define the concept called uncertainty; some of the definitions are: Uncertainty is the deficiency of knowledge (Funtowiez and Ravetz, 1990); Walker *et al.,* 2003 defined uncertainty as "*a departure from the unattainable state of complete determinism resulting from either a deficiency of knowledge or natural variability in a system*"; uncertainty is a situation of inadequate information revealed as inexactness, unreliability or border with ignorance; Brugnach *et al.,* 2007 introduced another viewpoint of "ambiguity" in the definition of uncertainty with ambiguity defined as *"...concurrent existence of numerous equally valid frames of knowledge*" (Dewulf *et al.,* 2005). Uncertainty is becoming a progressively more important factor in the decision making and policy analysis because of the swiftly changing, complex, and unpredictable nature of our world (Walker, 2003).

Walker identified the following types of uncertainty encountered in decision making and policy analysis: uncertainty about model form; uncertainty about the values of a model's parameters; uncertainty about underlying probability distributions and structural uncertainty "this refers to uncertainty in future structural elements of the world, unknowable at the time of analysis" (Walker, 2000). He then classified uncertainty (Walker *et al.,* 2003) into different levels described as follows;

1) *Location of uncertainty*: where the uncertainty manifests itself in the model complex; in the context, in the model itself ('model technical' or 'model structure' uncertainties), in the input, in parameters or in the output. Here the marker "output" is introduced by Janssen *et al.,* 2010.
2) *Level of uncertainty*: where the uncertainty manifests itself along the continuous spectrum, between deterministic knowledge and total ignorance. Here the markers are 'statistical', 'scenario' and 'recognized ignorance'; while qualitative level of uncertainty (which cannot be quantified, but can be described) was added by Janssen *et al.*, 2010.
3) *Nature of uncertainty*: whether the uncertainty is due to imperfection of knowledge (epistemic) or inherent variability of the phenomena being described; ambiguity is introduced here by Janssen *et al.,* 2010.
4) *Context uncertainty*: The uncertainty in the model context concerns choices made in the step from natural system to conceptual model. Questions about the model boundaries and

choice of input and output variables are associated with this type of uncertainty. Assumptions or scenario's are usually used to address these uncertainties.

Other categorizations of uncertainties include:

a) *Model structure uncertainty* can be described as 'arising from a lack of sufficient understanding of the system of reference, including the behaviour of the system and the interrelationships among its elements' (Walker *et al.,* 2003). According to, Van Asselt and Rotmans (2002), this is the most difficult type of uncertainty to address.
b) *Model technical uncertainty* concerns 'uncertainties related to the computer implementation of the model' (Walker *et al.,* 2003); it consists of both software and hard-ware errors.
c) *Input uncertainty* is both uncertainty about 'driving external forces that produce changes within the system' and uncertainty about 'the system data that 'drive' the model and quantify significant features of the reference system'; it is considered to be stochastic in nature.
d) *Parameter uncertainty* is uncertainty related to the a-priori chosen parameters, described by Walker et al. (2003).
e) *Aggregated uncertainty* results from all uncertainties above (Janssen *et al.,* 2010).

Janssen *et al.,* 2010, based on the additions to the work of Walker *et al.,* (2003); then came up with an analysis framework for uncertainties. Van Asselt, (2000) developed a taxonomy for the sources of uncertainty; here she identified 2 classes variability (ontological dimension of uncertainty) and lack of knowledge (epistemological dimension of uncertainty). Each class is further sub-divided as follows:

Variability: a) Inherent randomness of nature, b) Value diversity, c) Human behaviour, and d) Societal and technological randomness;

Lack of knowledge: a) Unreliability from inexactness and b) Structural uncertainty resulting from irreducible ignorance.

Identifying key uncertainties is one of the steps in the thinking phase of the adaptive policymaking process as defined in the work of (Walker, Cave, and Rahman, 2001; Walker, 2000; Walker *et al.,* 2003). Further, Walker *et al.,* (2003) provides a theoretical basis for the treatment of uncertainty systematically in model-based decision support activities, this involves the use of uncertainty matrix. The uncertainty matrix enables the categorization of uncertainties based on the three categories of; location (also referred to as '*source*' by Eker and van Daalen (2012a, and b), level, and nature. Other Methodologies / approaches for identifying and analysing various types of uncertainty are summarized in **Table 2**.

Table 2: Different approaches for various types of Uncertainty

Uncertainty Types	*Methodologies/Analytic approach*
Structural uncertainty	1. Ignoring uncertainties 2. Conduct '*what if*' policy analysis 3. Muddling through an adaptive approach (Walker, 2000; Walker *et al.*, 2003).
	Quantitative Analytical approach (Walker and Haasnoot, 2011)
Level 1	Deterministic (optimization, sensitivity)
Level 2	Probabilistic (sensitivity, expected value, confidence intervals)
Level 3	Scenario analysis
Level 4	Exploratory (scenario) analysis, adaptive pathways
	Approaches by Janssen et al., 2010
Model technical uncertainty	Multiple simultaneous model implementations
Input uncertainty	Monte Carlo analysis
Parameter uncertainty	Calibration OR Selected fixed value
Aggregated uncertainty	Compositional framework

4. Techniques that help deal with uncertainties:

A number of techniques have been employed in dealing with and exploring uncertainties over the years; arising from the ease of use of cheap, powerful computing capability, as well as combination of computational speed, graphical display, and data handling ability of modern-day computer (Walker, 2000). The techniques that have been identified in this study are presented in **Table 3**. These techniques include SD, EM and EMA, MCDA, MAMCDA, ABM, NUSAP, PRIM, combination techniques of SD with one or more of these other techniques (see **Table 3**).

Inherent advantages of SD in dealing with uncertainty that have been identified include: ability to produce qualitative interpretations, conclusions and recommendation; through addition of rich information; use of multi-model approaches; use of sensitivity analysis and uncertainty analysis (Pruyt, 2014 and Walker *et al.*, 2014); use of new advanced techniques and tools; potential for dealing with deep uncertainty; basic foundation for most of other techniques; and ability to work successfully with the other techniques briefly described as follows:

EM and EMA represent a quantitative approach to uncertainty analysis, useful for exploring deep (multi-faceted and multi-dimensional) uncertainties. These techniques allow the generation of myriad scenarios, for analysing dynamic behaviours and testing robust policies. The resulting policies are adaptive and capable of accommodating unexpected turn of events.

MCDA and MAMCDA are techniques that involve the modelling of multi-dimensional issues or uncertainties, and thereafter identifying most appropriate solutions rather than optimal ones through the ranking of a countable set of policy alternatives on a multiple criteria basis. ABM as a technique utilizes algorithms to quantify and describe uncertainties.

NUSAP as a technique provides an analysis and diagnosis of uncertainty in science-for-policy, through the assessment of qualitative and quantitative uncertainties based on the five attributes of the acronym. These are Numeral, Unit, Spread, Assessment, and Pedigree, useful

Table 3: Techniques for dealing with uncertainties

Techniques	*Description*	*Examples of use*
System Dynamics (SD)	1. making quantitative simulation models 2. generating plausible behaviours over time 3. results in qualitative interpretation	Ford *et al.*, 1989; Ford 1989; Ford & Bull, 1989, Ford, 1990 Lowry *et al.*, 2012; Walker *et al.*, 2014
Exploratory Modelling (EM)/ Exploratory Modelling Analysis (EM/EMA)	EM/EMA is a quantitative uncertainty analysis approach 1. it systematically explores deep uncertainty 2. tests the robustness of policies 3. generates and explores plethora of scenarios 4. simulates and analyses dynamic behaviours	Bankes, 1993; Pruyt, 2007; Agusdinata, 2008; Pruyt, et al 2011a);
Multiple Criteria Decision Analysis (MCDA)	MCDA is an iterative technique for 1. modelling and analysing multi-dimensional issues 2. finding *most appropriate* solutions instead of optimal ones 3. identifying, structuring, modelling and exploring	Roy and McCord 1996; Figuera, Greco and Ehrgott 2005; Pruyt, 2007
Multi-Attribute Multiple Criteria Decision Analysis (MAMCDA)	MAMCDA is used for describing, choosing or ranking *countable* sets of alternative policies on multiple criteria	Pruyt, 2007
Agent Based Modelling (ABM)	ABM describes elements in a model with the use of algorithms	Hamarat *et al.*, 2013
Compositional Fuzzy-rule based	combines the evaluation of model structure, input and parameter uncertainties for their extensive assessment	Janssen *et al.*, 2010
Numeral Unit Spread Assessment Pedigree (NUSAP)	NUSAP is a heuristic for good practice in science for policy, which 1. enhances reflection on the various dimensions of uncertainty 2. makes uncertainties explicit 3. qualifies uncertainties using these five qualifiers: Numeral, Unit, Spread, Assessment and Pedigree 4. diagnoses uncertainties on the basis of spread and strength	Funtowicz and Ravetz (1990); Van der Sluijs *et al.*, 2003
Patient Rule Induction Method (PRIM)	PRIM is used to find areas in the input space responsible for an observed behaviour	Moorlag et al 2014
SD + 1 or more other Techniques		
Exploratory System Dynamics Modelling and Analysis (ESDMA) = SD + EMA	ESDMA is a mainly a quantitative multi-method that involves; 1. exploration to broaden the horizon 2. deep robustness aimed at testing, design of adaptive policies, and resilient systems. 3. particularly appropriate for systematically exploring and analysing plethora of plausible dynamic behaviours over time 4. testing robustness of policies over all these scenarios 5. it leads to qualitative interpretations, conclusions and recommendations	Auping, 2011; Eker and van Daalen 2012 (a, and b); Pruyt, et al, 2011; Pruyt and Kwakk el al., 2012 a & b
SD + MAMCDA		Pruyt, 2007
SD + EM		Pruyt, 2007
SD + ABM + PRIM		Moorlag, *et al.*, 2014

for providing insight on two independent properties related to uncertainty in numbers; that is spread and strength, which are then combined in a Diagnostic Diagram mapping.

PRIM as a method that deals with uncertainties by identifying areas in a selected input space, responsible for observed patterns and behaviour.

5. Methodology:

In this study, both primary and secondary data were collected, to obtain adequate information on the uncertainties associated with OS development in Nigeria. Secondary data were derived from literature, while primary data were obtained from survey of stakeholders. These stakeholders considered of paramount importance to OS development in Nigeria, comprised the following categories: researchers conducting studies on Nigerian OS, policy makers in government agencies involved in policy formulation process for OS development in Nigeria, and residents of host communities to OS deposit.

SD methodology developed by Forrester is useful for analyzing and understanding the behavior of complex and dynamic systems. It is based on the use of informal maps, causal relations, and feedback loops, with the aid of computer simulations to generate plausible scenarios of the system under study. It entails the use of causal loop diagrams (CLD's); which are diagrams that help to depict interactions−causes and effects in existence among variables of interest within a system−as-well-as create and indicate the direction of flow.

In uncertainty classification, Walker *et al.*, (2003) defined what is known as location of uncertainty in their model-based analysis of uncertainty. However, in conceptual uncertainty analysis, Meijer (2008) introduced the term 'source of uncertainty' to replace location, and identified six sources of uncertainties. These comprise the following; technological, resource, competitive, supplier, consumer and political, Eker and van Daalen (2012b) further introduced one more source known as societal.

In this study, we also introduced two other sources of uncertainty known as environmental and infrastructural. These eight sources are used to categorize the myriad uncertainties identified as associated with OS of Nigeria, and are presented in the next section.

6. Findings: Use of SD for identifying the cause-and-effects relationships among the uncertainties

In this section, myriad uncertainties that have been identified in association with the development of OS in Nigeria are categorized using Walker et al (2003) framework, and presented in the following table (**Table 4**) following which cause-and-effect interactions among the uncertainties were investigated using SD methodology.

Table 4: Uncertainties associated with OS in Nigeria and their associated factors

Sources of Uncertainties	***Associated Factors/Variables***
Technological	Availability of required technology, technological advancement, number and type of wells required, time needed for extraction, importation of technology
Environmental	Carbon emissions, tailings generation, water requirements, land use, reclamation and restoration of land, other environmental effects
Political	Policy and legal framework, tax regimes, political will, nature and interest of leaders, political regime/politics, land approval requirements and time, government support
Social/societal	Host community perspective and support or otherwise, livelihood of residents, public opinion, security issues, environmental protection policy
Infrastructural	Road network, drilling equipments, pipelines and other social amenities; housing facilities, medical conveniences
Consumer/Demand	Existence of conventional crude and other substitutes, availability of market, consumer preference, price of products
Supply	Availability of drilling and other equipments, quality of equipments delivered, delivery time of equipments,
Resource (OS reserves and Human)	Estimates of reserves, value of recoverable reserves, geological characteristics of reserves, nature of occurrence of reserves, availability of skilled and un-skilled man-power required (human resources), quality of human resources available, time needed for employment of required man power
Financial	Investment requirements, estimated period to before break-even, return on investments, profitability and viability.

*Causal loops diagrams (*CLD*)*: the CLDs' are diagrams that provide insight, enhance the exploration of plausible behaviours, and help to depict the interactions; causes and effects in existence among variables of interest within a system; they create and indicate the direction of flow. These diagrams drawn with Vensim PLE software, showing the interactions and effects of the identified uncertainties are as shown (**Figures 1{a & b}, 2, 3 and 4**).

Figure 1a and **1b** is an illustration of the CLD of the uncertainties identified and their effects on OS development; portraying probable interrelationships and effects of these uncertainties on development of OS in Nigeria and vice versa (where a + sign implies a positive effect, and a - sign a negative effect). The development of OS is expected to result in a decrease in uncertainties associated with the development of this resource; however this may not be the case especially for environmental and social as the development could lead to creation of new uncertainties in this group that were initially not envisaged. Furthermore, major causal links and feedback loops among these uncertainties are shown in figure 1b. For instance, four balancing loops (B) and five reinforcing loops (R) are identified and shown, to capture overall causal relations among uncertainties, and between uncertainties and Nigerian OS development. Reinforcing feedback loops indicates that all the factors eventually increase in the same direction; that is any change in a variable in this loop, results in a change in the variable in the same direction again. While balancing feedback loops implies that the factors increase in such a way that they counter one another; this implies that the self-change in any variable in the loops occurs in an opposite direction. Knowledge of these causal factors is useful in future analysis of the uncertainties for the identification of effective treatments and generation of robust policies for the resource development. **Figure 2** depicts the relationship between FIR uncertainties and the contributory variables associated with them.

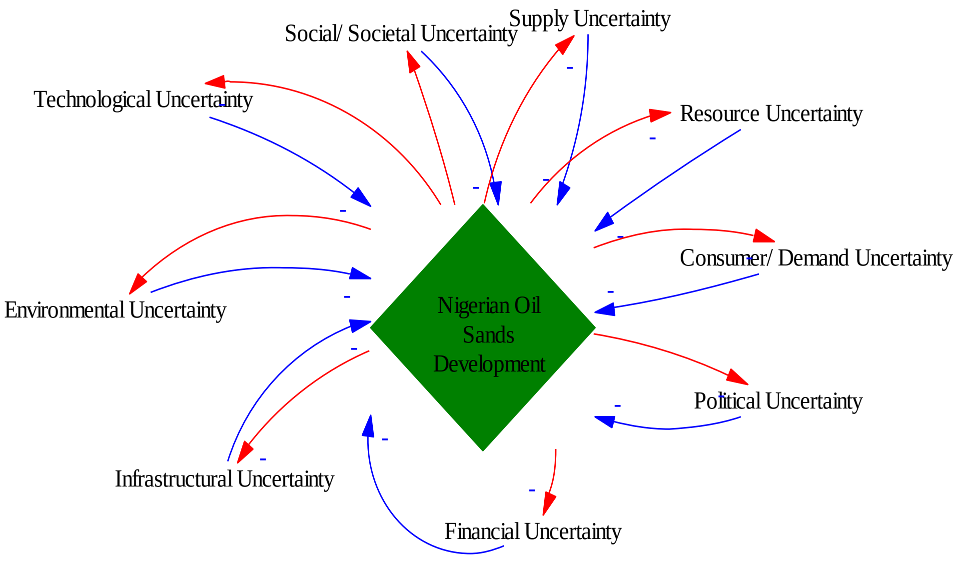

Figure 1a: CLD of Uncertainties in OS Development

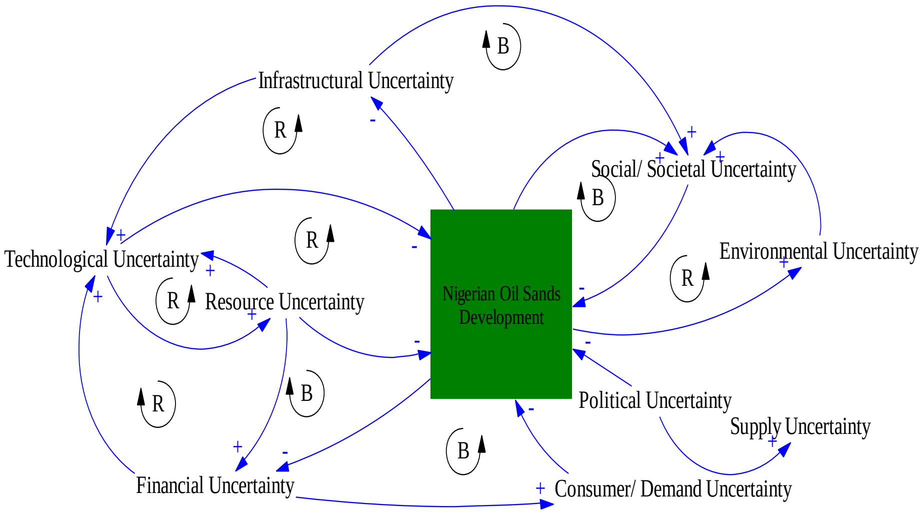

Figure 1b: CLD of Uncertainties in OS Development

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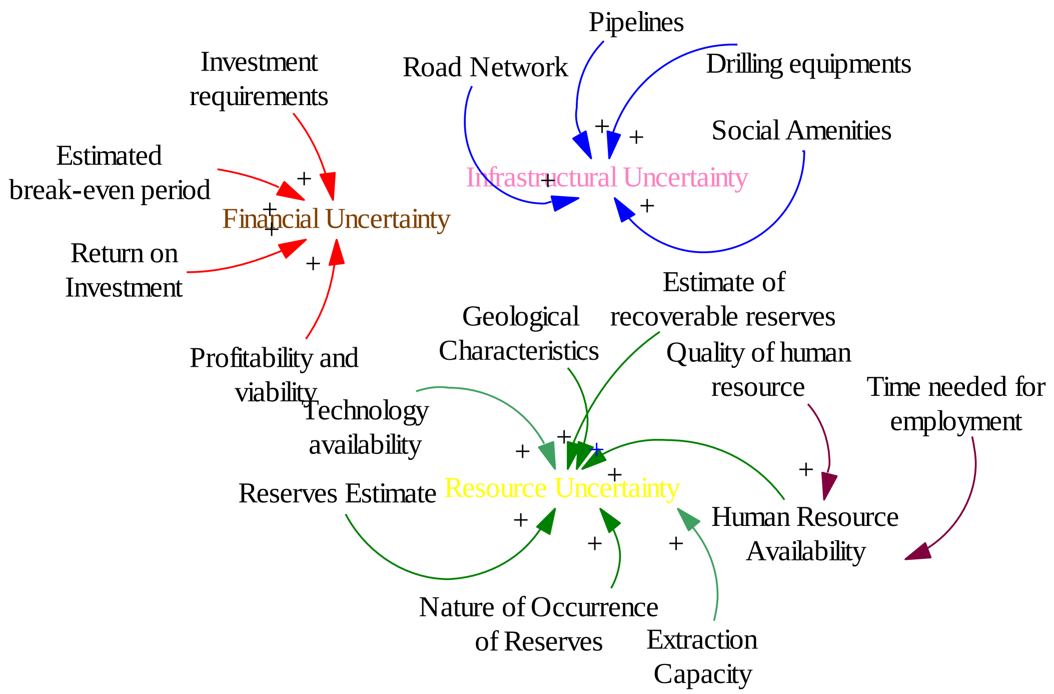

Figure 2: CLD of Relationship between Financial, Infrastructural and Resource (FIR) Uncertainties in OS Development.

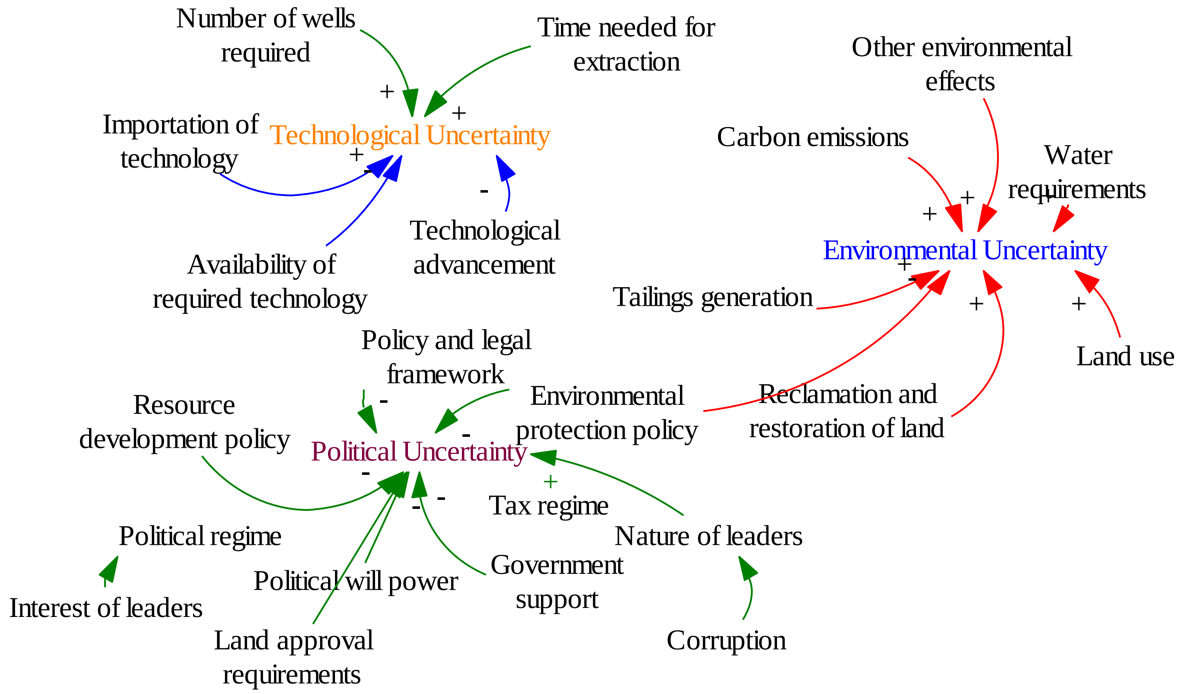

Figure 3: CLD of Relationship between Technological, Environmental, and Political (TEP) Uncertainties in OS Development.

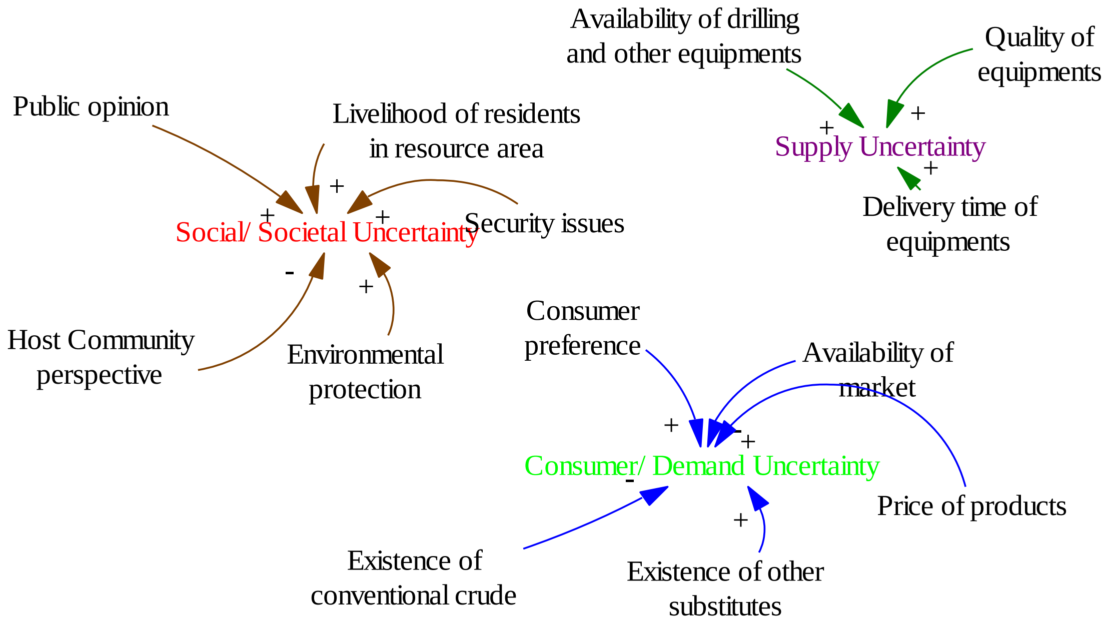

Figure 4: CLD of Relationship between Social/Societal, Consumer/Demand, and Supply (SCS) Uncertainties in OS Development.

The depiction (**Figure 3**) of the interactions and effects on TEP uncertainties by their related variables is as shown; while **Figure 4** represents the relationship between SCS uncertainties and their variables/factors. These are anticipated relationships which may change as more information become available during the course of the investigation and analysis.

7. Conclusions:

This exploratory study has contributed significantly to the subject matter of associated uncertainties in the projected development of Nigerian OS; having firstly investigated various classes, types and taxonomy of uncertainties as well as methodologies and techniques for approaching and handling these uncertainties. Also, the advantages of SD technique for identifying uncertainties as well as uncertainties in the development of OS in Nigeria were identified with their cause and effects depicted.

These uncertainties including; technological, social/societal, supply, environmental, infrastructural, resource, consumer/demand, political and financial were identified and their contributory variables were identified for their place in the development of OS in Nigeria.

The cause and effects (CLDs') are anticipated relationships identified from the survey and investigation, conducted both in literature and sampling of stakeholder groups. The work being exploratory and work-in-progress, we present the CLDs' useful for identifying important feedback structures and interrelationships among the uncertainties. These are to be developed further into modules of the major uncertainties and their likely effects on OS development. Following which an SD model will be developed to incorporate the modules. In order to identify adaptive policy options that could enhance the development of OS in the near future.

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REFERENCES

Adegoke, O.S. (1974): *Preliminary proposal for the exploration and Utilization of Bitumen of Western State of Nigeria*. Unpublished Report, Geological Consultancy Unit, University of Ife.

Adegoke, O.S., Ako, B.D., Enu, E.I., Petters, S.W., Adegoke, A.C.W., Odebode, M.O. and Emofurieta, W.O. (1974): *Geotechnical investigation of the Ondo State bituminous sands. Report*, Geological Consultancy Unit, University of Ife, Ile-Ife. Pp 257.

Alberta Energy (2014a): *What is Oil Sands*? http://www.energy.alberta.ca/OilSands/793.asp, accessed 3/3/2015.

Alberta Energy (2014b): *Facts and Figures*, http://www.energy.alberta.ca/OilSands/791.asp, accessed 6/3/2015.

Ate, B.E. and Nwoke, C.N. (1998): *Towards a Viable Energy Policy for Nigeria*. Seminar Organized by the Nigerian Institute of International Affairs, Lagos, Jan 5-7.

Auping, W.L. (2011): *The uncertain future of copper - An Exploratory System Dynamics Model and Analysis of the global copper system in the next 40 years*. Delft University of Technology, Delft.

Auping, W.L., DeJong, L., Pruyt, E., and Kwakkel, J.H. (2014): *The Geopolitical Impact of Shale Gas: The Modelling Approach*. Int'l System Dynamics Conference, Delft, the Netherlands, 2014.

Bankes, S. (1993): Exploratory Modelling for Policy Analysis, *Operations Research*, 41(3), 435-449.

Bassi. A. M., Powers, R., and Schoenberg W. (2010): An integrated approach to energy prospects for North America and the rest of the world. *Energy Economics,* 32, 30-42.

Brugnach, M., Dewulf, A.,Pahl-Wostl, C., Tallieu, T., (2007): *Towards a relational concept of uncertainty: incorporating the human dimension*. In: CAIWA Conference, Basel.

Canadian Energy Research Institute (CERI) (2011): Canadian Oil Sands Supply Costs and Development Projects (2010-2044). Study no 122, May 2011. www.ceri.ca accessed 10/3/2015

CERI, (2014): Canadian Economic Impacts of New and Existing Oil Sands Development in Alberta (2014-2038) http://www.ceri.ca/images/stories/CDN_Economic_Impacts _of_ New_and_Existing_Oil_Sands_Development_in_Alberta_-_November_2014_-_Final .pdf, accessed 15/3/2015.

Conference Board of Canada (2012): *Fuel for Thought: The Economic Benefits of Oil Sands Investment for Canada's Regions*. http://www.albertacanada.com/files/albertacanada /AIS_FuelforThought.pdf , accessed 8/3/2015

Dewulf, A., Craps, M., Bouwen, R., Taillieu, T.,Pahl-Wostl, C., (2005): Integrated management of natural resources: dealing with ambiguous issues, multiple actors and diverging frames. *Water Sci. Technol*. 52, 115–124.

Eker, S., and van Daalen, C.E., 2012(a): *Uncertainties in the Development of Unconventional Gas Production in Europe*. 9th International Conference on the European Energy Market.EEM12, Florence, Italy.

Eker, S. and van Daalen, C. E., 2012(b): *Investigating the Effects of Uncertainties Associated with the Unconventional Gas Development in the Netherlands*. 3rd International Engineering Systems Symposium CESUN 2012, Delft University of Technology, 18-20 June 2012. Delft, the Netherlands.

Ekweozor, C.M. (1990): *Geochemistry of Oil Sands of South-western Nigeria*. In Occurrence Utilization and Economics of Nigerian Bitumen B.D. Ako and E.I. Enu (Eds.). Proc. of the workshop on Tar-Sands/ Ogun State University, Ago-Iwoye. Ogun State, Nigeria. Pp. 50-62.

Enu, E.I. and Adegoke, O.S. (1984): *Potential Industrial mineral resources associated with the Nigerian bitumen,* 27th International Geological Congress. Vol. VII, pp. 345.

Enu, E.I. (1990): *Nature and Occurrence of Bitumen in Nigeria*. In Occurrence Utilization and Economics of Nigerian Bitumen B.D. Ako and E.I. Enu (Eds.). Proc. Of the workshop on Tar-Sands/ Ogun State University, Ago-Iwoye. Ogun State, Nigeria. Pp. 11-15.

Falebita O. A. (2014b): *The Nigerian Tar Sands: A Techno-Economic Analysis*. ISBN 978-3-659-61698-3, Lambert Academic Publishing, Saarbrücken, Germany.

Geological Consultancy Unit (GCU) Report (1980): *Geotechnical Investigations of the Ondo State Bituminous Sands*. Vol. 1, the Caxton Press Limited Ibadan.

Hall, C.A.S., Cleveland, C. J., Kaufmann, R., (1986): *Energy and Resource Quality the Ecology of the Economic Process*. John Wiley and Sons (Wiley Interscience New York).

International Energy Agency (2010): *World Energy Outlook*, OECD/IEA, Paris http://www.responsiblenergy.org/tarsands.asp, accessed 26/03/2011

Janssen, J.A.E.B., Krol, M.S., Schielen, R.M.J., Hoekstra, A.Y., de Kok, J.-L., (2010): "Assessment of uncertainties in expert knowledge, illustrated in fuzzy rule-based models". *Ecological Modelling* 221 (2010) 1245–1251.

Meyer, R. (1995): Bitumen, In Encyclopedia of Energy Technology and the Environment, Vol.1, A. Bisio and S. Boots (Eds.), John Wiley and Sons, New York, N. Y.

Ministry of Solid Minerals Development (2006): *Technical Overview; Nigeria's Bitumen Belt and Development Potential*, Pp 27.

Ministry of Mines and Steel Development (2010): *Bitumen and Bitumen Exploration Opportunities in Nigeria*. Pp 14.

Oblad, A. G., Bunger, J. W., Hanson, F. V. (1987): *Tar Sand Research and Development*, Ann. Rev, Energy 12. Pp 283-336.

Odell, P. R. (2004): *Why Carbon Fuels will dominate the 21st Century's Global Energy Economy*, Multi-Science Publishing Company Ltd., Brentwood, Essex, UK.

Ojeme, S. (2011): *FG moves to develop bitumen deposits*. The Punch Newspaper, Nigeria, Thursday, August 4, 2011. Pp 32.

OPEC, (2014): *OPEC Share of World Crude Oil Reserves*, in Annual Statistical Bulletin. http://www.opec.org/opec_web/en/publications/202.htm, accessed 14/3/2015.

Pimentel, D. (Ed.), 2008: *Biofuels, Solar and Wind as Renewable Energy systems*: *Benefits and Risks*. Springer.

Pruyt, E., Kwakkel, J., Yucel, G., and Hamarat, C. (2011a): *Energy Transitions towards Sustainability I: A Staged Exploration of Complexity and Deep Uncertainty*. Int'l System Dynamics Conference 2011a, Washington DC, USA.

Pruyt, E. (2014): *System Dynamics and Uncertainty*. Int'l System Dynamics Conference 2014. Delft, the Netherlands.

Smil, V. (2003): *Energy at the Crossroads: Global Perspectives and Uncertainties*, The MIT Press. 0262194929.

Speight, J.G. (1997): *Bitumen*, in Kirk-Othmer Encyclopedia of Chemical Technology.

van Asselt, M. (2000): *Perspectives on uncertainty and risk: the PRIMA approach to decision support*, Kluwer Academic: Dordrecht. 1.2.3.4.5.

Walker, W. E (2000): *Uncertainty: the Challenge for Policy Analysis in the 21st Century*, Lecture presented on November 29, 2000 at Delft University of Technology on the occasion of the inauguration of the author as Professor of Policy Analysis and Decision Support Systems in the Faculty of Technology, Policy, and Management.

Walker, W.E., Jonathan Cave, J. and Rahman, S.A., (2001): Adaptive Policies, Policy Analysis, and Policymaking, *European Journal of Operational Research*, 128(2).

Walker, W.E., Harremoes, P., Rotmans, J., Van Der Sluijs, J.P., Van Asselt, M.B.A., Janssen, P., and Krayer Von Krauss, M.P., (2003): "Defining Uncertainty - A Conceptual Basis for Uncertainty Management in Model-Based Decision Support", *Integrated Assessment*, 4(1), pp. 5-17.

Walker, L.T.N., Malczynski, L.A., Kobos, P.H., and Barter, G., (2014): *The Shale Gas Phenomenon: Utilizing the Power of System Dynamics to Quantify Uncertainty*. Int'l System Dynamics Conference 2014, Delft, the Netherlands.

World Energy Council (2013): *World Energy Resources: Oil*. http://www.worldenergy.org/wp-content/uploads/2013/10/WER_2013_2_Oil.pdf, accessed 14/3/2015.