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External Oil Supply Risk in Different Climate- and Supply Scenarios

Energy Security Scenarios Affected by Peak-Oil to 2035

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'I don't know when global oil supplies will start to decline. I do know that another resource has already peaked and gone into free fall: the credibility of the body that's meant to assess them'

George Monbiot, 2009

'One global crisis at a time, please..'

Jeremy Leggett, 2014

'It takes all the running you can do, to keep in the same place'

The Red Queen, Alice in the Looking Glass

Executive Summary

Energy has been stated to be '*the oxygen of the economy and the lifeblood of growth*' (World Economic Forum, 2012). The inflow of energy for countries where domestic production is unable to meet domestic demand, is essential to keep their economies going and growing. Securing these supplies is thus of vital importance for these nations. The aim of this research was to combine and expand the research done by Yang et al (2014) and Aleklett et al (2010) by adding updated future external oil supply risk scenarios up to 2035, taking into account different climate- (CPS, NPS and 450) and oil-supply projections for the EU, the US, China, Japan and India (being the five largest importers of oil in the world). This research considered the risks associated with supplies from oil-exporting nations, as well as the potential exports in future oil supply of these nations and adds the concepts of 'peak oil' and long-term external oil-supply risks (EOSRs) to the model of Yang et al (2014) and Aleklett et al (2010). This report focussed on the following question: *What is the impact of different climate- and oil supply scenarios on external oil supply risks for major oil-importing countries up to 2035?*

The Climate Scenarios were based on projections from the IEA WEO 2012, in which three 'energy futures' are modelled, based on the expected temperature rise in 2050: 2DS (450 Scenario), 4DS (New Policies Scenario) and 6DS (Current Policies Scenario). However, these figures have been criticized for being unreliable and highly optimistic with regards to future oil production rates. The IEA expects that future oil supply will simply keep pace with increasing oil demand, based on current reserve estimates, which seem sufficient to meet oil demand far into the future. However, opposing scientists - e.g. from the Association for the Study of Peak Oil and Gas - state that it is not about the size of the reserves in the world, but the extraction rate of oil to fuel the economies. This view is commonly summarized as: '*what we have to worry about is not so much the size of that tank, but the size of the taps'.* Dubious reporting procedures from the countries with the largest oil reserves (mainly OPEC-members) make an estimation of the exact timing of a global peak in oil production even more challenging.

As crude oil production has peaked, global oil supply shifts to unconventional oil for 'filling the gap' with increasing demand. However, there are problems with large scale unconventional oil production. Numerous technical- (low EROEI), economic- (higher marginal costs of production) and environmental constraints (higher carbon intensity) make a rapid expansion of non-conventional oil production extremely challenging. Most of the factors mentioned above are likely to continue to hamper unconventional oil production in the foreseeable future and it is therefore also possible that global oil production may peak or plateau in a relatively near future. This pessimistic context is modelled in the Uppsala Scenario, in which future oil supply of the IEA figures is challenged and the peak of oil production is incorporated, to provide a wide array of potential EOSRs for the economies investigated.

It can be concluded from this research that risks associated with external oil supply in the Climate Scenarios, are higher for all five economies investigated in the CPS Scenario, followed by the NPS and the 450 respectively. Thus, the extent of implementation of more stringent climate policies has a significant effect on external oil supply risks for the five largest oil-importing nations in the world. When the modified diversification indices are compiled for the IEA Climate Scenarios, the US has the highest import diversification and a positive trend in this risk is observed over time. China ranks second with this index, followed by India, the EU and Japan. China has the lowest country risk in 2011 in the Climate Scenarios, however, the nation is quickly surpassed by the US from 2020 onwards in all three scenarios. When potential exports are taken into account, China becomes the nation with the highest risks, followed by the EU and the stable Japan. India remains at a relatively constant level of external oil supply risks when potential exports are concerned. When country risk and potential exports are both taken into account, the same ranking remains, with the differences increasing between China and the EU. The US approaches 'zero risk' in the CPS and NPS, and even becomes oil-independent in the 450 Scenario. It becomes clear that the largest impact on falling overall external oil supply is caused by oil import reliance on OPEC members, with Japan being the most prominent example. However, it can be concluded from the sensitivity analysis that (assumptions for) the R/P ratio has a significant impact on the results in these scenarios. When investigating the exclusion of Russia from the EU's supplier portfolio, it becomes clear that excessive reliance on a single oil-supplier also has a significant effect on the results for the indices in this report. Another important risk factor is the variable of country risk. The dependency factor is also a major determinant for the indices. Dependency of oil imports increase for the EU in the CPS and NPS, with a stable 450 Scenario. For China and India, the dependency factor increases in each scenario. Japan, and more prominently the US, have decreasing dependency factors over time, which has a major impact on the indices for the US, and to a lesser extent Japan.

In general, it can be seen that EOSRs are higher for any country and any index in the Uppsala Scenario, followed by the CPS, NPS and 450 respectively. This is mainly due to higher dependency factors in the Uppsala Scenario, as a consequence of lower, less optimistic projections of future oil production for the five economies. These differences in the extent of risks become larger when country risk is considered, and more prominently, when potential exports are taken into account. In the Uppsala Scenario, Japan has the lowest oil import diversification, followed by the EU. The US ranks third, and India second. China is exposed to the lowest level of risk in this context. When country risk is taken into account, China's EOS risks increase and the US surpasses China with having the lowest risks. The picture changes completely when potential exports are taken into account. Japan faces lower external oil supply risks, by relying on suppliers with high R/P ratios and large shares in total world oil trade. Japan is followed by India, China and the EU respectively. The US is exposed to the highest risks when potential exports are taken into account.

When production figures were adjusted for a future peak in global oil supply, in combination with the projected growth figures of the IEA WEO 2012, to construct the potential net oil exports of the supplier countries within this scenario, only a fraction of the expected total world oil trade is met by these suppliers. It is unclear whether this is due to the fact that future world oil trade is significantly lower in terms of decreased oil volumes, or which countries, that are currently not a supplier of oil for the economies investigated, will fill this 'gap' in total future global oil trade. It can be concluded that future oil production will remain a challenge in terms of meeting increasing demand, and it remains unclear how, and by which suppliers, this growing demand will be met. It becomes apparent that risks will become extremely high in this scenario, which would almost certainly cause major supply-disruptions in the future. It is therefore essential for substitutes of oil (mainly in transport), to be developed rapidly and implemented on a large-scale. However, a proper chance of achieving this requires functional markets with transparent information. When information on falling oil-supply is not available and publicly criticized by the oil-incumbency, and government policies on energy are completely reliant on information from unreliable and inaccurate reports from e.g. the IEA and BP, this realization will come too late. This could potentially cause a new oil-crisis for which the world was (intentionally) not prepared.

There is a growing realisation that peak oil should be acknowledged as part of a complex energy situation with the realisation that cheap fuel is no longer available and we now face circumstances where prices will increase. The constructed scenarios, and the oil-supply risk indices derived from these scenarios, present a picture of increased risks for the five largest oil-importing nations in the world, when more stringent climate policies are prevented from being implemented (or implemented too slowly). When a peak of oil supply is considered in the model, an even more pessimistic outlook is provided for the five economies in this research, with increased risks in all indices. High energy-based economic growth will be limited and harder to achieve, and come at an increasingly higher financial-, energetic- and environmental cost, causing increased external oil-supply risks for oil-importing nations.

Units and Abbreviations

Units

b = barrel

k = thousand (10^3) - kilo

M = million (10^6) - mega

G = billion (10^9) - giga

kb/d = thousand barrels per day

Mb/d = million barrels per day

b/tonne = barrel per tonne

m^3/b = cubic feet per barrel

Gb = Giga barrels

Mt = Mega tonnes

Mtoe = Mega tonnes of oil equivalents

US$/b = United States Dollar per barrel

GDP = Gross domestic product

HHI = Herschmann-Herfindahl Index

IEA = International Energy Agency

NPS = New Policies Scenario

NOE = Net oil exports

NOI = Net oil imports

OPEC = Organisation of Petr. Exporting Count.

OSRI = Oil supply risk index

PE = Potential exports

PO = Peak oil

R/P ratio = Reserve-to-production ratio

SPR = Strategic Petroleum Reserve

TPES = Total Primary Energy Supply

Abbreviations

CAAGR - Compound average annual growth rate

CPS - Current Policies Scenario

C_i - Consumption

CR_i - Country risk

D_i - Oil import dependency

EIA - Energy Information Administration

EOSR - External oil supply risk

EROEI - Energy return on energy investment

ES - Energy security

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CHAPTER I - INTRODUCTION

Energy is fundamental to the quality of our lives. As energy is a key ingredient in all sectors of modern economies and societies, humankind is absolutely dependent on an abundant and uninterrupted supply of cheap energy for living and working (European Commission, 2014). The energy sector's impact on the economy and daily life is largely overlooked as energy is an input to nearly every good and service in the economy. Reasonable energy prices are therefore beneficial to sustaining and expanding economic growth (World Economic Forum, 2012). As Peter Voser, the CEO of Royal Dutch Shell the Netherlands, states: '*Energy is the 'oxygen' of the economy and the life blood of growth'* (World Economic Forum, 2012).

1.1 Trends in Energy Use and Potential Problems

In 2012, the world's primary energy demand reached 523 EJ (BP, 2014). However, by 2030, world population is projected to reach 8.3 billion, meaning an additional energy need for 1.3 billion people, combined with an expected doubling of world income in 2030 relative to the 2011 level in real terms. This population and income growth is expected to increase global energy demand, and associated emissions, by 36% by 2030 (BP, 2013; BP, 2014), and even double by 2050 (European Commission, 2014).

This surge for energy has an enormous effect on the global climate, since the energy sector is the single largest source of greenhouse-gas emissions, being accountable for two thirds of global greenhouse-gas (GHG) emissions (IEA, 2013a; IEA, 2013b). Despite many countries and large multinationals taking new actions, the world is drifting further and further away from the 2°C average global temperature increase scenario (450 ppm of CO_2-equivalents) - of which the majority of scientists reached consensus - which would prevent the world from serious climatic disruptions in the future (IEA, 2013a). Since the agreement was made by governments at the United Nations Framework Convention on Climate Change in Cancun, Mexico, in 2010, on the 2°C scenario, global CO_2 emissions from fossil fuel combustion increased again in 2012. Worldwide emissions amounted to a record high 31.6 Gt. An increase of 0.4 Gt in comparison to 2011 was measured, or +1,4% in GHG-emissions worldwide. A level that would suggest a long-term temperature increase of 3.6°C or more, if continued (IEA, 2013a).

The dependency on energy, and especially oil, has had serious consequences on the economy in the past, in the form of price volatility and shocks. The two oil shocks of 1973 and 1979, the Gulf War in the 90's and the so-called 'Aggregate Disruption' (Nigeria, Venezuela, Middle East and US due to the super storms Katrina and Rita) of the 2000's in which major oil-exporting countries reduced production due to geopolitical motivations, caused major oil-price peaks (Yergin, 2011). The concentrated nature of fossil fuels and the political unrest in the countries with the largest energy deposits creates pressures for the security of energy supply on which entire economies float. Concerns over energy security are not limited to oil as power blackouts on both the East and West Coasts of the US, Europe and Russia, as well as chronic shortages of electricity in China, India and other developing nations are recurring problems around the world (Yergin, 2006).

1.2 The Concept of Energy Security

'Energy security is the reliable, stable and sustainable supply of energy at affordable prices and social costs' (World Economic Forum, 2012). This definition combines all three key aspects within the wider concept of energy security (ES); the environmental-, economic- and strategic geopolitical aspect (Brookings, 2014). The need for energy security was the main objective underpinning the establishment of the International Energy Agency (IEA) in 1974 to maintain emergency measures for responding collectively to disruptions in oil supply of a magnitude likely to cause economic harm to its members (IEA, 2014). The IEA works towards improving energy security by promoting diversity, efficiency and flexibility within the energy sectors of the member countries, as well as promoting international cooperation with all players in the global energy market (IEA, 2014).

The rise in the need for energy worldwide, the overreliance of the world economy on finite resources, geopolitical challenges due to the concentrated nature of fossil resources, the depletion of these energy carriers, the increase in greenhouse gas emissions associated with energy production and the ever more stringent regulation to combat global climate change, will have a major impact on policy formulation and worldwide geopolitics in the coming decades. Massive exploration efforts for fossil resources and technological enhancement in current fossil fuel production and extraction, in combination with the technological development of, and societal pressures for alternative forms of energy production will change the current energy landscape at an unprecedented scale and pace. Since the world economy is dependent on energy to keep it growing, energy security is of major importance for all nations.

1.3 Oil-Security and External Oil Supply Risk

Energy security has become a popular catch phrase, both in the scientific- as well as in the political arena. However, the term energy security remains rather vague and subject to many different interpretations (Löschel et al, 2010). Due to the ubiquity of energy production and use and the complexity of many of the underlying processes, economic assessment of the welfare effects of energy insecurity are typically uncertain and fail to provide clear guidance to policy makers (Lefévre, 2009; Bollen et al, 2010; Löschel et al, 2010; Jansen et al, 2004; Ecofys, 2009a).

The energy insecurity discussion has increasingly focused on issues beyond oil dependence. So, a more holistic approach to measuring the concept is desired. Most conventional approaches to long-term energy security tend to zoom in on one aspect of the concept like; a supply-side focus (excluding demand-side efforts like efficiency advances and behavioural change - Jansen & Seebregts, 2010); a single energy carrier (i.e. oil - Greene, 2010); dependence and vulnerability (Markandya and Pemberton, 2010; Helm, 2002; Stirling, 2010), or are too simplified to measure the complex interactions in energy security aspects (European Commission, 2010). However, up to now, no aggregate indicator provides an adequate measure of all the relevant root causes of energy insecurity and current attempts to do so lead to a strong trade-off in transparency (Ecofys, 2009b).

This research focuses on one aspect of the energy security domain, external oil supply risk (EOSR). The world is heavily dependent on oil for meeting its energy requirements, fulfilling about 32% of the global energy demand, and 90% of total transportation energy demand (IEA, 2013b; Gupta, 2008).

Historical evidence suggests that a shortfall of oil supply relates approximately 1:1 with a decrease in a nation's GDP (Hirsch, 2008). Thus small decreases in world oil production or supply can have a large economic impact and requires very large levels of mitigation hardware and investment. The oil industry is largely globalized, with about 60% of the global oil supply being internationally traded, mostly driven by a mismatch in supply and demand. On the supply side, oil reserves are unequally distributed, with the Organization of Petroleum Exporting Countries (OPEC) holding 72.6% of world's proven oil reserves and controlling about 43.2% of global oil production in 2012 (BP, 2014). Many of these oil-exporting countries are characterized by a high degree of political instability. Oil demand is focused mainly in North America, Europe and Asia-Pacific, consuming 77.3% of global oil supply in 2012 (BP, 2014), with about two-thirds of this amount being transported by sea through various 'chokepoints' such as the Strait of Hormuz, the Strait of Malacca, the Suez Canal and the Strait of Bab el-Mandeb (Yergin, 2011; Gupta, 2008). Increasing reliance on imports of oil exacerbate a country's vulnerability to the effects of oil shocks as risks occur in the oil importing process.

1.4 Long-Term EOSR and Scenarios

The centre of gravity of energy demand is switching rapidly to the emerging economies, particularly China, India and the Middle East, which drive global energy use one-third higher up to 2035 in comparison to 2012. It is expected that China will become the largest importer of oil, and India the largest importer of coal by the early 2020s. The United States is expected to move steadily towards meeting all of its energy needs from domestic sources by 2035 (IEA, 2013b). Together, these changes represent a re-orientation of energy trade from the Atlantic basin to the Asia-Pacific region, creating implications for cooperative efforts to ensure oil security. Large consuming countries/regions such as the European Union, Japan, India and China are increasingly becoming dependent on oil imports to meet their energy requirements, obtaining a large part of their oil from non-OPEC sources. However, as the production in non-OPEC regions (such as the North Sea) is declining, all the consuming countries are progressively becoming more dependent on OPEC countries for their oil needs (Gupta, 2008; BP, 2014).

The Middle East is the only large source of low cost oil and remains at the centre of the longer-term oil outlook. The role of OPEC countries in supplying the world's oil is expected to be reduced temporarily over the coming decade due to rising output from the United States, from the Alberta oil sands in Canada, deepwater production in Brazil and from natural gas liquids. But, by the mid-2020s, non-OPEC production is expected to fall back and countries in the Middle East provide most of the increase in global supply, since national oil companies and their host governments within the OPEC-cartel control the vast majority of the world's conventional oil reserves (IEA, 2013b).

The IEA forecasts assume that oil supply will simply keep pace with growing demand (Aleklett et al, 2010). Many scientists and organizations - like the Association for the Study of Peak Oil - have argued that oil supply has already 'peaked' and that the figures of the IEA's forecasts are highly optimistic (Aleklett et al, 2010, Leggett, 2014, Monbiot, 2009). The term 'Peak Oil' refers to the point in time when, as a global society we have reached the maximum possible rate for petroleum extraction per unit of time (i.e. million barrels of oil per day - Mb/d). Thereafter, experts predict that demand for oil will begin to outstrip supply, increasing the price of oil substantially which will increasingly affect oil supply security for importing nations (Kerschner et al, 2013; Leggett, 2014; Gupta, 2008). As production in most non-OPEC countries has already peaked (i.e. Norway), the ability of OPEC to control world oil supplies is likely to increase in the near future. OPEC is also not investing sufficiently to meet the rising oil demand from emerging countries, with the result being falling spare capacity (Gupta, 2008). Spare oil production capacity is essential for buffering against supply-shocks in unstable regions to prevent price-shocks, and when this spare capacity diminishes over time, oil supply security problems worsen.

The growing dependence on the same (declining) sources, expanding international trade, and peaking oil production is increasingly stimulating intense geopolitical competition among the major importing nations to secure potential future imports (Gupta, 2008). For policy makers, it is useful to know the long-term potential energy security risks with current policies and energy markets to secure the nation's competitiveness and stability since energy investments usually have long development periods and lifetimes.

It is difficult to predict future developments in energy use and demand. However, many 'energy future' scenarios have been formed by different organisations in which energy demand and supply have been modelled, based on predictions from scientific research and data from national and international oil companies (IEA, 2013b, Shell, 2014, Ecofys, 2013, Van Vuuren, 2009). Since, future developments in energy use and demand are difficult to predict, different energy scenarios provide a tool to take into account different predictions and assumptions and allows for a wider representation of energy security risks for policy makers. Legislation can be adjusted when needed to ensure long-term energy security and by using accurate data and different 'energy future' scenarios, setting unrealistic or weak targets can be avoided and potential risks can be circumvented in different contexts.

1.5 Aim of this Research

Energy security in this report will be focussed on the role of oil in world energy demand and supply to enhance transparency and focus, since no theoretical model can capture all aspects of the complex nature of energy security. This model could add to the understanding of the issues involved and contribute to the debate on measuring external oil supply risks on a country level. This leads to the creation of an indicator framework which is able to measure energy (in)security - in the form of EOSR - in the long run, which has consistently been ignored in existing scientific literature up to date (Jansen & Seebregts, 2010; Yang et al, 2014). The aim of this research is to combine and expand the research done by Yang et al (2014) and Aleklett et al (2010) by adding updated future scenarios up to 2035, taking into account different climate- and oil supply projections for a selection of major oil-importing economies. This research considers the risks associated with supplies from oil-exporting nations, as well as the potential exports in future oil supply of these nations and adds the concepts of 'peak oil' and long-term EOSR risks to the model of Yang et al (2014) and Aleklett et al (2010). This report will focus on the following question: *What is the impact of different climate- and oil supply scenarios on external oil supply risks for major oil-importing countries up to 2035?*

This report will start with a description of the methodological foundation of this research. Then, the current state of the oil industry will be discussed in Chapter III, which is essential for understanding Chapter IV, in which the concept of peak oil is elaborated upon. Chapter V will provide an overview of existing indicators for assessing energy security, with a focus on oil-supply risk. A framework will then be introduced to assess EOSR in this research. Chapter VI will describe the scenarios used in this report as well as the input figures within these scenarios. The results will be presented in Chapter VII, in which oil security scenarios are formed up to 2035, and assessed for long-term EOSRs on a country/regional level. A sensitivity analysis and discussion will elaborate on the shortcomings and data insecurities within this research (Chapter VIII), followed by a conclusion in chapter IX.

CHAPTER II - METHODOLOGY

This chapter will elaborate on the methodological foundation of this research for answering the main research question, starting with the research method, followed by a detailed description of the research steps and the related data collection methods. This research consists of two main parts, which will be described in more detail in sections 2.1-2.4. Section 2.5 will elaborate on the country/region selection for this research and the final section (2.6) will discuss the sensitivity analysis for this report.

2.1 Research Method Part I

The first part of this study will entail the development of an indicator framework to assess external oil-supply risks on a country and regional level for different future energy scenarios. At first, the main themes within the current state of the oil industry will be discussed, which is essential for understanding the concept of peak oil. The relation between EOSR and energy security will be elaborated upon in the next step, followed by an overview of the current state of the art in measuring EOSR by doing a literature review. The chosen framework for this research will then be discussed, as well as a description of the input figures used for measuring EOSR with this framework in different climate- and supply scenarios. The underlying arguments for the choice of this research framework will be discussed here as well. Research steps 1 to 4 describe the first part of this research in more detail in section 2.2.

2.2 Research Steps Part I - An Indicator Framework for EOSR

The following steps in the research will help to structure the data search. Potential data sources are added for each research step.

Part I - 1. The Oil Industry and the Concept of Peak Oil - This research step starts with an overview of the current oil industry and an elaboration on the main themes within this domain in order to provide a basis for understanding and interpreting the chapters that follow. Secondly, the concept of, and debate around peak oil (PO) will be discussed. Since this research contains multiple future energy scenarios, the changing role of oil resources and types in the world's oil supply mix needs to be investigated. The IEA's stance on oil supply is simple: it will keep pace with world oil demand up to 2035, and the extent of supply only depends on the extent of demand in different climate scenarios (Aleklett et al, 2010). This optimistic stance is criticized by many scientists and organisations - i.e. the Association for the Study of Peak Oil and Gas. This critical view on the IEA's figures, as well as the consequences for future oil supply and demand will be discussed in this section, as well as the implications of a potential peak in global (crude) oil supply for the industry, the environment and the global economy in the future. Research step 1 will be dealt with in Chapter III and IV.

Part I - 2. The Role of EOSR in Energy Security - An elaboration on the different concepts of importance for determining energy security. To determine the most important concepts in energy security for this research, a clear description of the issue needs to be identified. The '4A's' express the multidimensional concept of energy security; energy resource Availability, Accessibility barriers, environmental Acceptability and investment cost Affordability (European Commission, 2010). A description of, and the role of EOSR within energy security will be elaborated upon in this section.

Both international scientific journals and available reports will be used to collect data that is up-to-date. Research step 2 will be dealt with in Chapter V.

Part I - 3. Existing Indicators for Assessing External Oil-Supply Risks - The European Commission (2010) categorizes different energy security indicators in 'simple indicators' (i.e. oil price or the Oil Security Metrics Model by Greene, 2010), 'diversification indicators' (i.e. Shannon-Wiener Index or Herfindahl-Hirshman Index - Stirling, 2010) and 'composite indicators' (i.e. EIA Energy Security Indicators - Lefévre, 2009); Willingness To Pay (Bollen et al, 2010); Supply/Demand Index (Scheepers et al, 2007; Jansen et al, 2004); Ordered Weighted Averaging (Rocco et al., 2011) and the MOSES model (Jewell, 2011; IEA, 2011). Another method is to incorporate energy security in a climate model (i.e. including energy security in the MERGE model - Bollen et al, 2010; and i.e. IAEA, 2005; IAEA, 2007). A time dimension is added to the discussion on energy security indicators by Löschel et al. (2010) by categorizing Ex-post Indicators (past) and Ex-ante Indicators (future). All these, and other attempts to measure energy security and EOSR will be presented in more detail in this research step, showing differences and overlap among them. Finally, the choice for this research for the indicator framework as discussed by Yang et al (2014) will be elaborated upon (Chapter V).

Part I - 4. Energy Security in a Peak-Oil Context - An Indicator Framework - A composite indicator is formed when individual indicators are compiled into a single index, on the basis of an underlying model of the multi-dimensional concept that is being measured, in this case EOSR. A composite indicator is especially useful in monitoring performance and time trends, as well as conveying policy measures by presenting potential risks (European Commission, 2010). The main criteria for establishing/selecting the composite indicator are:

- All factors in EOSR taken into account need to be quantifiable/measureable
- Data should be available for all concepts of EOSR taken into account
- The final outcome should be simple, inclusive and easy to interpret for policy makers

This research uses the composite indicator as described by Yang et al (2014), who propose a modified diversification index with country risk and potential oil exports in determining external oil supply risk. The index satisfies all three abovementioned criteria. This research will extend the research of Yang et al (2014), by forming future EOSR scenarios up to 2035, using different 'energy futures'. These scenarios will be the basis for determining EOSR using the created indicator framework, up to 2035, for the chosen economies. These three Climate Scenarios will be accompanied by a fourth scenario - 'the Uppsala scenario', in which future oil supply is challenged and the peak of oil production is incorporated in future oil supply (based on Chapters III and IV, discussed in Chapter V).

Part I - 5. Scenario Descriptions and Input Figures - Research step 5 entails the choice for the Climate Scenarios and the Uppsala Scenario, as well as the description of the input figures used for scenario formation. The input figures for each scenario, as needed for the composite indicator will be presented here, Chapter VI.

2.3 Research Method Part II

Part two of this research concerns assessing EOSR for a selection of major oil-importing economies by developing future scenarios and determine expected developments/EOSRs for the period up to 2035. The purpose of this part of the research is to assess possible risks on a country/regional scale in the coming decades and estimate the effects of interventions (read: climate- and supply scenarios) that may increase/lower security. Research steps 6 and 7 describe this process in more detail in the following section.

2.4 Research Steps Part II - Oil Security Scenarios up to 2035 - A Risk Assessment

Part II - 6. Oil-Security Scenarios up to 2035 - The composite indicator will be used to form oil-security scenarios from 2011 up to 2035 for a selection of regions/countries, based on the input figures as described in Chapter VI. Figure 1 presents an example of a possible outcome for the selected countries/regions for an EOSR-index as described by Yang et al (2014).

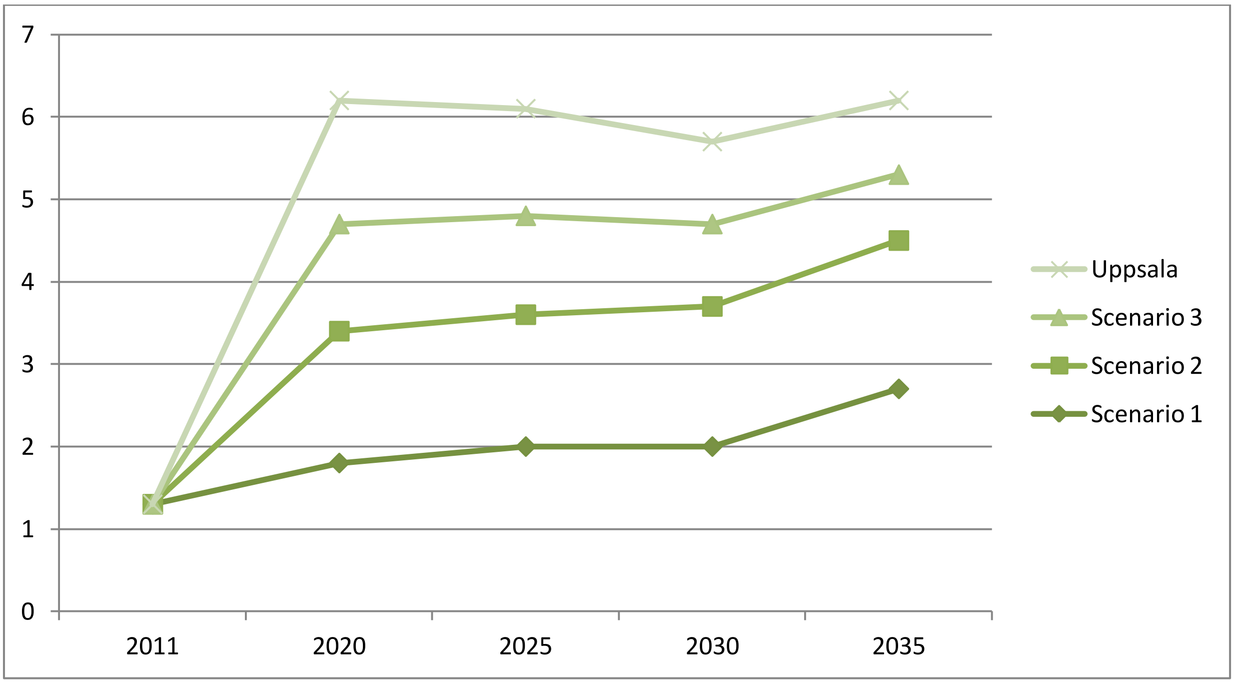


Figure 1: Example of an Outcome of a given EOSR-Index for a Selected Economy

This example of an outcome for an EOSR-index can then be constructed for each EOSR-index (4), and for each selected country/region. Then, the impact of varying R/P-ratios will be determined, which will be described in Chapter VIII. All results for the EOSR-indices will be presented in Chapter VII.

Part II - 6. Assessment of Long-Term Oil Security Risks - The formed EOSR scenarios will be assessed for potential risks up to 2035 for the selected countries/regions. The differences in outcomes in the energy scenarios will be elaborated upon, as well as differences in the EOSR-indices for each country/region, based on varying oil-supply and demand figures for each country region.

2.5 Country/Region Selection

This research includes the five largest importers of oil products in the world, being the European Union, the United States, China, Japan and India respectively (EIA, 2012). the IEA World Energy Outlook provides the most detailed projections of future oil supply and production as well as oil demand, and the five largest importers of oil are represented in this report, ensuring data availability. The framework this research uses is applicable only to countries with net imports of oil, which these five nations/regions all are currently (2014). This selection of five countries/regions represents a diverse mix of energy policies, current- and future energy consumption, and represents 59.6% of total primary energy demand (TPED) in the world in 2011 and 56.6% in 2035 (see tables 1 and 2). 52.6% of total primary oil demand is represented by this selection of countries/regions in 2011 and 47.7% in 2035, as projected in the New Policies Scenario by the IEA (IEA, 2013c).

Brazil is also represented in the WEO 2013 of the IEA, and is also an oil-importing nation in 2013. However, Brazil is excluded from this research since the country is expected to export more crude oil in 2014 than it will import. This statement is supported by the director general of Brazil's oil regulator, the ANP. The oil trade surplus will be Brazil's first since 2012, as the country had an oil trade deficit in 2013, importing $16.3 billion of crude oil and exporting $13 billion (Reuters, 2014).

Table 1: Overview of TPED and Primary Oil Demand in 2011 and 2035 for Selection of Countries (*Source: IEA, 2013c,* note:[%] means share of total/world)

	TPED [Mtoe]				Primary Oil Demand [Mtoe]			
Country/Region	**2011**	**(%)**	**2035**	**(%)**	**2011**	**(%)**	**2035**	**(%)**
European Union	1,659	12.7	1,541	8.9	549	13.4	367	7.9
United States	2,189	16.7	2,242	12.9	787	19.2	614	13.2
China	2,743	21.0	4,060	23.4	446	10.9	726	15.6
Japan	461	3.5	443	2.5	206	5.0	131	2.8
India	750	5.7	1,539	8.9	167	4.1	380	8.2
World	**13,070**	**100**	**17,387**	**100**	**4,108**	**100**	**4,661**	**100**

Table 2: Overview of Total Oil Net Imports in 2012 for the Selected Countries/Regions (*Sources: EIA, 2014; BP, 2013; European Commission, 2012*)

Country/Region	**Total Oil Net Imports 2012 [1,000 b/d]**	**Share of Total World Trade [%]**
European Union	10,314	18.6
United States	7,907	14.3
China	6,598	11.9
Japan	4,522	8.2
India	2,522	4.6
World	**55,314**	**100**

The selected countries/regions account for a total of 57.6% of total oil net imports in 2012, representing the bulk of total world trade in 2012 (EIA, 2014a; BP, 2013).

2.6 Sensitivity Analysis

A sensitivity analysis will be performed during the research when forming the different climate- and supply scenarios for the chosen economies up to 2035. As different policies and mitigation scenarios are taken into account within the climate scenarios, and a downward revision of forecasts in supply is presented by the Uppsala Scenario, the underlying input figures are given in a range. This can be seen as a sensitivity analysis on the underlying figures and policies of the scenario outcomes.

Parameters that have a major influence on the results will be varied to assess the impact of uncertainties and assumptions within these parameters on the results. A prime example of a parameter that has a major influence on the results is the reserve-to-production ratio, which will be examined in Chapter VIII.

Oil was formed in the geological past, and the bulk of current production comes from just two epochs of extreme global warming some 90 and 150 million years ago. Oil has been known for a long time but the first wells were drilled for oil in the mid 19th Century in Pennsylvania and on the shores of the Caspian Sea. What followed was a cheap and abundant supply of energy, changing the world in unimaginable ways, leading to the rapid expansion of industry, transport, trade and agriculture, which has allowed the population to expand six-fold since then (Campbell, 2014). However, the oil industry is changing at an unprecedented pace and scale, and there are criticisms on the reporting procedures of resources and reserves, recoverability of unconventionals and affordability of oil in the future. These issues are essential to understand in order to form the different 'energy futures' to assess EOSR in varying contexts.

It is essential for this research to outline the current oil industry in order to review the main themes within the domain of oil production, and to be able to relate to the subjects that follow. This chapter will elaborate on the classification of oil resources and reserves, followed by an overview of the availability, accessibility barriers, environmental acceptability and investment cost affordability of oil within the industry at present (APERC, 2007).

3.1 Classifying Oil Resources and Reserves

To be able to determine the availability of oil in the world, a classification of different types of oil is required. Figure 2 provides a classification of oil resources. The initial oil-in-place is divided into a part which is un-recoverable and the ultimately recoverable resources (URR). The URR is comprised of cumulative production and remaining recoverable resources which then again entails proven reserves, reserves growth - the projected increase in reserves in known fields - and as yet undiscovered resources that are judged likely to be ultimately producible using current technology. URRs can be defined either as technically recoverable, i.e. producible with current technology, or as technically and economically recoverable, meaning that they are exploitable at current oil prices. There are different classification systems for oil reserves and resources. Appendix 20 provides an overview of a classification of all liquid fuels.

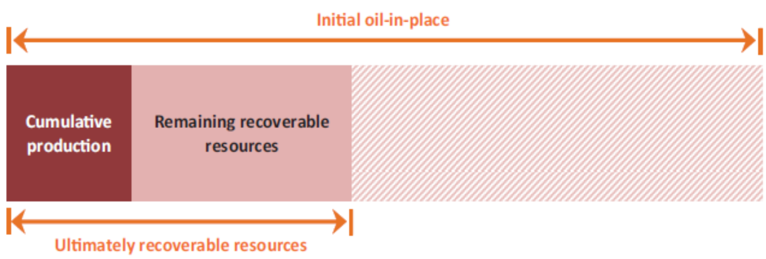


Figure 2: Classification of Global Oil Resources (*Source: IEA, 2013b*)

Technically recoverable resources are not necessarily economically recoverable, with a prominent example being the Arctic offshore undiscovered oil. Even if some offshore Arctic resource developments appear to be viable at current oil prices, exploitation will depend on gradual infrastructure developments and technological progress (IEA, 2013b).

Different types of oil reserves can be categorized by their probability of recovery (IEA, 2013b; Graefe, 2009):

- **Proved reserves** (1P or P90) - the amount of oil that has a more than 90% probability of being produced. This implies not only near certainty of the geological presence of the oil and of the ability to produce it at current oil prices, but also a high probability of implementation of an actual production project.
- **Probable reserves** (2P or P50) - the amount of oil that has a more than 50% probability of being produced as part of projects that have a high probability of being implemented. The uncertainty can be in the geology, the possible production rates or the economics of producing that part of the resources. 2P reserves are usually quoted as including 1P reserves or 'proven plus probable'.
- **Possible reserves** (3P or P10) - the amount of oil that has a more than 10% probability of being produced. The uncertainty usually reflects the availability of only limited information on the geology and the ability to produce. 3P reserves are usually quoted as including 1P and 2P reserves or 'proven plus probable plus possible'.

These reserves or resources can then be divided into conventional oil and unconventional oil, which mainly depends on the difficulty involved in extracting and producing the resource. The division between these two classes of oil is in practice an inexact and artificial one. There is no unique definition that allows for differentiation between them and what is unconventional today may be considered conventional tomorrow (IEA, 2013b). Conventional oil can be defined as oil that can be extracted and produced under existing (or foreseeable) technological and economic conditions and more technically, having a petroleum density (API gravity) of at least 22° and a resistance to flow (viscosity) of less than 11cP (centipoise; Graefe, 2009). Conventional oil includes crude oil, condensate and natural gas liquids and can be categorized in (IEA, 2013b; Miller & Sorrell, 2014):

- **Known oil** - including both cumulative production and reserves in known reservoirs.
- **Reserves growth** - an estimate of how much oil may be produced from known reservoirs on top of the 'known oil', based on improved knowledge of the reservoir and technology.
- **Undiscovered oil** - a basin-by-basin estimate of how much more oil may be found, based on knowledge of petroleum geology.

Unconventional resources can be defined as any petroleum liquid having less than 22° API gravity and a viscosity above 10,000cP and includes (Graefe, 2009; Miller & Sorrell, 2014):

- **Extra heavy oil** - crude oil with an API gravity of less than 10° and typical viscosity more than or equal to 10,000cP. Most current production is from the Orinoco belt in Venezuela.
- **Oil sands** (tar sands) - a near-surface mixture of sand, water, clay and bitumen, where the latter has an API gravity less than 10° and typical viscosity of 10,000-1,000,000cP. Most current production is from the Alberta tar sands in Canada.
- **Tight oil** (shale oil) - light crude oil contained in shale or carbonate rocks with very low permeability. Most current production is from the Bakken and Eagle Ford shales in the US.
- **Kerogen oil** ('oil shale' oil) - oil obtained from processing the kerogen contained in fine-grained sedimentary rocks. Not likely to become economic in the foreseeable future.

- **Gas-to-liquids** (GTLs) - derived through liquefaction of methane.
- **Coal-to-liquids** (CTLs) - derived by pyrolysis or gasification of coal.
- **Biofuels** - transport fuels derived from biological sources, mainly ethanol and biodiesel.

GTLs, CTLs and biofuels are generally termed 'synthetic oils', since these oils are not derived through natural processes.

3.2 Availability of Oil

At present, there are around 70,000 producing oil fields in the world, with only 25 fields accounting for one quarter of global production, 100 fields account for half of production and up to 500 fields account for two-thirds (Sorrell et al, 2010). Most of these 'giant' fields are relatively old, many well past their peak of production and most of the rest will begin to decline within the next decade and few new giant fields are expected to be found (see figures 3 and 4).

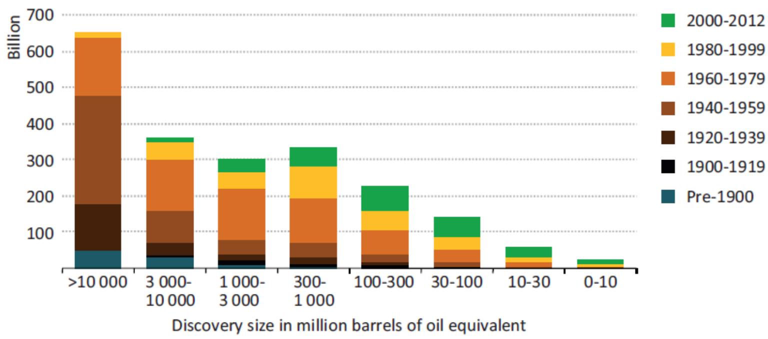


Figure 3: Conventional Crude Oil Resources by Field Size and Year of Discovery (*Source: IEA, 2013b*)

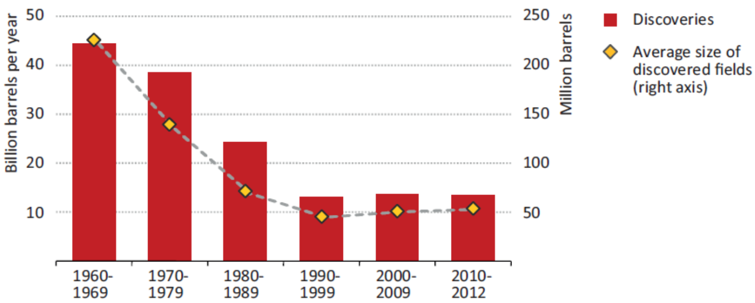


Figure 4: Observed Discovery Rates and Average Discovery Size (*Source: IEA, 2013b*)

At present, around 14 bbl of new discoveries are added each year to the recoverable resource estimate, in comparison with around 44 bbl per year in the period 1960-1969. Figure 5 presents an overview of the distribution of the global oil reserves by region, and the growth of reserves reported worldwide.

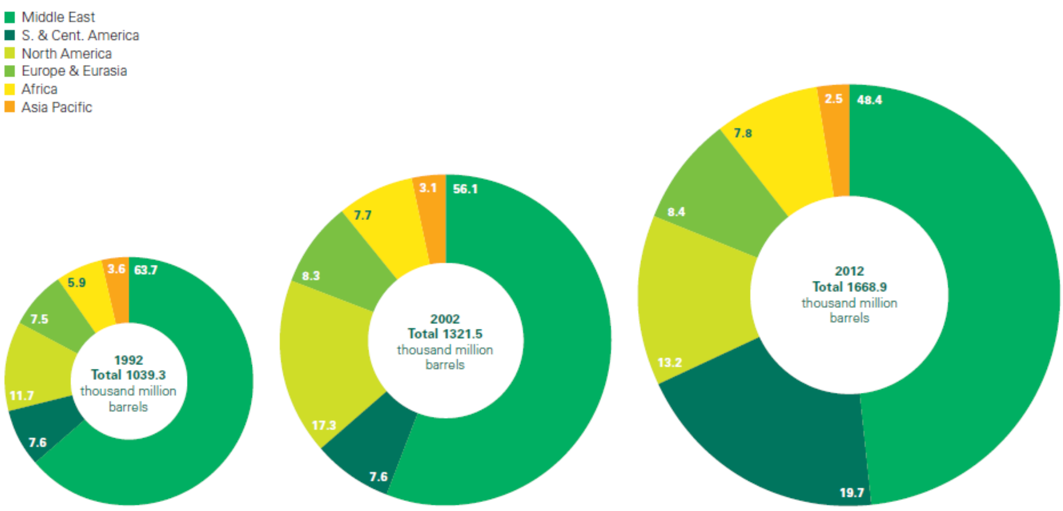


Figure 5: Distribution of Proved Reserves in 1992, 2002, 2012 [%] (*Source: BP, 2014;* note: of which Canadian Tar Sands: 167.8 Gb, Venezuelan Orinoco Extra Heavy Oil: 220.0 Gb)

World proved oil reserves at the end of 2012 reached 1668.9 bbl, which is sufficient to meet 52.9 years of current global production (BP, 2014). Estimates of the global ultimate recoverable resources (URR) for conventional oil vary widely in their definitions, methods, assumptions and results. Contemporary estimates now fall between 2000 bbl to 4300 bbl, compared to cumulative production through 2007 of 1128 bbl (Sorrell et al, 2010a). Adding natural gas liquids (NGLs) and unconventional oil more than doubles the size of the URR. However, resource estimates are inevitably subject to a considerable degree of uncertainty, which particularly true for unconventional resources that are very large, but still relatively poorly known in terms of the extent of the resource in place and judgements about how much might be technically recoverable (IEA, 2013b).

Estimates of the ultimately recoverable resources of individual fields tend to increase over time as a result of improved geological knowledge, better technology, changes in economic conditions and revisions to initially conservative reserve estimates. This process is currently adding more to global reserves each year than the discovery of new fields (Sorrell et al, 2010b). Reserve change is caused by production (downward), new discoveries (upward) and reserve growth (upward). Figure 6 presents an (history) overview of the resource-to-production ratios for different regions in the world.

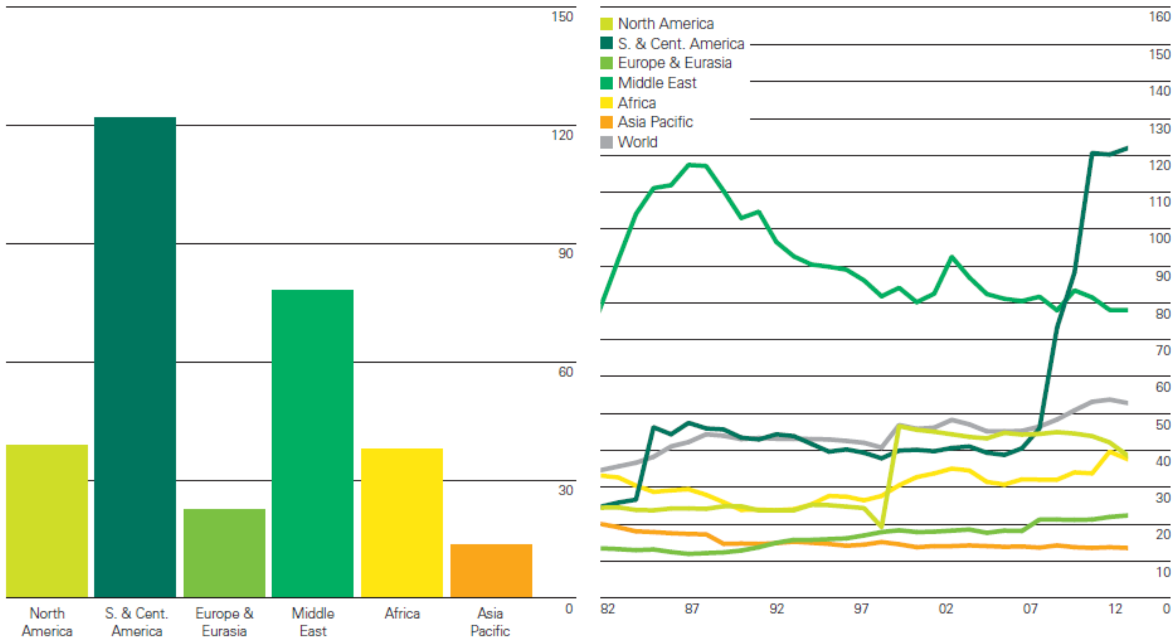


Figure 6: Reserves-to-Production (R/P) Ratios [yr] in 2012 by Region (left) and History Overview (right) (*Source: BP, 2014*)

The R/P ratio of South and Central America is the highest and exceeds 100 years, mainly due to Venezuelan extra heavy oil deposits in the Orinoco Belt. The world average R/P ratio stands at 52 years at present. Despite increased global production of oil and declining numbers of discoveries, the R/P ratio has increased over time. this is mainly due to reserve growth, the application of enhanced oil recovery (EOR) and more prominently changing technical- and economic conditions (the oil price).

Enhanced oil recovery techniques can extend global oil reserves once oil prices are high enough to make these techniques economic. The combination of an expected higher oil price in the future, and the fact that new giant fields are becoming increasingly difficult to find, is creating the conditions for extensive deployment of EOR (Muggeridge et al, 2014). The average recovery factor from mature oilfields around the world is somewhere between 20-40%. EOR involves injecting a fluid (type of fluid is dependent on the situation and discovery site) into an oil reservoir that increases oil recovery over that which would be achieved from just pressure maintenance by water or gas injection. This is sometimes confused with IOR, which means 'improved oil recovery' and entails better engineering, project management, seismic analysis or production methods. Using combinations of traditional EOR and IOR technologies, it has been possible to achieve recovery factors between 50-70% (Muggeridge et al, 2014). EOR is expected to unlock an additional 300 bbl on top of the current resource estimates (IEA, 2013b).

The oil industry must continually invest to replace the decline in production from existing fields. The rate of decline from all currently producing fields is at least 4% per year, which implies that at least 3 Mb/d of new capacity must be added each year to maintain production at current levels (Sorrell et al, 2010b). Decline rates are expected to increase over time as more giant fields enter decline, as production shifts towards smaller, younger and offshore fields (which decline faster) and as changing production methods lead to more rapid post-peak decline (enhanced oil recovery - EOR). This implies that more than two-thirds of current crude oil production capacity may need to be replaced by 2030 to prevent production from falling (Sorrell et al, 2010a; Leggett, 2014).

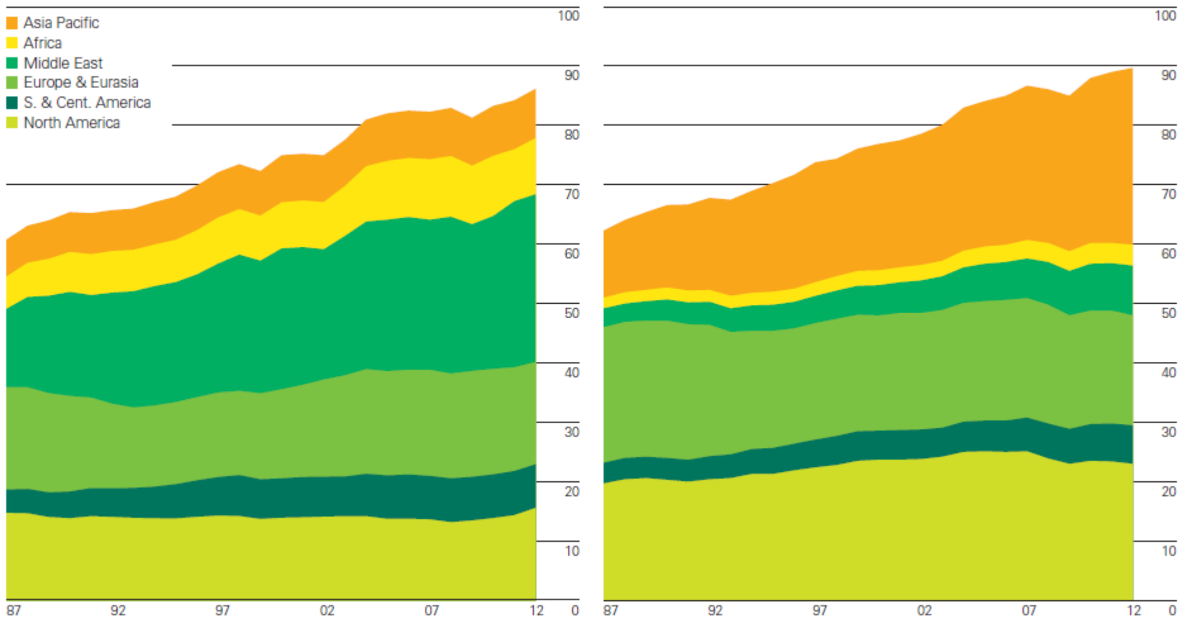


Figure 7: Oil Production by Region (left) and Consumption by Region (right) [Mb/d] (*Source: BP, 2014*)

Figure 7 provides an overview of oil production (left) and consumption (right) by region in 2012 which shows the 'mismatch' between supply and demand of oil products, most prominently true from the Middle East at present. Of the 86,152 million barrels of oil that were produced daily in 2012, 55,314 million barrels, or 64% was traded internationally, mostly by sea through various 'chokepoints' such as the Strait of Hormuz, the Strait of Malacca, the Suez Canal, the Strait of Bab el-Mandeb (Yergin, 2011; Gupta, 2008; BP, 2014). Figure 8 provides an overview of the major trade movements of oil around the globe, with the centre of oil exports being the Middle East.

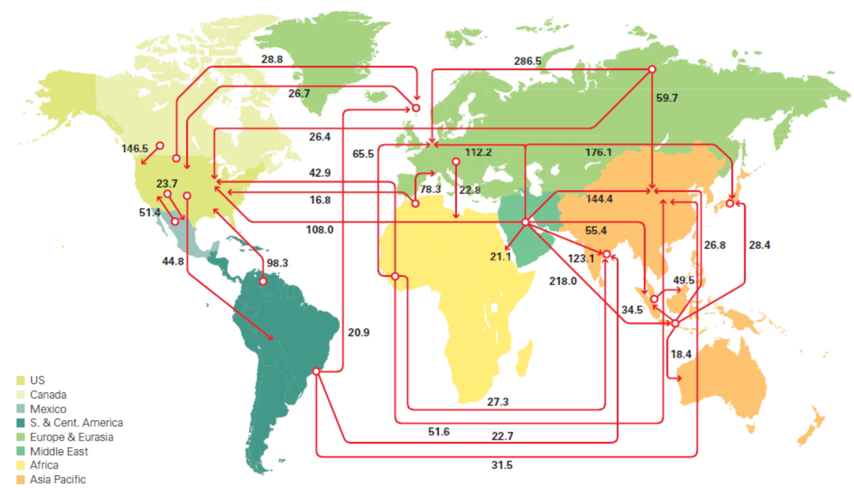


Figure 8: Major Trade Movements 2012 [Mt] (*Source: BP, 2014*)

3.3 Accessibility to Oil

The ability to access the available oil resources is one of the major challenges to securing energy supply. There are barriers to energy supply accessibility which are affected by geopolitical factors, geographical constraints and problems with workforce and technology (APERC, 2007). Geopolitical barriers are mainly present due to the distribution of reserves, as seen in figure 5, and by the differences in the type of ownership of these reserves. Four different types of ownership can be distinguished (IEA, 2013b):

- **National Oil Companies (NOCs)** - majority- or fully owned by their national governments, concentrating their operations on domestic territory, mainly found in the Middle East (Saudi Aramco, National Iranian Oil Company), Russia (Rosneft) and Latin America (PDVSA).
- **International National Oil Companies (INOCs)** - majority- or fully owned by their national governments but have significant international operations alongside their domestic holdings (PetroChina, Sinopec, Petrobras, CNOOC).
- **Majors** - privately-owned companies (BP, Chevron, ExxonMobil, Shell, Total, ConocoPhillips)
- **Independents** - majority privately-owned companies except the Majors (Lukoil, GDF Suez)

Nearly 80% of the world's 'proven plus probable' reserves, including both conventional and unconventional, are controlled by NOCs (see figure 9), and also include the reserves with the lowest average development and production costs. Remaining reserves are shared between the Majors (7%) and the Independents (13%). Around 40% of the reserves held by Independents consist of unconventional oil (IEA, 2013b).

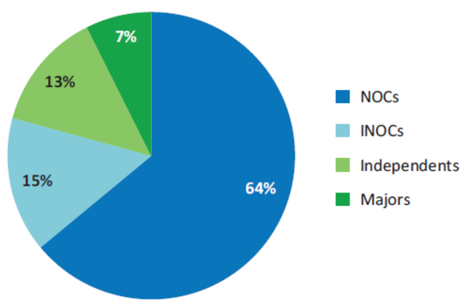


Figure 9: Ownership of 2P Oil Reserves by type of Company in 2012 (*Source: IEA, 2013b*)

In terms of the investment purpose, NOCs generally have different objectives than IOCs, as their investments are based on returns and profit margins, while NOCs may strive for economic independence, social benefits and both the economic and environmental sustainability of their reserves. However, NOCs might lack sufficient capital or technology to sustainably develop their oil resources while IOCs need access to new reserves. NOCs need access to the expertise of IOCs to develop the resources. As such, cooperation between NOCs and IOCs can benefit both parties by enhancing accessibility of new supplies which increases overall profits simultaneously (APERC, 2007).

Geographical constraints mainly consist of resources which are difficult to develop, like deep sea or arctic areas, having high development costs and environmental restrictions. However, the bulk of yet-to-find oil fields is expected to be in these type of regions, like Greenland or the Gulf of Mexico. The oil industry also faces a shortage of trained and technically qualified workers, which hinders the ability of the producing sector to find and develop required supplies (APERC, 2007; Leggett, 2014). Technological progress is needed to lower the development costs of unconventional oil, which is expected to supply future oil demand. Development costs of unconventional oil are higher than conventional oil and technology improvement are therefore essential to improve the economics of production for these reserves, thereby increasing the accessibility (APERC, 2007).

Oil demand is expected to rise in the coming decades, and with this rising trend in energy use, energy-related environmental impacts are expected to increase simultaneously. The acceptability of oil in terms of environmental impacts is discussed in more detail in sections 4.3 and 4.4.

3.4 Affordability of Oil

Historical trends show a high degree of oil price volatility (see figure 10).

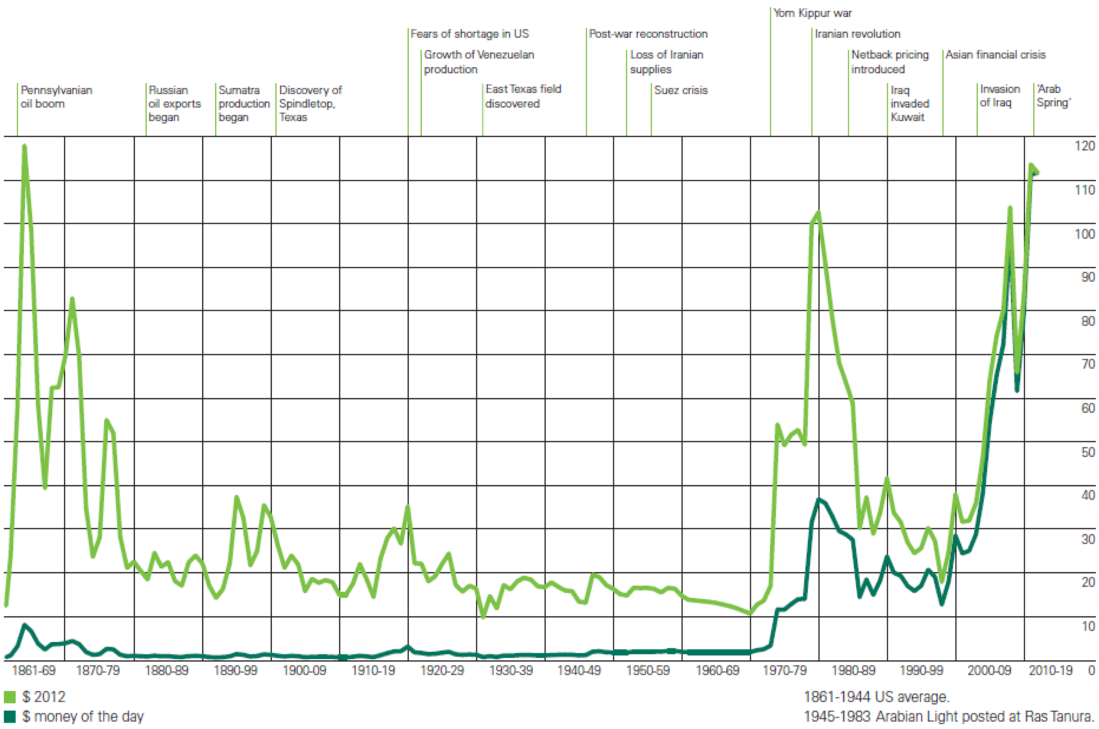


Figure 10: Crude Oil Prices 1861-2012 [US$/b] and World Events (*Source, BP 2014*)

Several factors contribute to these fluctuations, for instance geopolitical issues, imbalances between demand and supply or global financial crises. Investment in oil upstream exploration and development is highly correlated with oil price movements, which are then again affected by the timing of major oil companies' investments. Since IOCs have limited access to reserves and are critically influenced by host government's policies, and NOCs on the other hand have to deal with limited funding, expertise and technology, cooperation could lead to higher investment levels, which is currently not common (APERC, 2007; Leggett, 2014). Exploration costs dominate the major's capital expenditures and its share is increasing. Spending on global exploration has increased from the year 2000 and has recently flattened off (see figure 11). In addition, an effective way to enhance energy security and stable oil prices is to have oil stocks that function as a buffer against supply or price shocks. However, these stocks are very capital intensive (APERC, 2007).

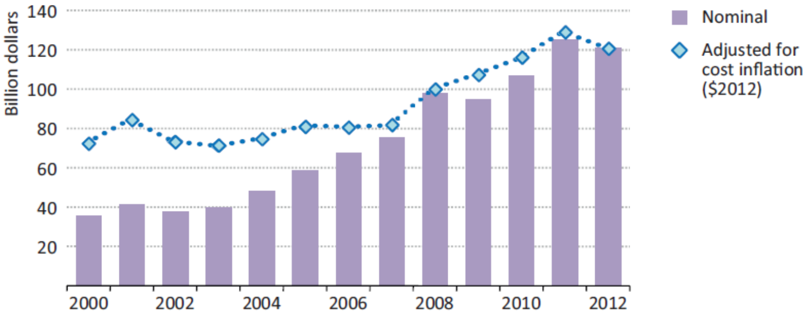


Figure 11: Global Exploration Spending 2000-2012 (*Source: IEA, 2013b*)

To conclude, the total global oil reserve base is large and can sustain current production for many years to come. However, many factors influence the actual size of the recoverable basin, as well as the cost of recovering these reserves in the future, which has a major impact on the supply mix of different types of oil resources, and their associated problems, which is a major topic of discussion. This debate will be elaborated upon in the following chapter on the concept of peak oil.

CHAPTER IV - THE CONCEPT OF PEAK OIL

Chapter III has discussed the main issues in the oil industry, and this chapter investigates the debate around the concept of peak oil, with its consequences for (projections of) future oil supply, not only in terms of the volume of future oil production, but also regarding potential problems in environmental-, economical- and political terms. Since the IEA's projections of future oil supply and demand - based on government data and reports from (inter)national oil-companies - have been criticized in scientific literature, it is important to address the risks that are associated with oil supply in a context of falling oil production. The concept of peak oil will be addressed first.

Since oil is a result of a natural process of millions of years of chemical reactions and accumulations of hydrocarbons, it follows that these are finite natural resources, being subject to depletion by mankind to fuel the economy. The current rate of global oil generation has been estimated at no more than a few million barrels per year, compared to global consumption of some 30 billion barrels per year (Miller & Sorrell, 2014). This means that production in any region starts following the initial discovery and ends when the resources are exhausted. The peak of production is normally passed when approximately half the total of a given reservoir has been taken, termed the midpoint of depletion (Campbell, 2014). The peak of oil discovery was passed in the 1960's, and the world started using more than was found in new fields in 1981. The gap between discovery and production has widened since (see figure 14). Peak oil is the point at which the depletion of existing oil reserves around the world can no longer be replaced by additions of new flow capacity. Oil production reaches the highest level it ever will, and drops (Leggett, 2014).

4.1 The Peak Oil Debate

Evidence for the concept of peak oil comes in part from the work of Shell Oil geologist Hubbert, who predicted that the US production would peak in 1970, closely matching actual peak production in 1971 (Chapman, 2014). Leggett (2014) describes the problem of a potential peak as follows: *'If we think of all the theoretically extractable oil under the ground as a tank, what we have to worry about is not so much the size of that tank, but the size of the taps: the actual global oil production capacity. Oil reserves under the ground are not the same as oil flows from production pipes at the surface'*. This statement essentially describes the debate around peak oil. The debate over peak oil has its roots in long-standing disputes between 'resource optimists' and 'resource pessimists', which have opposing standpoints on the issue, mainly due to differing incentives and views on the ultimately recoverable resource base, and the availability and recoverability of oil in the future.

Up until recently, peak oil was a major discussion point crossing from academic research into mainstream journalism, yet it now attracts far less interest (Chapman, 2014). There are several reasons for this. Leggett (2014) states that politicians and society can only handle 'one crisis at a time', referring to the deepest financial crisis since the 1930s. Chapman (2014) and Miller & Sorrell (2014) bring forward other arguments, mainly on interpretation of figures and incentives for under- or overestimating data on reserves and recoverability of oil. Many countries (including some important producers) have already passed their peak, suggesting that the world peak of production is now imminent. Many scientists and organisations, and even some major oil companies (Total) state that it is evident that the world faces the dawn of the 'Second Half of the Age of Oil', when this critical commodity, on which the entire world economy float, heads into decline due to natural depletion, and alternative sources being unable to fill the gap on the timescale required (Campbell, 2014; Leggett, 2014; Sorrell et al, 2010a).

In contrast, others argue that liquid fuels production will be sufficient to meet global demand well into the 21st century, as rising prices stimulate new discoveries, enhanced oil recovery and the development of non-conventional resources, such as deepwater oil, shale oil and oil sands (Sorrell et al, 2010b). Yergin, chairman of the influential oil industry consultancy Cambridge Energy Research Associates (CERA) states: '*I don't see why human genius can't meet the challenge of keeping production growing'*. The oil incumbency, having the incentive to remain optimistic with regards to oil reserves and future oil supply to keep the required investments flowing, obscures the significance of any scientific report on climate change (like the IPCC report) or on a possible peak in oil production. ExxonMobil simply states: '*The theory does not match the reality. Carbon dioxide: they call it pollution. We call it life'* (Leggett, 2014). Opposing scientists state that peak oil is not even a theory, its inevitability, only the timing is in doubt since oil is a finite resource. A CERA report in November 2006 essentially describes the motive of the oil incumbency to inaccurately present oil data by stating that peak oil theory was based on 'faulty analysis' and could 'distort debate'. '*Oil is simply too critical to the global economy to allow fear to replace careful analysis'* (Leggett, 2014).

The date at which the global peak in oil production is expected varies widely from 2005-2015 (early peak advocates) to 2017-no peak (late peak advocates; Chapman, 2014). Were valid data available in the public domain, it would be a simple matter to determine both the date of peak and the rate of subsequent decline. However, a maze of conflicting information, ambiguous definitions and lax and non-transparent reporting procedures are - in some case intentionally - blurring the larger picture of oil supply (Leggett, 2014; Campbell, 2014; Sorrell et al, 2010a). Many different sources produce and publicise different values of present oil supply and a large discrepancy can be seen in the reports which model future oil supply (see figure 12). Big changes occur at the beginning of the year when definition changes take place. Vague terms such as 'proved' (1P) and 'proved and probable' (2P) reserves are widely used and these are defined and interpreted in different ways with only limited progress towards standardisation (see section 3.1). Only a subset of global reserves is subject to formal reporting requirements and this is largely confined to the reporting of highly conservative 1P data for aggregate regions (Sorrell et al, 2010a). Most of the proven oil (1P) is in countries where information is provided by state monopolies, which need not necessarily comply with industry procedures. The assumptions on current technology and market conditions and the different bases of these measures give variations in results and may cause confusion. Observers can

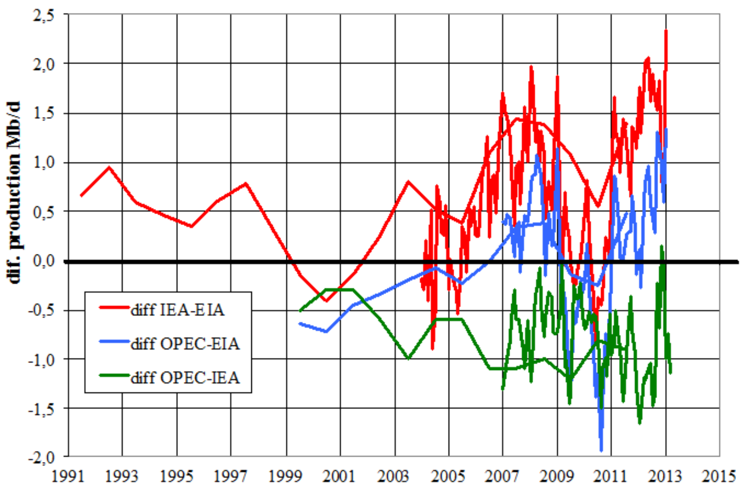


Figure 12: Annual and Monthly Difference from World Oil Supply between EIA, IEA and OPEC (*Source: The Oil Drum, 2013*)

look at the same fields using different definitions and come up with dissimilar figures. Therefore there are concerns that firms and countries may (un)intentionally, over- or under-report or leave estimates unchanged for years. The measurement of liquids, which are produced at dedicated plants alongside oil production sites, is also difficult in terms of definitions and reporting. A liquid, known as *condensate,* condenses naturally from gas at surface conditions of temperature and pressure, and may be treated as ordinary oil for most purposes. In addition, *natural gas liquids* (NGLs), mainly pentane and butane, are produced from different fields, making it difficult to attribute the production to the fields concerned (Campbell & Heapes, 2008). Even if firms or states adhere to the same classifications, the figures are only probability-based estimates with inherent assumptions about technology, operating conditions and the economic situation. Since these factors are constantly changing, reserves estimates can be significantly changed (see figure 5 in case of BP), without the real reserve quantity being affected (Chapman, 2014).

In addition to variations in methodology, there are political and financial incentives to misreport figures. The major international oil companies tend to report cautiously, being subject to strict Stock Exchange rules, whereas OPEC countries exaggerated during the 1980s when they were competing for quotas, based on a percentage of reported reserves, to benefit flow rates and therefore income (Campbell, 2014). As can be seen in figure 13, the claimed proved conventional oil reserves figures of the Middle East OPEC members increased by around 360 billion barrels between 1984 and 2011 (85%), despite constant production.

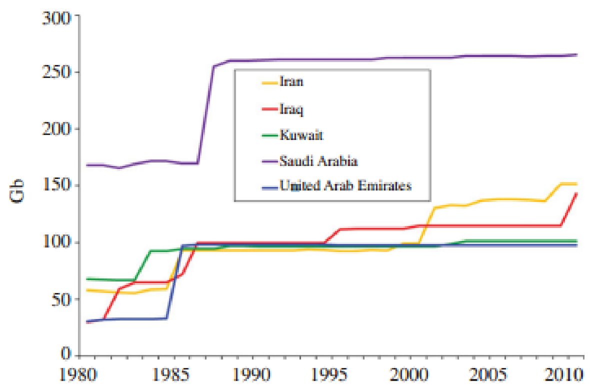


Figure 13: Annual Proved Reserves Estimates for Five Middle East States from 1980-2011 (*Source: Miller & Sorrell, 2014*; note: Saudi Arabia and the UAE produced 100Gb and 27Gb respectively during this period)

Highlighting problems with OPEC data, internal Kuwaiti documents state that actual proven reserves are nearer 24 billion barrels, than the 100 suggested. Saudi Arabia's figures are also challenged by ex-ARAMCO staff and may be overstated by nearly 40% (Chapman, 2014; Leggett, 2014). Evidence of this over-reporting is that 7 million barrels of sea water are being injected on a daily basis into the main field, Ghawar, which is a technique for maintaining pressure and providing oil at a higher rate of extraction. Figures have also been revised upwards in the case of OPEC member Venezuela, adding nearly 270 bbl since 1984, most of this reserves being extra-heavy-oil which require sustained high oil prices and improved technology to be extracted profitably and on a large scale.

Saudi Arabia is also the nation with the bulk of the spare oil production capacity and says to have the capacity to raise production by 2.5 million barrels per day if the market needed it. However, Citi Group published a report in 2012 on Saudi Arabia's domestic oil-consumption problem and its derivatives were being used for about half the kingdom's electricity production, growing at about 8% per year. If this continued, the kingdom risks becoming an oil importer within just 20 years. Many scientists and analysts doubt Saudi Arabia's ability to make up for any shortfall in global oil supply due to souring oil consumption and the stagnation of global crude oil since 2005 at around 74 million barrels a day, being persistent up to the present. A global downward trajectory of crude exports is expected, being a large threat to global oil supply (Leggett, 2014).

OPEC reserves contribute 72% of global oil, therefore non-OPEC countries only make up 28%. Of these reserves, Canada is the biggest producer due to figures recently revised to account for oil-tar sands, adding 175 billion barrels. Russia is the biggest non-OPEC conventional oil producer. However, Russia declared all oil data a state secret in 2004, making it difficult to accurately predict what remains as reserves (Chapman, 2014). Confidential and codified data on reserves make it very difficult to exactly predict global reserves and the IEA and also BP, who provide reports that are used by policy-makers worldwide simply follow this data in these reports. The overstatement and inaccuracy of data on worldwide reserves is not mentioned in the IEA *World Energy Outlook* or BP *Statistical Review of World Energy* and the use of this unreliable data is justified as *'supplemented information from governments and international organisations, energy companies and consulting firms'* (IEA, 2013b).

4.2 Global Oil Supply Forecasts

Forecasts of future global oil supply of conventional oil have been made using a wide range of modelling approaches and multiple assumptions, mostly along two dimensions: the shape of the future production profile and the assumed ultimately recoverable resource (URR) of conventional oil. Conventional oil forms a subset of *all oil* production, which also includes oil sands and extra heavy oil and tight oil, and this in turn forms a subset of *all liquids* production, which includes coal to liquids (CTL), gas to liquids (GTL) and biofuels. Crude oil is expected to be gradually replaced by unconventional oil production, however, numerous technical, economic and environmental constraints make a rapid expansion of non-conventional production extremely challenging (Sorrell et al, 2010a). Section 4.3. will elaborate on the potential role of unconventionals in future global oil supply.

The future supply of conventional oil will be shaped by multiple technical, economic and political factors, but the range of possibilities will be constrained by three physical features of the oil resource (Sorrell et al, 2010b):

- Production from individual fields normally rises to a peak or plateau, after which it declines as a result of falling pressure and/or breakthrough of water.
- Most of the oil in a region tends to be located in a small number of large fields, with the balance being located in a much larger number of small fields.

These large fields tend to be discovered relatively early, in part because they occupy a larger area. Subsequent discoveries tend to be progressively smaller and often require more

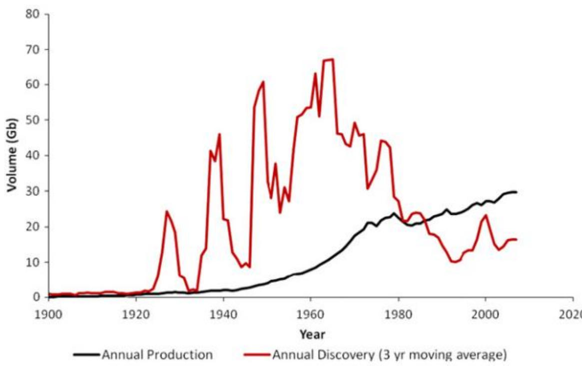


Figure 14: Global Trends in Production and Discovery of Conventional Oil (*Source: Sorrell et al, 2010b*)

effort to locate. Over half of the world's giant fields were discovered more than 50 years ago (see figure 14).

Most of the world's conventional oil was discovered between 1946 and 1980 and since that time annual production has exceeded annual discoveries. Reserve additions have been made each year however, by reserve growth at currently producing fields and some new discoveries (Sorrell et al, 2010a). The URR is the sum of cumulative production, future reserve growth at known fields and the volume of oil estimated to be economically recoverable from undiscovered fields, commonly termed yet-to-find (YTF). The global URR estimates are likely to increase over time as knowledge expands, prices increase and technology improves. The estimated quantity of remaining recoverable resources fall within the range 870-3170Gb. In other words, the highest estimate is nearly four times larger than the lowest estimate. However, the size of the URR does not have a large impact on the timing of the peak as an increase in the size of the remaining resource by 250% delays the peak by only 23 years (Sorrell et al, 2010b).

Another method of looking at the possible future global oil supply is to investigate depletion rates of existing fields. the depletion rate is the rate at which recoverable resources of a field or region are being produced, or the ratio of annual production to remaining recoverable resources. The maximum depletion rate of giant oil fields typically falls within a relatively narrow band, with a mean of 7.2%. The average depletion rate over the full production cycle of a field is typically much lower than the maximum rate, the global average rate being approximately 1.2% (Sorrell et al, 2010a). Depletion rates have a major impact on the availability of oil to the global economy as it represents '*the size of the taps*' as mentioned earlier by Leggett (2014).

Global crude oil supply has been on a plateau of around 74 million barrels per day since 2005. Crude plus condensate plus natural gas liquids have been on a plateau of 82 million barrels per day. What has changed is that total production in 2006 averaged 85.2 million barrels a day and in 2011 averaged 87.4 billion barrels a day, by adding 'all liquids' production made up of refinery gains, unconventional oil, biofuels and oil released from stockpiles (Leggett, 2014). Tanaka, the chief director of the IEA, states that by 2030, 106 million barrels a day will be needed to supply the growing demand by China and India. Due to depletion of existing fields at a rate of 6.7% per year, 64 million barrels a day of totally new production capacity will be needed on-stream in 2030, which is fully six times the production of the largest oil producing nation in the world, Saudi Arabia (Leggett, 2014). However, even though the IEA admits that crude oil production has peaked, it expects that there will not be a peak in the coming decades for all-oil production, but a gradual approach to a plateau of production around 101 million bbl/d in 2030 (IEA, 2013b).

This positive stance with regards to the increasing flow rate of oil is mainly fuelled by an - in the eyes of some scientists - overly optimistic growth rate in oil production capacity in Iraq. The country has announced its intention to raise production from its 2011 level of 2.5 to 12Mb/d by 2017, while the previous maximum output was some 3.5Mb/d in 1990. Although Iraq has already signed contracts with various IOCs and NOCs for much of this new production, the existing infrastructure is evidently inadequate for such volumes, and after decades of war and sanctions, it is widely understood to be heavily degraded and in need of replacement. It is unclear how sufficient infrastructure, almost equivalent to a new Saudi Arabia, could be built in just seven years. Furthermore, Iraq remains a politically unstable country, which makes the country vulnerable for many years by economic and political obstacles (Miller, 2011). The IEA admits that security concerns, infrastructure constraints and logistical difficulties are present in Iraq but remains positive with regards to future oil production (IEA, 2013b).

Another, upcoming category of reserves is the deepwater, pre-salt deposits, which can mainly be found in Brazil. The IEA (2013b) predicts in their NPS that oil production rises from 2.2Mb/d in 2012 to 6Mb/d in 2035. However, the complexity of their development and the scale of investment required are high. The State oil company Petrobras budgeted for Brazil's development of the deep-water sub-salt fields around $286,000 per b/d of installed capacity, which suggests that very high oil prices will be required before net profits are generated. At current prices it would take ten years to amortise the principal. Therefore, it is expected that oil production from Brazil's subsalt province will be far lower than optimists (like the IEA) expect unless prices rise substantially to improve the economics, at which point this will not be cheap oil (Miller, 2011).

The IEA was established as the formal body for supplying information and analysis on matters of global primary energy to the member states of the OECD. As such, its view of the likely future of oil supply is key to the formulation of both national policies in those states, and of commercial policies adopted by industry. These views are published annually in their World Energy Outlook and takes a long-term view up to 2035. The stance of the IEA is however constantly changing towards future oil supply and projections for 2035 have been revised downward year after year, from a maximum of 123 Mb/d by 2030 in the WEO 2004 (Miller, 2011). The IEA categorizes six different resource types and investigates them separately. Table 3 provides the figures as presented in the New Policies Scenario of world oil production by resource type in their WEO 2012. Biofuels and processing gains are excluded from these figures.

Table 3: World Oil Production by Type in the New Policies Scenario [Mb/d] (*Source: IEA, 2013b*) - * CAAGR: Compound Average Annual Growth Rate

	2012	2020	2030	2035	2012-2035 CAAGR*
Conventional	82.1	82.5	82.3	83.1	0.1%
Conventional crude oil	**69.4**	**67.7**	**65.5**	**65.4**	**-0.3%**
Existing fields	68.0	50.9	32.8	27.1	-3.9%
Yet-to-be-developed	n.a.	13.9	18.1	19.8	n.a.
Yet-to-be-found	n.a.	1.4	12.3	15.9	n.a.
Enhanced oil recovery	1.3	1.5	2.2	2.7	3.1%
Natural gas liquids	12.7	14.8	16.8	17.7	1.4%
Unconventional	**5.0**	**10.4**	**14.2**	**15.0**	**4.9%**
Of which light tight oil	2.0	4.7	5.9	5.6	4.7%
Total	**87.1**	**92.8**	**96.5**	**98.1**	**0.5%**

The IEA projections of future oil demand are driven by projections of population growth and economic development, and the relationship between gross domestic product and oil consumption. The association assumes a constant match of supply with growing demand. However, the underlying figures are confidential and there is no access to public data, so the figures can never be tested. The swings in the IEA's outlooks on future oil supply, from positive to negative and back again, was based upon several factors (Miller, 2011):

- A reduction in the overall rate of decline in oil production from 3.5-3.7 to 3.1 Mb/d per year. Critics are unable to verify the change without access to the IEA's confidential data and any such reduction could reasonably be a temporary effect arising from the current economic downturn.
- A rise in the forecasted future efficiency gain in oil use from 2% to 3% per year. Again, there is no convincing evidence for a permanent change, and any such reduction could reasonably be a temporary effect arising from the current economic downturn.
- Higher potential oil production from new sources, particularly Brazil, Iraq and the Canadian oil sands. All three sources have significant obstacles to growth, such as cost, environmental issues and resourcing.
- The IEA appears to count every yet-to-be-developed field as economically viable. It is likely that a significant portion, perhaps 25-50% can never be exploited at an affordable price and therefore does not qualify as cheap oil.
- In the IEA modelling, the required rate of production for both yet-to-be-developed and yet-to-find fields appear to be unrealistically high according to the industry's current experience.

Moreover, Sorrell et al (2010b) state that the following (unlikely) conditions must be met to achieve these high production rates, partly overlapping the abovementioned criticisms:

- Lower rates of oil demand growth than experienced in the past
- A global URR that is greater than 3600Gb
- A rapid decline in production following the peak of around 3%/year or more
- Cumulative production at the date of peak that exceeds 50% of the global URR, which is much greater than previously observed in the majority of post-peak regions
- Cumulative production at the date of peak that exceeds 60% of cumulative 2P discoveries, which is much greater than previously observed in the majority of post peak regions
- An annual rate of new discoveries over the period to 2030 that equals or exceeds that achieved over the last decade, reversing the trend of the last 40 years, despite the declining size of newly discovered fields and the widening gap between production and discoveries since the 1980s (see figure 15)
- An annual rate of reserve growth over the period to 2030 that equals or exceeds that achieved over the last decade, despite the growing share of newer, smaller and offshore fields that have less potential for reserve growth
- Depletion of these resources at an average rate that is several times greater than the maximum rate previously achieved in any oil-producing region
- Favourable 'above-ground' conditions including appropriate incentives for investment, sufficient access to prospective areas, and political stability, in all major oil-producing regions

Aleklett et al (2010) informally known as the 'Uppsala Group' analysed the IEA's WEO 2008 projections for future conventional crude oil production, and came to similar conclusions as Sorrell et al (2010b) and Miller (2011). The WEO 2008 was the most pessimistic projection from the IEA, but the Uppsala Group found that it was still demonstrably optimistic in its assumptions and methodology. Aleklett et al (2010) analyzed every category of reserve type (like in table 3) in the IEA WEO 2008 and found that world oil supply by 2030 will only be 75.8Mb/d. The figures for crude oil from currently producing fields have been found to be sound and there is no substantial difference and nothing to object to in the IEA's outlook. However, the only conclusion that can be made is that significant new capacity additions will be required to offset decline in existing production, and the immense scale of this challenge seems to be adequately understood by the IEA (Aleklett et al, 2010). However, in the IEA WEO 2012, these figures are upgraded again to 32.8Mb/d in 2030 in comparison to 27.1Mb/d in the WEO 2008. This difference of 5.7Mb/d in 2030 has not been discussed by Aleklett et al (2010) since only the WEO 2008 has been analyzed.

For fields yet-to-be-developed, Aleklett et al (2010) conclude that the IEA figures are highly optimistic and are only possible with unreasonably high depletion rates. The Uppsala obtains a very different future outlook for field yet-to-be-developed (YTD) when depletion behaviour, consistent with historical experience and production policies (OPEC production policies with low, sustainable, depletion rates) are applied, with 13.5Mb/d being produced from these fields in 2030. And even though this projection is much lower than the from the IEA (18.1Mb/d in 2030; IEA, 2013b), it can still be considered rather optimistic as the YTD reserves of 257Gb in the WEO 2008 are located in 1874 fields that should come into production during the next 20 years. This means 8 fields per month coming on stream during that period, with a significant proportion of these fields being developed at a pace equal to that of the North Sea - having the highest depletion rate ever measured. Even if the oil exists, it is questionable whether the necessary investment needed to produce in such a rapid pace of development can be achieved in timely fashion (Aleklett et al, 2010).

In the WEO 2008 Reference Scenario, 16% of total global oil production is predicted to come from fields yet-to-be-found (YTF) and is expected to be around 114Gb with an assumed production rate of 19Mb/d in 2030. This figure is revised in the WEO 2012 to 12.3Mb/d (IEA, 2013b). This number is based on unrealistically high depletion rates, never before seen in history, without providing any justification for this dramatic deviation from historical behaviour. The Uppsala Group expects a production rate of YTF fields to be 9Mb/d in 2030 to be realistic, considering even optimistic 'North Sea' depletion rates (Aleklett et al, 2010).

In the WEO 2004, additional enhanced oil recovery (EOR) was estimated to be in the order of 25Mb/d by 2030. In the WEO 2008, this number has been reduced to 6.4Mb/d and in the WEO 2012 further revised downward to 2.2Mb/d in 2030 (Aleklett et al, 2010; IEA, 2013b). The IEA attributes great importance to CO_2-injection, and the Uppsala Group believes that the oil industry will use any and all means available to increase oil production from old fields because the decline in production from existing fields will be severe (Aleklett et al, 2010; Höök et al, 2014a). Currently, only a small fraction of the world's oil fields are using EOR since most EOR processes are more expensive to implement than a conventional water flood and only become economically attractive for larger oilfields in times of high oil prices (Muggeridge et al, 2014). The response to the application of EOR techniques in terms of increased oil production rate is usually slow, typically months or years after the process is initiated. These issues, combined with the use of large quantities of expensive chemicals or valuable hydrocarbon gases means that they are only economical when the oil price is high (Muggeridge et al, 2014), causing the growth in implementation to be halted severely.

Natural gas liquids (NGLs) are expected to deliver approximately 18% of total global oil supply in 2030 in the WEO 2012. The chosen unit of measurement in this case is barrels per day following the convention used for oil. However, this is misleading in the case of NGL, since the energy content of NGL is significantly less than the energy content of a standard barrel of oil. One barrel of NGL can only replace 0.7 barrels of oil in terms of energy and thus, the figure for NGLs should be multiplied by this ratio, bringing the figure down to 11.8Mboe/d in 2030. The WEO 2008 states: *'output of natural gas liquids, that are produced together with natural gas and recovered in separation facilities or processing plants - is expected to grow rapidly over the Outlook period. Global NGL production is project to almost double in 2030, driven by the steady rise in natural gas output'.* However, the IEA projects world gas production to increase with 47% up to 2030 in comparison to 2007. At the same time NGL production is expected to increase by 90%, which is not consistent with the assumptions made. The figures as estimated by the IEA seem unrealistically high with regards to natural gas liquids (Aleklett et al, 2010; IEA, 2013b). The Uppsala Group revised the projected NGL-content adjusted figure downward with 23% in the projected period from the WEO 2008, so the NGLs contribution in 2030 will be adjusted to 9.1Mb/d in 2030 with regards to the WEO 2012 (IEA, 2013b; Aleklett et al, 2010).

Estimates of the URR of all-oil by the IEA are large, 7119Gb. In interpreting these numbers, it is essential to recognize that large quantities of resources do not provide a guarantee that these can be produced at particular rates and/or at reasonable cost. There are variations both within and between resource types in terms of size of accumulation, depth, accessibility, chemical composition, energy content, extraction cost, net energy yield, local and global environmental impacts and the feasible rate of extraction as well as the geopolitics of access (Miller & Sorrell, 2014). Higher quality resources tend to be found and developed first, and as production continues, increasing reliance must be placed on less accessible, poorer quality and more expensive resources that have a progressively lower net energy yield and are increasingly difficult to produce at high rates. This is especially true for unconventional oil, which will be discussed in the following section.

4.3 The Potential Role of Unconventional Oil Production in Future Oil Supply

A peak in conventional oil supply will only be associated with a peak in liquid fuels supply if non-conventional sources are unable to substitute in a sufficiently timely fashion. However, numerous technical, economic and environmental constraints make a rapid expansion of non-conventional oil production extremely challenging. An estimate of a 'crash-programme' to develop the Canadian oil sands could deliver only 5mb/d by 2030, which is less than 6% of the IEA projection of global liquid fuels demand in 2030, with other non-conventional sources being projected to deliver much smaller volumes (Sorrell et al, 2010a). These alternative sources of oil are by some scientists expected to be unable to fill the gap at acceptable cost on the time scale required. Countering this, other commentators argue that rising oil prices would stimulate the discovery and enhanced recovery of conventional oil, the development of non-conventional resources such as oil sands, and the diffusion of substitutes such as biofuels and electric vehicles (Miller & Sorrell, 2014).

Unconventionals are expected to supply 15.0Mb/d in the WEO 2012 of the IEA in 2035, with an compound average annual growth rate of 4.9% (IEA, 2013b). In the WEO 2008, non-conventional oil is anticipated to increase to 8.8Mb/d by 2030 with an average annual growth rate of 8%, comparable to the rate of development of the oil boom following the Second World War. The Uppsala Group expects global output from unconventionals to reach 6.5Mb/d in 2035, which is 8.5Mb/d less than the WEO 2012 figures. However, since the research done by the Uppsala Group has preceded the rapid expansion of unconventional oil production in mainly the US and Canada, these figures will be re-evaluated below.

Unconventional fossil hydrocarbons fall into two categories: resource plays and conversion-sourced hydrocarbons. Resource plays involve the production of accumulations of solid, liquid or gaseous (not discussed here) hydrocarbons that have been generated over geological time from organic matter in source rocks, and include (Chew, 2014): solids (bitumen; e.g. oil sands in Alberta, Canada) and liquids (extra heavy oil; e.g. Orinoco Belt, Venezuela, and tight oil; Bakken Shale and Eagle Ford Shale, US/Canada). These unconventional hydrocarbons comprise accumulations of hydrocarbons that are trapped in an unconventional manner and/or whose economic exploitation requires complex and technically advanced production methods (Chew, 2014).

Tight oil or light tight oil (LTO), is mostly found in the US, and less prominently in Canada (expected production of 500kb/d in 2035), with Russia (450kb/d in 2035), China (210kb/d in 2035) and Argentina (220kb/d in 2035) having major, undeveloped and mostly unknown deposits as well (Chew, 2014; IEA, 2013b). The oil volume ranges from 10 to 500Gb in the US but recoverable volumes will probably amount to only a few percent. The US EIA estimates that total US tight oil production reached 2.0Mb/d in 2012 and will peak at around 2.8Mb/d in 2020. However, the IEA (2013b) expects the light tight oil revolution to speed up in the future and production is expected to increase to 5.6Mb/d (37% of total unconventional oil production in the US) in 2035, with no major expansion of LTO outside the US for the projected period (IEA, 2013b). The rise in tight oil production has been extremely fast (IEA, 2013b), and is not even mentioned in the research by Aleklett et al (2010). Total tight oil production is projected to be 4.2Mb/d in 2035 adding the more reserved estimate of the US EIA and the smaller fractions for Canada, Russia, China and Argentina.

Canada has one of the largest oil reserves, mainly due to the large volumes of oil sands or bitumen in the Alberta area. The IEA (2013b) expects oil sands in Canada to produce 4.3Mb/d in 2035, up from 1.8Mb/d in 2012. While the resources are unquestionably large enough to support such an expansion, achieving it is contingent on the construction of major new pipelines to enable the crude to be exported to Asia and the United States. Aleklett et al (2010) from the Uppsala Group expects future oil supply from oil sands to reach 3.9Mb/d in 2030. The numbers have been revised downward by the IEA in their WEO over time as expectations were lowered due to lower investments. The global in place bitumen resource is likely to exceed 3,000Gb, with the oil sands in the Alberta region alone having an ultimate potential of 2,500Gb, approximately twice the volume of liquid hydrocarbons that has been produced throughout the world over the past 150 years (Chew, 2014). However, only a fraction can ever be recovered and this fraction is estimated to be around 15-20% (APERC, 2007; Kjärstad & Johnsson, 2009). Russia, Kazakhstan and the US also have considerable deposits of oil sands but major development of these resources in not expected in the projected period.

Estimated worldwide resources of heavy and extra-heavy oil are substantial and located primarily in Venezuela. Russia and the US are also major resource holders. The latest estimate of the Venezuelan State company PDVSA of established recoverable resources is around 262Gb from an in-place resource of 1338Gb, which implies a recovery factor of 20%. Current projects in the country developed up to date have a recovery factor of only 8%, but this can be increased by more modern production methods (Chew, 2014). Kjärstad & Johnsson (2009) provide a recovery factor of 20%, while APERC (2007) gives an estimate of 15%. The IEA classifies extra-heavy oil as conventional oil, and its production is not discussed in great detail, so the reason for this classification remains unclear. Aleklett et al (2010) expects the production in 2030 to be 0.7Mb/d, and this is seen as compliant with the IEA WEO 2008 figures. However, the IEA (2013b) has revised its figures in the WEO 2012 upward with an expected total production of 3.3Mb/d in 2035, up from 2.7Mb/d in 2012. However, production from the extra-heavy oil in the Orinoco Belt is expected to stagnate, due to a lack of investment by the PDVSA, and policies that have discouraged foreign investment. There are view signs of a change of course under the new president. Given that PDVSA revenues are a vital source for government expenditure, the squeeze on funds available for investment is likely to continue, making a rapid reversal in declining crude oil and NGLs production unlikely (IEA, 2013b). Chew (2010) expects total output from the Orinoco Belt in Venezuela to reach 2.3 Mb/d in 2021 if all projects proceed as scheduled. For this research, a slower implementation of production capacity is predicted so this figure is projected to be reached by 2030.

The second category of unconventional hydrocarbons, comprises gas (not considered here) and liquids manufactured from coal- (CTLs), gas- (GTLs), or organic rich shales (kerogen) and non-geological biofuels (Chew, 2014; not considered here. For a detailed elaboration on the role of biofuels in substituting conventional oil in future global oil supply, see: Timilsina, 2014).

Current world capacity of hydrocarbon liquefaction is around 400kb/d, providing a marginal share of the global liquid fuel supply (Höök et al, 2014b). Rapid growth is envisaged by the IEA (2013b) in their WEO 2012 for GTLs output in the latter part of the projection period, with the largest volumes coming from Qatar and North America, and in CTLs production, primarily in China with South Africa, Australia, Indonesia and the United States also contributing. Despite the size of the resource base, production of kerogen oil remains marginal because of relatively high costs and environmental concerns (see figure 15). Total CTL and GTL output in 2035 is expected by the IEA to be around 2Mb/d in 2035 (IEA, 2013b). However, these numbers seem optimistic as there are vital technical-, economic-, environmental- and supply-chain issues (only 6 countries in the world have large enough coal reserves for viability of coal liquefaction) involved with hydrocarbon liquefaction. First, significant amounts of coal (an estimated 1-3 b/tonne of coal) and gas (283m^3/b) would be required to obtain anything more than a marginal production of liquids. Second, the economics of CTL plants are prohibitive, but are better for GTL. Large-scale GTL plants still require very high upfront costs, and for three GTL plants out of four at present, the final cost has been approximately three times that initially

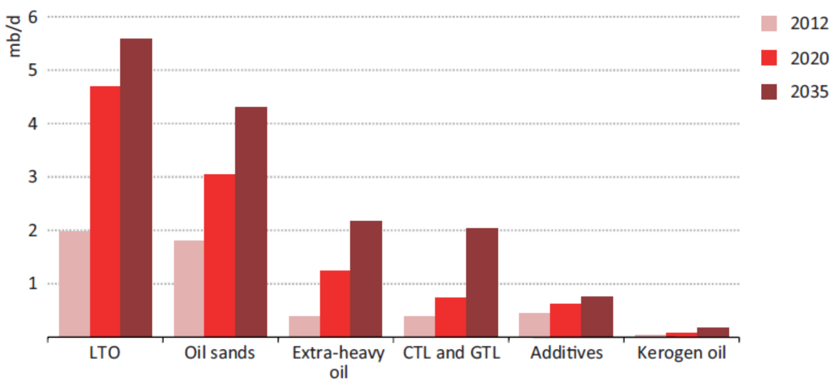


Figure 15: Unconventional Oil Production in the NPS (*Source: IEA, 2013b*)

budgeted. The costs of CTL varies from around 50-110 US$/b. Third, both CTL and GTL incur significant environmental impacts, ranging from increased greenhouse gas emissions to water contamination (acidity and particulate matter) and water requirements (6-9 tonnes of freshwater/ton of synthetic oil).

For the abovementioned reasons, The Uppsala Group (Aleklett et al, 2010) conclude that the CTL and GTL output expectations are optimistic and only vaguely justified, and not achievable if proper investments and development is pursued. The IEA estimates GTL production to be 0.65Mb/d in 2030 and 1.0Mb/d for CTL output in 2030 (Aleklett et al, 2010).

Additives, or chemical additives are barely mentioned in the WEO 2008 and the increase expected by the IEA in their WEO 2012 is seen as unrealistic by the Uppsala Group. The contribution of chemical additives will remain at 0,2Mb/d up to 2030 (Aleklett et al, 2010). Processing gains are expected to be correctly projected in the IEA figures.

Comparing the WEO 2012 figures for total oil consumption with the figures from the Uppsala Group gives a difference of 23.4Mb/d of global oil output in 2030 (see table 4). The difference is mainly due to an optimistic view on the development of unconventionals, a contribution of NGLs that is unachievable and methodologically incorrect, and projections for crude oil production with unrealistically high depletion rates.

Table 4: Comparison of the IEA WEO 2012 Oil Supply Projections with the Uppsala Group Oil Supply Projections for 2030 [Mb/d]

Fractions defined by IEA in WEO 2012	Oil production from IEA WEO 2012 in 2030	Oil production figures from the Uppsala Group in 2030
Crude oil - currently producing fields	32.8	27.1
Crude oil - to be developed	18.1	13.5
Crude oil - new discoveries	12.3	9.0
Crude oil - EOR	2.2	2.2
Crude oil - Total	**65.5**	**51.8**
Non-conventional oil	14.2	12.1
Natural gas liquids	16.8	9.1
Sum of all fractions	**96.4**	**73.0**
Processing gains	2.6	2.6
World oil supply	**99.0**	**75.6**

4.4 Potential Problems in Unconventional Oil Production and the Carbon Budget

The abovementioned projected production figures of the IEA have been revised to account for problems in recoverability and availability of oil resources in the world. These problems are particularly present in the case of unconventional oil production. However, global oil supply is expected to become increasingly reliant on unconventionals as crude oil supply falls over time (IEA, 2013b). It is therefore worthwhile to address the main problems in unconventional oil production to assess the major economic-, technical- and environmental impacts of this shift towards this oil type. It is expected that the role of unconventionals is only limited in terms of production volume in the future, which has consequences for future oil supply in the Uppsala Scenario in this report.

Unconventional hydrocarbons share some similar downsides. Compared with conventional exploration and production, drilling and completing a producing well is complex, and therefore expensive. Certain processes, such as oil upgrading are capital intensive. There is a relatively low energy return on investment (EROI), which in turn, generally results in relatively high GHG emissions per unit of production. Production methods may require significant volumes of water, causing groundwater contamination, since chemical additives are added to the injected fluids in hydraulic fracturing or liquefaction (Chew, 2014). LTO and tar sands are expected to account for the largest part of unconventional oil production in the future and will be discussed below (IEA, 2013b).

There are major problems with tight oil extraction. A typical North Dakota Bakken well has an initial production rate of 900b/d and is forecast to decline to 65b/d after 5 years, to 20b/d after 25 years, producing around 615,000 barrels of oil over it productive lifetime. Large numbers of wells will therefore be required to recover the full potential of a shale and it is estimated that 36,000 wells will be needed over the next 20 years, costing an average of US$9 million to drill and complete. The newly placed wells are currently only offsetting the steep decline in older wells (Chew, 2014). The IEA (2013b) estimates that maintaining the Bakken production at 1Mb/d will require drilling around 2,500 new wells per year. In comparison, maintaining output of 1Mb/d at a large conventional field in southern Iraq would require only around 60 wells per year. This requires continuous investment and drilling, only to offset the large initial decline rates for individual wells. The Uppsala Group estimates that only 1-2% of the tight oil resources as mentioned in the IEA WEO 2012 are recoverable. America has been drilling 25,000 wells per year, each costing US$10 million, to bring production levels back to 2000 levels. Oil drilling has recently turned down in the US, and tight oil reservoirs have been overstated by a minimum of 100-500%, according to actual well production data (Leggett, 2014).

The slow development of increased production rates of the Canadian tar sands is mainly due to the standstill following the economic downturn in 2008. However, old plans are being re-started and new projects lined up. Investment in tar sands production from ExxonMobil, Shell and BP had been US$60 billion in 2007 alone, and have not led to increased production (Leggett, 2014). Also, Canadian tar sands oil output is only marginally profitable at current oil prices, with the typical cost being around US$65/barrel, and one proposed expansion at Shell's Athabasca site will cost US$143,000 per b/d of installed capacity (Miller, 2011). Besides the high investment costs, major difficulties regarding environmental damage, water and gas supply and skilled labour shortages hinder the fast development of these resources significantly. Environmental damage is caused by removing two million tonnes of ore each day in the Alberta fields, leaving large open pits in the environment, following major deforestation programs. It requires 3.4 barrels of water per barrel of bitumen produced (Chew, 2014), and only 10% of the water injected can be returned to the natural water basins as the water is heavily polluted with chemicals, being left in large, toxic open ponds (APERC, 2007). During the process, large amounts of SO_2, NO_x, H_2S, CO, ozone and particulate emissions are released into the air (Chew, 2014).

Since unconventional oil is generally harder to extract than conventional oil, it has a lower energy return on energy investment (EROEI). *Net energy* is commonly defined as the difference between the energy acquired from a given source, and the energy used to obtain and deliver that energy, measured over a full life cycle - net energy = E_{out} - E_{in}). A related concept is the *energy return on energy investment*, defined as the ratio: EROI (or EROEI) = E_{out}/E_{in}. The average global EROI is 17 and declining from an average of 30 in 2000, while for the US the average EROI has declined from 20 in 1970 to 11 in 2014. The EROI of oil production from ultra-deep-water areas is most probably lower than 10 and producing oil from shale oil (LTO) gives an EROI of roughly 1.5 (Murphy, 2014). Results from literature, as summarized in Murphy (2014) of different EROI investigations are:

- There appears to be a negative exponential relationship between the aggregate EROI of oil production and oil prices.
- There appears to be a comparable relationship between EROI and the potential profitability of oil-producing firms.
- The relationship between EROI and profitability appears to become non-linear as the EROI declines below 10.
- The minimum oil price needed to increase global oil supply in the near term is comparable to that which has triggered economic recessions in the past.

If society were to transition from an energy source with an EROI of 11 to one with an EROI of 5, then gross energy production would have to increase by 14% simply to maintain the same net energy flow to society. The implication of these arguments is that, if the world pursues growth by using sources of energy with a lower EROI, perhaps by transitioning to unconventional fossil fuels, long-term economic growth will become harder to achieve and come at an increasingly higher financial, energetic and environmental cost (Murphy, 2014).

The higher financial costs of producing oil resources becomes apparent in the worldwide upstream oil and gas investment of the oil-producing companies (see figure 16).

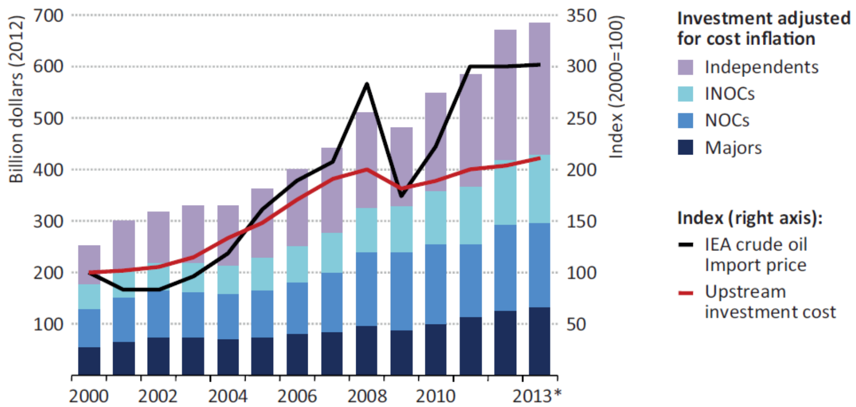


Figure 16: Worldwide Upstream Oil and Gas Investment (*Source: IEA, 2013b*)

Annual global upstream oil and gas investment increased in real terms almost three times between 2000 and 2013. However, total output hardly increased in the same period. In 2013, the 70 largest energy companies invested a total of $573 billion in upstream activities (IEA, 2013b). The IEA estimates that the total investment required in upstream oil activities for the period from 2013 to 2035 is around $9.4 trillion (2012 US$) in the New Policies Scenario. The ability to invest over a period of decades is subject to a number of potential barriers. It is expected that the bulk of investments up to the 2020s will come from private companies, broadly in line with the gradual expansion of non-OPEC supply (mainly LTO and tar sands production increases). However, reliance on additional oil capacity is placed on OPEC countries after this period. Some additional considerations become more prominent, being the policies of major resource-owning countries, rising government call on oil revenue in some major producing countries and the related possibility that oil revenues could be so apportioned as to leave the upstream short of capital for investment. At the same time, instability and other political considerations provide an unpredictable basis for future oil supply, with the conflict in Syria and the economic sanctions imposed by the United States and the European Union on Iran and more recently on Russia, provide two recent examples (IEA, 2013b). As crude oil production has peaked, global oil supply shifts to unconventional oil for 'filling the gap' with increasing demand. However, as figure 17 depicts, marginal costs of these resources are higher and can reach US$160/b (Miller & Sorrell, 2014). It becomes increasingly difficult, at current oil prices to invest in new oil production capacity where the marginal costs of production are this high, and therefore return on investment is low or even negative. Future investment in global oil supply capacity is therefore questionable into these 'new resources'.

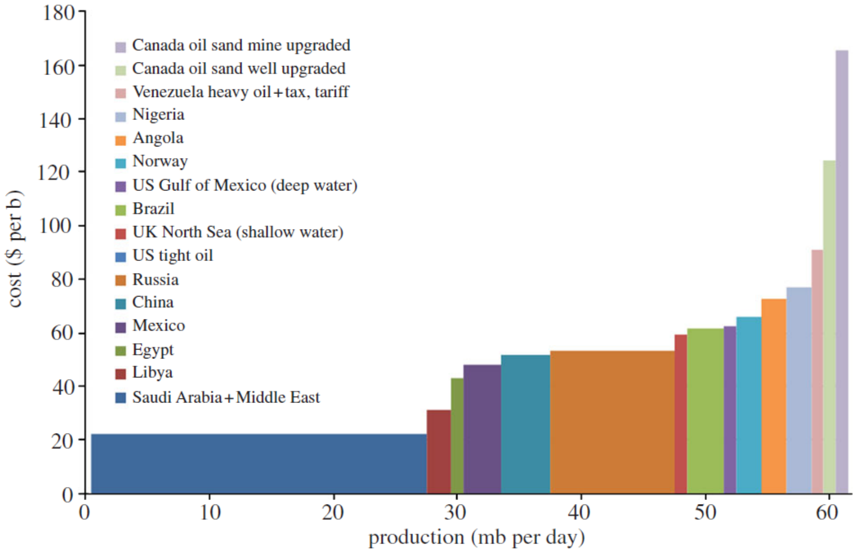
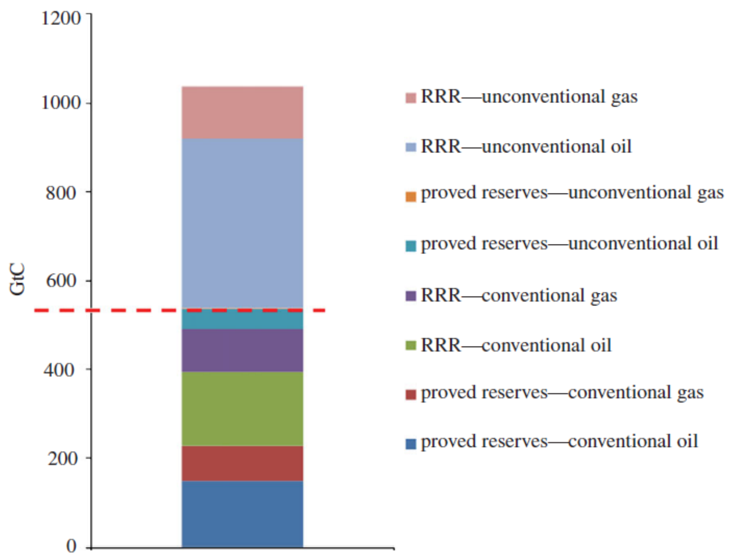


Figure 17: Estimated Production Costs of Various Oil Resources (*Source: Miller & Sorrell, 2014*)

As explained above, these resources have a lower EROI and have a higher carbon intensity. Ambitious targets for reducing carbon emissions are likely to be inconsistent with expanding the supply of non-conventional liquids. Avoiding dangerous climate change requires the bulk of these resources to remain untapped (Miller & Sorrell, 2014). Several modelling studies suggest that the most probable cumulative emissions for an average global temperature increase of 2°C is around 1,100Gt of carbon. Given that humanity has already emitted some 550Gt of carbon (to end 2011), meeting the 2°C target requires the future cumulative emissions to remain below a similar value,

Figure 18: Oil and Gas Resources and Cumulative Carbon Emissions (*Source: Miller & Sorrell, 2014*)



approximately 550Gt. As figure 18 indicates, such a threshold will be reached if the remaining recoverable resources (RRR) of conventional oil and gas are used, together with the proved reserves of oil sands and extra-heavy oil. However, this analysis ignores the emissions from coal combustion, which are currently 70% of those from oil and gas and are increasing more rapidly. As a result, the allowable 'budget' of oil and gas resources is much less than indicated here, which implies that only some of the conventional oil and gas resources can be used.

These reserves are listed as company assets on stock exchanges, and assuming the investment level of 2013 will stay the same, oil, gas and coal companies are going to invest another six trillion dollars over the coming decade on turning fossil-fuel deposits into reserves (Leggett, 2014). This is mentioned by the IEA as *stranded assets* and is not paid much attention to in their WEO 2012 (EIA, 2013b). However, since only around 20% of these reserves can be produced to stay under the 2°C threshold, new and stricter climate regulations can turn these investments into a bubble with an enormous impact on the global economy. This is known as the Carbon Bubble (Leggett, 2014).

Most of the factors mentioned above are likely to continue to hamper unconventional oil production in the foreseeable future and it is therefore also possible that global oil production may peak or plateau in a relatively near future, not as a consequence of limited resources but because too many factors over long time constrain investments into exploration and production (Kjärstad & Johnsson, 2009). The modern global economy has been built on cheap energy and history shows that higher oil prices will have a serious negative effect on already weak growth and trade. There is a growing realisation that peak oil should be acknowledged as part of a complex energy situation with the realisation that cheap fuel is no longer available and we now face circumstances where prices will increase and high energy-based growth will be limited (Chapman, 2014).

The following chapter deals with measuring the concept of energy security and more specifically, external oil supply risks for major oil importing nations, taking into account the projections of future oil supply as mentioned in this chapter.

The preceding chapters have shown that future oil supply is subject to intense debate and clear and public data is hardly available on the underlying figures for projections of oil production at present, and more prominently in the future. Since the five economies investigated in this report are dependent on oil imports for keeping their economies growing, it is essential to measure the potential impacts of supply disruptions or risks of delivering the essential inflow of oil into these nations, especially into the future. In order to be able to measure the concept of external oil supply risks for these nations, a framework needs to be constructed that quantifies the essential elements in energy security with regards to oil supply and demand. First, the root causes of energy security will be discussed, and the role of EOSR within the wider domain of energy security is identified. Then, different indicators for measuring energy security, and more specifically EOSR, will be reviewed, which leads to an indicator framework which is able to quantify the most important elements of EOSR for the countries/regions investigated in this research.

5.1 The Root Causes of Energy Insecurity

The concept of energy security has its roots in the first World War when the First Lord of the Admiralty, Winston Churchill, made a historic decision: to shift the power source of the British navy's ships from coal to oil, attempting to make the fleet faster than its German counterpart. This switch meant that the Royal Navy would rely not on coal from Wales, but on insecure oil supplies from what was then Persia (Yergin, 2006). Energy security thus became a question of national strategy. Since then, energy security has become a popular catch phrase, both in the scientific- as well as in the political arena. However, the term energy security remains rather vague and subject to many different interpretations (Löschel et al, 2010). Since the energy insecurity discussion has increasingly focused on issues beyond oil dependence, with a increasingly wider focus beyond the Middle East, a paradigm shift can be recognized. Concerns are not only restricted to oil, all conventional energies are considered (APERC, 2007) In the period after the 1970's oil shocks, other factors that affect fuel supply stability and energy prices have been added to the definition of energy security, including: political conflicts, unexpected natural disasters, concern on terrorism, and energy-related environmental challenges (APERC, 2007), as well as countries' fundamental needs for energy to power their economic growth (Yergin, 2006).

Yergin (2006; World Economic Forum, 2012) also distinguishes the national and international context of energy security, since there is a huge gap between developing and developed countries with regards to access to basic energy resources. Lefèvre (2010) notes that energy security concerns are also different for different fossil fuels since the coal and oil market are more mature and international than more locally regulated gas markets. So, national gas markets have to deal to a larger extent with availability than oil and coal markets where price is a major component of energy security concerns. However, the oil market is characterized by greater political instability then both the coal and gas markets. In the case of gas, the transition from regional to world market structure between 2004 and 2010 leads to a significant improvement in political stability, with the exception of the Russian-Ukrainian gas dispute of 2006, temporarily cutting off supplies to Europe (Yergin, 2006).

Three fundamental, overarching elements of energy security are presented in APERC (2007):

- **Physical energy security** - the availability and accessibility of supply sources.
- **Economic energy security** - the affordability of resource acquisition and energy infrastructure development.
- **Environmental sustainability** - the sustainable development and use of energy resources that 'meets the needs of the present without compromising the ability of future generations to meet their own needs', as stated in the Brundtland Report in 1987.

These elements are highly consistent with the three aspects of energy security as mentioned by the Brookings Energy Security Initiative (2014), in which the strategic- (physical energy security); economic-, and environmental perspective are laid out. The '4A's' of energy security, as expressed by the APERC study (2009), stress the multidimensional concept of energy security, and can be subdivided under the three fundamental elements (see also Ecofys, 2009b):

- **Energy Resource Availability** - Whether the energy available is sufficient to meet demand (conventional and unconventional hydrocarbon resources, renewable resources (wind, solar, biofuels etc.).
- **Accessibility Barriers** - Adding geopolitical elements. Even if resources are available, they may not be accessible. Barriers (geopolitical, financial and human constraints, fiscal regimes, and need for major infrastructure and technology deployment) to explore and develop available resources.
- **Investment Cost Affordability** - Despite energy being available and accessible, its affordability may have significant economic and social impacts. It is all about consumers being able to afford energy services and capital and operating cost structures for developing various energy sources.
- **Environmental Acceptability** - Even if the above three dimensions are favourable, environmental or societal elements may also impact on energy security.

Table 5 presents an overview of the relevant factors within the dimensions of energy security.

Table 5: Overview of Dimensions and Relevant Factors of Energy Security (ES) (*Source: Ecofys, 2009b*)

Dimension of ES	Relevant Factors
Availability	The overall level of demand for energy The physical existence of resources The ability (economical and technical) to produce these resources
Accessibility	The level of import dependence on foreign supply The diversity of supply Market concentration of suppliers Political stability Types of energy transport infrastructure
Affordability	The impact of high/volatile prices on the economy and those on lower incomes The impact of energy prices on (timely) investments in production, refining and infrastructure
Acceptability	GHG emission constraints that limit the choice of energy sources Constraints on local air pollution Constraints on the development and use of certain technologies, nuclear or carbon capture and storage

The rise in the need for energy worldwide, the overreliance of the world economy on finite resources, geopolitical challenges due to the concentrated nature of fossil resources, the depletion of these energy carriers, the increase in greenhouse gas emissions and other environmental impacts associated with (alternative) energy production and the ever more stringent regulation to combat global climate change, will all have a major impact on policy formulation and worldwide geopolitics in the coming decades. Massive exploration efforts for fossil resources and technological enhancement in current fossil fuel production and extraction, in combination with the technological development of, and societal pressures for alternative forms of energy production will change the current energy landscape at an unprecedented scale and pace. The four 'A's comprise all these factors of the (widening) domain of energy security. The following paragraph will elaborate on the role of external oil-supply risks within energy security, and will show how these subjects are linked.

5.2 The Role of EOSR in Energy Security

Chapter III and IV have presented an overview of the main themes within the current and future oil industry/oil supply. The problems and insecurities related to oil production have been mentioned and can be related to the four 'A's which comprise the factors of relevance for determining energy insecurity. Markandya & Pemberton (2010) identify the following sources of energy (in)security, related to oil supply, supplemented by Kruyt et al (2009) and Leggett (2014), since they partly overlap.

- The narrowing margin between oil supply and demand, which has driven up prices (see figure 6)
- The volatility of oil prices arising from international tensions, terrorism and potential for supply disruptions (e.g. Nigeria, Iraq and Libya - see figure 10)
- The concentration of known reserves and resources in a limited number of the world's sub-regions (see figure 5)
- The restricted access to oil and gas companies for developing hydrocarbon reserves in some countries, the problem of IOCs being constrained from access to NOCs reservoirs (e.g. Venezuela)
- The lengthening supply routes (e.g. Canada, Kazakhstan and Russia)
- Prolonged inadequate investments levels in production, transportation and processing and distribution capacity and/or maintenance (e.g. Iraq)
- Deliberate policy changes in producing countries or producer country organizations (e.g. Saudi Arabia)
- Macro-economic instability in producer countries (e.g. Iraq)
- Socio-political instability in producer countries and/or regions (e.g. Russia, Iran or Venezuela)
- Regulatory instability in consumer countries (Japan)
- Market failures and government failures, leading to insufficient investment into new oil production capacity (e.g. Saudi Arabia, Venezuela and Iran)

All these factors hinder the sustainable and reliable supply of oil in world trade, and future supply can be severely affected by these barriers. These factors can be related to the physical- and economic availability of oil. The required, gradual movement towards unconventional oil production has its environmental problems, as explained in section 4.3 and 4.4. It is clear that external oil-supply risks for major importing nations are an important factor in the countries overall energy security policies, since all the important elements as presented by APERC (2007) and Ecofys (2009b) can be related to oil supplies and demand. The extent to which these factors become a hindering factor in future oil supply will be investigated in Chapter VI and VII. The following section will elaborate on measuring energy security, and more specifically, external oil-supply risks.

5.3 Indicators for Assessing External Oil-Supply Risks

The European Commission (2010) categorizes different energy security indicators in 'simple indicators', 'diversification indicators' and 'composite (aggregated) indicators'. Indicators are different from strategies for enhancing energy security and are focused on measuring and quantifying energy security, which can then lead to strategy formulation. Possible strategies include: increasing energy efficiency, conservation, and encouraging the use of endogenous energy sources. A widely used strategy for enhancing energy security is diversification, which entails: increasing the number of fuels and technologies that are in the energy mix; increasing the number of suppliers for each fuel (especially if these are imported) and developing storage capacity for different fuels (e.g. strategic reserves; European Commission, 2010). Indicators can also be categorized as 'short-term- and long-term energy security indicators, or demand side- and supply-side indicators.

Examples of simple indicators include: the *energy intensity* of an economy (TPES/GDP [J/US$]); *energy dependency* for different energy sources (import/gross inland energy [%]); *reserves-to-production ratio* (proven reserves/primary production [y]); or simply the oil price as an indicator of resource scarcity. *Sectoral* indicators are also given as for example: share of biofuels in road transport = biofuel consumption/petrol and diesel consumption [%]. These simple indicators do not provide an accurate impression of overall energy security in a country since many of the relevant factors in this concept are not included.

More complex indicators are diversity based indicators, measuring the concentration of supplier power or fuel type within an energy mix of a given nation. Prominent examples are the Shannon-Wiener Index and the Herfindahl-Hirschman Index. Diversity indices might yield significantly different results depending on the partitioning of options (e.g. fuel types or suppliers), and fail to include the problem of disparity (Stirling, 2010) - the degree to which categories are different (e.g. supplier risks from different nations, or the ability to deliver supplies on a sustaining basis). Some diversity indices - e.g. Jansen et al (2004), introduce a correction factor for socio-political instability of a supplier country but do this by multiplying with a 0 (unstable) or 1 (stable), which is rather simplistic since the country risk cannot be expressed on such a simple scale, and depend on political-, financial-, and economic conditions (ICRG, 2012). Another correction factor is introduced by taking into account resource depletion of supplier countries, using the proven reserves-to-production ratio for a given fuel type. However, the reserves-to-production ratio does not provide a complete insight into the ability of a supplier country to deliver on a sustained basis, since a supplier with a high R/P ratio is generally not a large exporter because its production volume is small or its domestic consumption is very large, while a supplier with high exports cannot sustain its current production in the future if it lacks oil resource endowment (Yang et al, 2014).

The third category of indicators mentioned by the European Commission (2010) are composite indicators, or aggregated indicators. A composite indicator is formed when individual indicators are compiled into a single index, on the basis of an underlying model of the multi-dimensional concept that is being measured, in this case energy security or EOSR. Scientific literature provides a range of applications of composite indicators in different forms. Scheepers et al (2007) propose a supply/demand (SD) index which attempts to cover the whole energy spectrum in the medium and long run (2020), and is based on expert judgement and subjective weights given to the importance of a given fuel. The purpose of this research is not to include all fuel types of the energy mix of the importing nations, so this framework is not applicable to measure EOSR in this research.

The IEA (Lefèvre, 2009) proposes the IEA energy security indices, which purpose is to develop a base methodology to analyse impacts of policy on energy security in the long run (2030) and focuses on the supply side only, with the physical unavailability of a given fuel and the price risk from supply market concentration at the centre of focus. The model introduces two indices: the *energy security price index (ESPI);* and the *energy security market concentration (ESMC)*, and takes into account political stability and the physical ability of supplier countries to deliver on a sustained basis (Lefèvre, 2009). However, demand side issues are ignored, and therefore energy security is not fully captured, since this factor can enhance or lower energy security for a given nation. The model only refers to international fuel markets, and neglects other sources in the energy mix, thereby ignoring the dependency of a given importing nation for a specific fuel (European Commission, 2010; Jansen & Seebregts, 2010).

The Herfindahl and Shannon Indices are developed further by Stirling (2010) with *Stirling's Ignorance Approach*. Stirling uses the diversity as an overarching concept with three subordinate properties: variety, balance and disparity. However, since this research is focussed on one single fuel - oil, disparity is not an issue and variety and balance can only be measured in the number and size of suppliers in an import portfolio of an oil-importing nation/region. Bollen et al (2008) introduced the concept of *Willingness to Pay*, a composite indicator which is expressed in monetary terms and expresses the percentage of GDP a country is willing to pay for decreasing security of supply. The model incorporates the import ratio of a fuel, share of a fuel in TPES and the energy intensity of a nation for a specific fuel. However, price volatility in the past has had an effect on perceptions of aspects such as political risk, resource depletion and carbon constraints and future predictions are very difficult on these aspects. Since the focus of this research is on a single fuel, this model seems not useful, as multiple fuels are incorporated.

Literature also provides some applications of indicators focused on oil only. Gupta (2008) proposed a composite indicator, the *Oil Vulnerability Index*, which comprises 7 simple indicators. The index captures the relative sensitivity of various economics towards the developments of the international oil market. However, it ignores the ability of supplier countries to deliver oil-exports on a long-term basis, which is critical in selecting a diverse and optimal mix of oil suppliers for an importing nation. Greene (2010) introduced the *Oil Security Metrics Model* that allows oil dependence costs to be estimated in many possible uncertain futures. This model excludes the political-, economic- and financial risks associated with supplier countries, and also the potential of these countries to deliver oil in the long run.

The main conclusion from this (incomplete) literature review is that many attempts have been made to measure energy security and external oil-supply risks, but many of the models exclude important elements to capture the entire spectrum of energy security aspects. It has been found to be complex to incorporate all the aspects of energy security. Usually, (composite) indicators cover energy security's four 'A's, with less focus on acceptability of oil use (European Commission, 2010). The following section will introduce the framework that is used for this research, the model as proposed by Yang et al (2014). This section will also provide the underlying motivation for the choice of this framework.

5.4 Oil Supply Security - An Indicator Framework

A composite indicator is a practical instrument for simple comparisons of countries and is especially useful in monitoring performance and time trends, as well as conveying policy measures by presenting potential risks (European Commission, 2010). These reasons make a composite indicator highly applicable for this research. The main criteria for establishing/selecting the composite indicator are:

- All four 'A's are included in the composite indicator
- All concepts of energy security taken into account need to be quantifiable/measureable
- Data should be available for all concepts of energy security taken into account
- The final outcome should be simple, inclusive and easy to interpret for policy makers

External oil supply is usually measured by portfolio (diversification) techniques. This research will expand the framework as presented by Yang et al (2014), who use a modified diversification index with additional variables of country risk and potential exports to measure external oil supply risk for different oil importing nations, since these variables both affect the stability and availability of oil supply. Yang et al (2014) use a portfolio approach, dividing oil supply risk into systemic risk and specific risk. The former is non-diversifiable risk, which typically affects most suppliers and in contrast, the latter is unsystematic or diversifiable risk. This risk is more unique or specific to individual suppliers. Yang et al (2014) attempt to measure EOSR from the perspective of diversification of sources, which is of great importance for enhancement of the understanding of the relationship between import risk and diversification of oil suppliers. The term 'diversification' originates from the financial markets and is often portrayed by the expression: *'Don't put all your eggs in one basket'*. In energy security terms, diversification is a choice to enhance the security of external oil supply by reducing excessive dependence on a single supplier (Yang et al, 2014), usually measured by using the Hirschman-Herfindahl index (HHI). The Hirschman-Herfindahl Index is initially developed to measure market concentration, and is also widely used in the energy field to assess energy diversification or supplier diversification (Yang et al, 2014).

This framework is useful for this research, as the four dimensions of energy security are included, all concepts of energy security taken into account are quantifiable and measureable, data is available for all the concepts measured and the final outcome is relatively simple, inclusive and easy to interpret for policy makers. By going through the different parameters of this framework, it will become apparent that all relevant dimensions of energy security and external oil-supply risk are included in this framework, starting with the HHI-index.

5.4.1 The Hirschman-Herfindahl Index (HHI)

The HHI treats all suppliers as the same, and calculates the degree of concentration of oil supplies. When the HHI is adopted for assessing oil import diversification, the index is computed as follows:

(1) $$\mathrm{HHI}_i = \sum_{j=1}^{N} w_{ij}^2$$ $$w_{ij} = x_{ij} / \sum_j x_{ij}$$ (2)

Where: HHI_i = the traditional oil import diversification index, w_{ij} = the share of supplier *j* in total oil imports of country *i*, and is computed by formula 2, representing oil imports of country *i* from supplier *j*. *N* stands for the number of total oil suppliers of country *i*. The value of the HHI_i depends on both the inequality of the shares in oil imports from different countries and the number of oil suppliers. The HHI_i takes a maximum value of 1 when a country imports oil from only one supplier and a minimum value of $1/N$ when a country imports the same amount of oil from *N* suppliers. The higher the value of the HHI_i, the lower is the degree of oil import diversification (Yang et al, 2014). The HHI is generally measured by using the price and volume information of oil imports. For this research, the volume of oil imports will be the basis for calculating the HHI for the European Union, the United States, China, Japan and India. This is taken as the micro risk of oil supply, while country portfolio can offer a macro risk perspective to optimize sources of oil imports for decision makers (Yang et al, 2014). Chapter VI will present the data sources and input figures for calculating the HHI_i for the selected countries. The accessibility dimension of ES is represented by measuring market concentration of suppliers and the diversity of supply.

5.4.2 Modified HHI with Country Risk (HHI-CR)

Scientific literature has paid attention to the macro supply risk which may come from the overall risk of a specific oil supplier. Economic-, financial- and political instability of a supplier country can influence the security of external oil supply, which are components of country risk in oil exporting regions (Yang et al, 2014). Since the HHI treats all suppliers the same regarding potential supply risks, an additional factor is added to the index, the Country Risk (CR) factor. CR-values are computed for each country by the Political Risk Services Group in the *International Country Risk Guide*, and will be used in this research to distinguish oil suppliers' differences in country risk (Yang et al, 2014; ICRG, 2012). This measure is used as a broad proxy of composite country risk since there is no easy way to quantify risk associated with an oil supplier (Yang et al, 2014).

$$\mathrm{HHI} - \mathrm{CR}_i = \sum_{j=1}^{n} w_{ij}^2 \times \mathrm{CR}_j$$ (3)

Where: CR_j = the overall country risk of oil supplier *j* and is computed as $\mathrm{CR}_j = 100 - \mathrm{ICRG}_j$. ICRG_j is the composite country risk ratings score computed by the PRS Group (ICRG, 2012), where high values indicate low country risk. The transformation above ensures that $\mathrm{HHI\text{-}CR}_i$ moves in the same direction as HHI_i. The downside of using the ICRG country risk factors is that it does not take into account any trade relationships between importing and exporting nations/regions, which potentially reduces the EOSRs for an importing nation in comparison to suppliers outside this relationship. However, this is the only measure that combines multiple variables in determining investments in a given country into one single composite country risk rating score. The accessibility dimension of ES is addressed by the CR-factor by taking into account political stability, and indirectly by taking into account the investment climate within a supplier country, which impacts the affordability of oil.

5.4.3 Modified HHI with Potential Exports (HHI-PE)

The potential exports capacities of oil suppliers are closely related to the physical availability of future oil supply and switching behaviours of oil importing countries (Yang et al, 2014), and presents an additional macro supply risk factor for oil importers. This factor is mainly determined by proven reserves, oil production capacity and export policies. Potential exports in this research contains the resources to production ratio (R/P) and a suppliers' share in world exports (4) and is computed in the modified HHI as seen in formula 5:

$$\mathrm{PE}_j = r_j \times s_j \qquad (4)$$

$$\mathrm{HHI}-\mathrm{PE}_i = \sum_{j=1}^{n} w_{ij}^2 \times \frac{1}{\mathrm{PE}_j} \qquad (5)$$

Where: PE_j = potential oil exports of supplier *j*, r_j = R/P ratio, s_j = share of supplier *j* in world exports. The reciprocal transformation of PE_j is to ensure that HHI-PE_j moves in the same direction as HHI_i and HHI-CR_i (Yang et al, 2014). The R/P ratio is the number of years for which proven oil reserves can sustain current production in a country. A suppliers' share in total global exports reflects its oil export volume and export policies. The oil supplier with a high PE_j is supposed to be an important oil exporter at present and in the future and plays a big role in ensuring oil supply security. With limited global oil resources and the continuing increase in consumption in upcoming nations, conventional oil production is approaching a peak and the number of net-exporters is expected to be reduced. With the depletion of oil resources, a number of small oil suppliers are beginning to reduce oil exports or have even become oil-importing countries (i.e. Indonesia), providing pressures for large oil-importing nations to find and switch to new oil suppliers. So, the availability of resources is of vital importance to take into account when measuring oil import diversification for a nation/region. Establishing stable trade relationships with oil suppliers having high potential exports can effectively ensure long-term stability of oil imports and thereby reduce EOSRs (Yang et al, 2014).

The PE-factor relates to the availability dimension of ES by taking into account the physical existence of resources and the ability (economical and technical) of exporting nations to produce these resources. Indirectly, the existence of a proper energy infrastructure is also addressed (accessibility of oil). The combined index, accounts for the country risk- and potential exports factors, and can then be constructed as follows:

$$\mathrm{HHI}-\mathrm{RE}_i = \sum_{j=1}^{n} w_{ij}^2 \times \mathrm{CR}_j \times \frac{1}{\mathrm{PE}_j} \qquad (6)$$

5.4.4 Measuring External Oil Supply Risk

Oil import dependency is often used to measure oil supply risk but a nation that is highly import-dependent may not be exposed to high risk if its oil supply sources are well diversified. Therefore, EOSR in this report will combine the concepts of import dependency and diversification, thereby combining demand side effects with supply side effects of oil production and dependence. Based on the four HHI 9indices described above, four EOSR indices (OSRI) can be constructed.

The first OSRI assumes that the same amount of oil imported from different suppliers faces the same risk:

$$\mathrm{OSRI}_i = D_i \times \mathrm{HHI}_i = D_i \times \sum_{j=1}^{n} w_{ij}^2 \qquad (7)$$

$$\mathrm{D}_i = \frac{\mathrm{NI}_i}{C_i} \qquad (8)$$

Where: D_i = oil import dependency (8), NI_i = net oil imports of country *i*, C_i = total oil consumption of country *i*. The dependency factor takes into account the overall level of demand for energy in an importing nation (availability dimension of ES), and the level of import dependence on foreign supply (accessibility dimension of ES)

The following three indices (9-11) are based on the modified diversification indices:

$$\mathrm{OSRI} - \mathrm{CR}_i = D_i \times \mathrm{HHI} - \mathrm{CR}_i = D_i \times \left(\sum_j w_{ij}^2 \times \mathrm{CR}_j \right) \qquad (9)$$

$$\mathrm{OSRI} - \mathrm{PE}_i = D_i \times \mathrm{HHI} - \mathrm{PE}_i = D_i \times \left(\sum_j w_{ij}^2 \times \frac{1}{\mathrm{PE}_j} \right) \qquad (10)$$

$$\mathrm{OSRI} - \mathrm{RE}_i = D_i \times \mathrm{HHI} - \mathrm{RE}_i = D_i \times \left(\sum_j w_{ij}^2 \times \mathrm{CR}_j \times \frac{1}{\mathrm{PE}_j} \right) \qquad (11)$$

The OSRIs (7), (9), (10) and (11) provide a multi-faceted measure of external oil supply risk of an oil importing country to track its oil import policy and to help make better policy decisions (Yang et al, 2014). Chapter VI describes the input figures used for determining the OSRIs in more detail.

This modified diversification index takes into account energy resource availability and accessibility in the variables 'potential exports' and 'country risk', and to a lesser extent, the affordability dimension. The following chapter on scenario descriptions and inputs, will further elaborate on the main elements of energy security that have been taken into account by adapting this model to be able to investigate long-term EOSR in different climate- and supply scenarios.

This research will extend the research of Yang et al (2014), by forming EOSR scenarios up to 2035, using different 'energy futures'. It is difficult to predict future developments in energy use and demand. However, many attempts of 'energy future' scenarios have been formed by different organisations in which energy demand and supply have been modelled, based on predictions from scientific research and data from national and international oil companies (IEA, 2013b; Shell, 2014; Ecofys, 2013; Van Vuuren, 2009). To facilitate this research in forming EOSR scenarios up to 2035, the three Climate Scenarios of the International Energy Agency's annual World Energy Outlook 2012 will be used, since these represent the most detailed description of future developments in energy supply and demand and more specifically oil supply and demand. The five countries/regions which will be investigated in this report have all been modelled up to 2035 on an individual basis which allows for country/region level investigation of EOSR.

These three scenarios will be the basis for determining EOSR using the created indicator framework, up to 2035, for the chosen economies. The Climate Scenarios will be accompanied by a fourth scenario - 'the Uppsala Scenario', in which future oil supply in the IEA figures is challenged and the peak of oil production is incorporated (based on Chapter IV). First, the IEA Climate Scenarios will be described in more detail, with an overview of the input data for these scenarios in the framework used, in section 6.2. Thereafter, the Uppsala Scenario will be discussed and section 6.4 will describe the input figures used for this scenario.

6.1 IEA Climate Scenarios Description

The Energy Technology Perspectives (ETP) is the IEA's (IEA, 2012) most ambitious publication on new developments in energy technology. It demonstrates how technologies can make a decisive difference in achieving the objective of limiting the global temperature rise to 2° and describes three scenarios. Figure 19 and figure 20 provide an insight of the routes the three Climate Scenarios take with regards to total CO_2 emissions (in Gt), and total primary energy supply (TPES, in EJ) respectively.

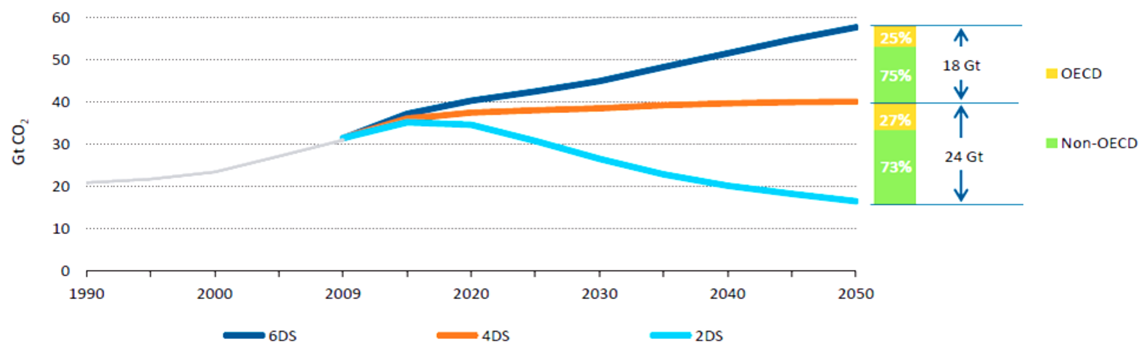


Figure 19: ETP 2012 Scenario CO_2 Emissions Pathways (*Source: IEA, 2012*)

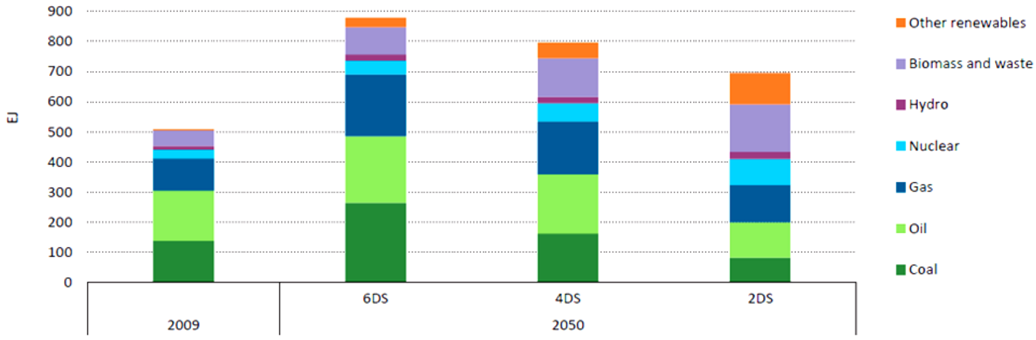


Figure 20: ETP 2012 Scenario Total Primary Energy Supply Pathways (*Source: IEA, 2012*)

The IEA describes three scenarios based on the expected temperature rise in 2050 (IEA, 2013a). The IEA's World Energy Outlook (WEO) publication of 2013 describes three similar scenarios with regards to energy demand and supply in different regions/countries up to 2035 (IEA, 2013b; IEA, 2013c), which are consistent with the ETP 2012 scenarios.

- **2°C Scenario (2DS)** - Consistent with the *World Energy Outlook 450 Scenario*: The focus of the ETP 2012. The 2DS describes an energy system consistent with an emissions trajectory that recent climate science research indicates would give an 80% chance of limiting average global temperature increase to 2°C. It sets the target of cutting energy-related CO_2 emissions by more than half in 2050 in comparison to 2009 (see figure 19), and ensuring that they continue to fall thereafter. This goal can only be achieved, provided that CO_2- and GHG emissions in non-energy sectors are also reduced.
- **4°C Scenario (4DS)** - Consistent with the *World Energy Outlook New Policies Scenario*: Takes into account recent pledges made by countries to limit emissions and step up efforts to improve energy efficiency. Projecting a long-term temperature rise of 4°C, the 4DS is already an ambitious scenario that requires significant changes in policy and technologies.
- **6°C Scenario (6DS)** - Consistent with the *World Energy Outlook Current Policies Scenario*: Is largely an extension of current trends. By 2050, energy use almost doubles compared with 2009 and total GHG emissions rise even more (see figure 19 and 20) In the absence of efforts to stabilise atmospheric concentrations of GHGs, average global temperature rise is projected to be at least 6°C in the long-term.

The following paragraph will go into more detail regarding the underlying figures of the scenarios.

6.2 Input figures for Climate Scenario Formation

For calculating the EOSR, using the indicator framework as described by Yang et al (2014), the figures as presented in table 6, are required for forming the scenarios.

Table 6: Overview of Variables and Sources for Determining the HHI Indices in the Three IEA Climate Scenarios (*Source: Yang et al, 2014*)

Variables	Symbol	Source	Assumptions
Oil import from each supplier	w_{ij}	European Commission, 2013 (European Union); EIA, 2014a (United States); Reuters, 2012a (China); Petroleum Association of Japan, 2014 (Japan); Reuters, 2012b (India)	Import figures from 2012/2013 from each supplier for each importing country/region equals oil import for the year 2011 and will be held constant to 2035 Concerns only crude oil imports, excluding oil products
Country risk rating score	CR_j	ICRG, 2012	Average of 'worst case' and 'best case' five-year forecast Constant from 2011 to 2035
Reserves/ production ratio	r_j	BP, 2014	R/P ratio held constant from 2011 to 2035, and R/P ratio revised downward by 0,5 year/year in the Sensitivity Analysis (see Chapter VIII)
The share of an oil supplier in total world oil trade	s_j	BP, 2014; EIA, 2014b	2012 figures equal 2011 figures Estimated net petroleum exports equals share in total world oil trade for supplier countries (see Appendices 1-5) When estimated net petroleum export are negative (net importing nation), these suppliers will be excluded from the HHI-PE_i and HHI-RE_i indices (see 'Notes' under Appendices 1 to 5)
Country i's net oil imports	NI_i	EIA, 2014b, IEA, 2013c	Japan oil production remains constant to 2035 and equals 2011 value Changing to 2035 in different energy future scenarios (see table 7)
Country i's total oil Demand	C_i	IEA, 2013c	Changing to 2035 in different energy future scenarios (see table 8) Consumption is demand in scenario formation as consumption implies supplies meeting demand

The oil import from supplier countries to an oil importing nation is measured by dividing the shares of oil delivery from a single supplier by the total oil imports for that nation. Since no data was available for all countries/regions for 2013, 2011 was chosen as a base year for the calculations (being the same year as given by the IEA in their energy futures). The import figures were available for 2012 (China, India) and 2013 (European Union, United States, Japan) in national/regional energy databases. This research assumes that the composition of suppliers and their oil exports to importing nations has remained constant from 2011 to the years where the data was available, and remains constant throughout 2035, since no projections can be made in this regard for future scenarios. This is also the sole purpose of this research, to investigate the risks associated with external oil supply for the five largest oil-importing economies, with their current supplier portfolio. Only crude oil imports are included in this variable due to a lack of data on imports of oil products for the European Union, Japan, China and India.

The country risk rating score is derived from the *International Country Risk Guide*, which provides a rating comprised of 22 variables in three different subcategories of risk: political-, financial- and economic risk. The Political Risk Index is based on 100 points, Financial Risk on 50 points, and Economic Risk on 50 points. The total scores from the three indices are divided by two to produce the composite country risk score, ranging from 0 to 100. A composite country risk score below 50 indicates very high risk and a score above 80 indicates very low risk (ICRG, 2012). For this research, the average of a 'worst case' and a 'best case' five-year forecast is taken, and held constant to 2035 in the IEA Climate Scenarios for the chosen countries/regions.

The reserves to production ratio is the proved reserves of oil (generally taken to be those quantities that geological and engineering information indicates with reasonable certainty can be recovered in the future from known reservoirs under existing economic and operating conditions) remaining at the end of any year, divided by the production in that year. The result is the length of time that those remaining reserves would last if production would continue at that rate (BP, 2014). The reserves to production ratio is derived from the *BP Review of World Energy Statistics 2013* (BP, 2014). Most R/P-ratios are given, but for countries where this data was not given in this report, the total reserves (billion barrels) were divided by the daily production (Mb/d) multiplied by 365 days/year. The R/P-ratio in this report includes gas condensate and natural gas liquids (NGLs) as well as crude oil. The R/P ratio is held constant throughout the projection period.

The share of an oil supplier in total world oil trade is measured by taking the *estimated petroleum net exports* as given by the Energy Information Administration (EIA, 2014b). Net oil exports are given by subtracting the supplier country's oil consumption (consumption of oil products and direct combustion of crude oil) from the total oil production of crude oil (including lease condensate, natural gas plant liquids and other liquids, and refinery processing gain, or loss, in case of negative values). It is assumed in this report that estimated petroleum net exports equals the share in total world oil trade. However, since these values do not account for the shares of net oil-importing countries in total world trade, the *inter-area movement* figures from the *BP Review of World Energy Statistics 2013* (BP, 2014) will also be used to determine their share of oil exports in total world oil trade, for the countries given, as well as the total amount of oil traded in 2012. It is assumed that this number equals the total world oil trade of 2011, the base year of the calculations in this report, and will be held constant up to 2035 for the countries outside the *BP Review of World Energy Statistics 2013.* The share of an oil supplier for countries that are represented in the *BP Review*, and for the economies investigated in this report, will change over time, as explained below. The *BP Review* is chosen because it provides the most detailed database on reserves, production and consumption, and is internationally recognized for this fact. However, as the figures in these reviews are criticized in the Uppsala Scenario, a downward revision is used in that particular scenario - see section 6.4.

The country's net oil imports are measured by the same formula as used by the EIA to calculate country's estimated net oil exports, by subtracting importing nations' oil consumption (in this case total oil demand [Mb/yr]) from total oil production (in this case the scenario projections of the IEA, 2013c [Mb/d], multiplied by 365 d/yr). It is assumed that the production figures are the same in the three Climate Scenarios since no production data was available for the different scenarios, and climate policy is expected to have no impact on future oil production. It is assumed that the production figures of 2012, as given in the IEA WEO 2013 are unchanged with regards to 2011. Since no future production figures were available for Japan in this document, the production figure for 2012 was taken en held constant to 2035. This oil production figure for Japan has a small influence on net estimated oil imports as it represents only a small fraction of total oil demand in Japan (EIA, 2014b). Appendix 6 provides the input figures and outcomes for the net oil imports for the different economies in the different Climate Scenarios. Table 7 presents an overview of the oil demand, production and net oil imports input figures in the NPS scenario with the oil import dependency for the selected countries/regions.

Table 7: Overview of Oil Demand, Production and Net Oil Imports Input Figures for Selected Economies in the NPS (*Source: IEA, 2013b*; note: (#) indicates Oil Import Dependency [%])

New Policies Scenario						
		EU	**US**	**China**	**Japan**	**India**
Oil Demand [Mb/a]	**2011**	3,921	5,621	3,186	1,471	1,193
	2020	3,379	5,586	4,393	1,221	1,600
	2025	3,121	5,200	4,764	1,114	1,950
	2030	2,850	4,786	5,014	1,014	2,321
	2035	2,621	4,386	5,186	936	2,714
Oil Production [Mb/a]	**2011**	1,278	3,358	1,533	51	329
	2020	1,132	4,234	1,606	51	292
	2025	949	4,307	1,570	51	256
	2030	803	4,198	1,497	51	256
	2035	730	3,979	1,241	51	219
Net Oil Imports [Mb/a]	**2011**	2,644 (67)	2,263 (40)	1,653 (52)	1,420 (97)	865 (73)
	2020	2,248 (67)	1,352 (24)	2,787 (63)	1,170 (96)	1,308 (82)
	2025	2,172 (70)	893 (17)	3,195 (67)	1,063 (95)	1,695 (87)
	2030	2,047 (72)	589 (12)	3,518 (70)	963 (95)	2,066 (89)
	2035	1,891 (72)	408 (9)	3,945 (76)	885 (95)	2,495 (92)

For calculating the country's total oil consumption, the total oil demand [Mtoe/a] is taken from the IEA WEO 2013 projections in the three Climate Scenarios, and multiplied by the conversion factor (see 'Note' under table 8) to be able to measure these values in [Mb/a]. Table 8 provides an overview of the oil consumption figures in the Climate Scenarios from 2011 to 2035 for the five countries investigated.

Appendix 1 up to 5 present an overview of all the input figures used per country to calculate the HHI-Indices for each country investigated. The OSRI Indices can then be constructed by using the dependency factor for each region/country investigated, for each climate scenario up to 2035. The dependency factors are presented in table 9. The dependency factor is calculated as: D_i = net oil imports (NOI_i)/oil demand (C_i)

Table 8: Oil Demand Figures in the Three Climate Scenarios (*Source: IEA, 2013b*)

		Oil Demand [Mtoe/a]					Oil Demand [Mb/a]				
	Country	**EU**	**US**	**China**	**Japan**	**India**	**EU**	**US**	**China**	**Japan**	**India**
Scenario	**Year**										
NPS	2011	549	787	446	206	167	3,921	5,621	3,186	1,471	1,193
	2020	473	782	615	171	224	3,379	5,586	4,393	1,221	1,600
	2025	437	728	667	156	273	3,121	5,200	4,764	1,114	1,950
	2030	399	670	702	142	325	2,850	4,786	5,014	1,014	2,321
	2035	367	614	726	131	380	2,621	4,386	5,186	936	2,714
CPS	2020	484	796	634	173	229	3,457	5,686	4,529	1,236	1,636
	2030	435	748	775	148	338	3,107	5,343	5,536	1,057	2,414
	2035	417	730	824	140	400	2,979	5,214	5,886	1,000	2,857
450	2020	450	763	580	162	216	3,214	5,450	4,143	1,157	1,543
	2030	320	566	558	119	291	2,286	4,043	3,986	850	2,079
	2035	272	462	520	102	315	1,943	3,300	3,714	729	2,250

Note: *Conversion factor Mtoe/a to Mb/y: 1:7.142857*

It becomes apparent that the United States has the lowest oil dependency in 2011, and continues to have the lowest dependency up to 2035. The United States even becomes oil independent in 2030 in the 450 scenario, being the only currently oil-importing nation investigated to do so. Japan has the highest oil dependency, being almost 97% in the NPS in 2011, slightly decreasing to 93% in the 2DS Scenario in 2035. No figures were available for the CPS and 450 scenario in 2011 and 2025.

Table 9: Dependency Factors in the Three IEA Climate Scenarios 2011-2035 (Note: red figures indicate oil independency)

	NPS					CPS					450				
	EU	**US**	**China**	**Japan**	**India**	**EU**	**US**	**China**	**Japan**	**India**	**EU**	**US**	**China**	**Japan**	**India**
2011	0.674	0.403	0.519	0.965	0.725										
2020	0.665	0.242	0.634	0.958	0.818	0.673	0.255	0.645	0.959	0.822	0.648	0.223	0.612	0.956	0.811
2025	0.696	0.172	0.671	0.954	0.869										
2030	0.718	0.123	0.702	0.950	0.890	0.742	0.214	0.730	0.952	0.894	0.649	0.038	0.625	0.940	0.877
2035	0.721	0.093	0.761	0.945	0.919	0.755	0.237	0.789	0.949	0.923	0.624	0.206	0.666	0.930	0.903

All the input figures for determining the external oil supply risk indices are given, and the results will be presented in the next chapter.

6.3 The Uppsala Scenario Description

The volume of future oil production is challenged by many factors, which have been elaborated upon in Chapter IV. The role of the International Energy Agency, and the criticisms on the figures presented in their annual World Energy Outlook present a case for carefully examining the possibility of a potential peak in future oil production, and the consequences that this concept brings in terms of energy security for the countries investigated.

Therefore, this research will also provide a fourth 'energy future' which represents a critical stance on the figures published by the IEA. Many scientists and organizations - like the Association for the Study of Peak Oil - have argued that oil supply has already 'peaked' and that the figures of the IEA's forecasts are highly optimistic (Aleklett et al, 2010, Leggett, 2014, Monbiot, 2009). This fourth scenario will be called the 'Uppsala Scenario', as researchers from the Uppsala University in Sweden quantitatively showed that the IEA's forecasts must be wrong and overly optimistic (Aleklett et al, 2010). The same variables from the model of Yang et al (2014) will be investigated, and the input figures for this scenario will be presented in section 6.4. Aleklett et al (2010) have come up with an 'Uppsala Scenario' in their research, based on revised figures of the IEA WEO 2008. This research will update the research by Aleklett et al (2010) by revising the figures from the IEA WEO 2012, using the same method. These figures will form the input for the fourth 'Uppsala Scenario' in the framework by Yang et al (2014).

6.4 Input Figures for the Uppsala Scenario Formation

Table 10 provides an overview of the variables, sources and assumptions for the Uppsala Scenario.

Table 10: Overview of Variables and Sources for Determining the EOSR in the Uppsala Scenario that are Different from the IEA Climate Scenarios (*Source: Yang et al, 2014*)

Variables	Symbol	Source	Assumptions
Country risk rating score	CR_j	ICRG, 2012	'Worst case' five-year forecast Constant from 2011 to 2035
Reserves/production ratio	r_j	BP, 2014	R/P ratio revised downward by 0,5 year/year up to 2035 When R/P ratio is negative during projection period, revised to 1
The share of an oil supplier in total world oil trade	s_j	BP, 2014; EIA, 2014b; Campbell, 2008; Campbell, 2013	Estimated net petroleum exports equals share in total world oil trade for supplier countries (see Appendix 7a-b) When s_j is negative during projection period, excluded for that year (revised to 0) and correction factor used (see 'Notes under Appendices 8-12)
Country i's net oil imports	NI_i	EIA, 2014b, IEA, 2013c; Campbell, 2013	See table 15
Country i's total oil demand	C_i	IEA, 2013c	See table 15

The oil import from each supplier is calculated in the same way as the three IEA Climate Scenarios, and is expected to be unchanged, for reasons of data availability and comparability. For the Uppsala Scenario, the 'worst case' five-year forecast is assumed for the country risk rating score, since - as explained in the previous chapters, geopolitical tensions are expected to increase as more production is required from a smaller set of suppliers, which have a lower average country risk rating score on average (which implies higher country risk), e.g. OPEC members (ICRG, 2012). Overall, risks associated with oil imports are expected to increase as falling supply in major oil-producing nations, due to a lack of investment and sustainable oil production policies in countries with the largest reserves, among other reasons (see Chapter VI), cause exports of oil to decline in the future (Campbell, 2013; Aleklett et al (2010); Leggett, 2014).

The reserves-to-production ratio will be revised downwards with 0.5 yr/yr in the Uppsala Scenario, since overstatements in reserves - mainly in OPEC countries, but also in the recoverability of unconventionals, will cause the R/P ratio to be lower in practice, and will not remain constant or increase (which is the historical trend - see figure 6). Revising the R/P ratio downwards with 1 yr/yr would be unrealistic, since this assumes that no discoveries will be made and no reserve growth will take place within existing producing fields. However, R/P ratios have always increased in the past mainly due to questionable reserve additions and dubious reporting procedures. A constantly increasing R/P ratio may also be unrealistic (see Chapter IV) so for this scenario, a decrease of 0.5 yr/yr is used for the R/P ratio in the projection period. When the R/P ratio becomes negative in the projection period, the figure will be revised to 1, for the model to function properly. These effects will be discussed following chapter and Sensitivity Analysis (Chapter VIII).

Region/Country	CAAGR 2012-2035 [%]
Americas	-0.6
US	-0.9
Europe	-1.2
Eastern Europe and Eurasia	+0.6
Russian Federation	+0.4
Middle East	+1.6
Africa	+1.3
Latin America	+1.1
Brazil	+1.0
Asia	+2.3
Asia Oceania	-1.5

Table 11: Projected CAAGR 2012-2035 [%] in World Oil Consumption by Region (*Source: IEA, 2013b*)

For this scenario, the share of an oil supplier in total world oil trade is similar to the figures as given in the Climate Scenarios. However, an important finding arises when the original method of calculating the share in total world trade is used for this Scenario, as explained below.

The share of an oil supplier in total world oil trade is measured by the formula for net oil exports. Net oil exports are calculated by subtracting the expected consumption of a supplier country by its oil production in a given year. Consumption of a supplier country is provided by the Energy Information Administration (EIA, 2014b) for the year 2011, and these figures will change over time by an expected compound average annual growth rate, as projected by the IEA WEO 2012 depending on the region - see table 11. Growth in consumption of oil in states with the largest reserves (e.g. Saudi Arabia) is expected to have a major impact on future oil trade, since the net oil exports of these states are negatively affected by growing domestic demand.

The production figures for the supplier countries in the Uppsala Scenario are derived from *Campbell's Atlas of Oil and Gas Depletion* (Campbell, 2008; Campbell 2013) by Campbell, the founder of the Association for the Study of Peak Oil and Gas, who projected future production for all countries and regions of importance in oil consumption and production. Since not all the production figures were publically available in the most updated Atlas of 2013, the Atlas of 2008 was used as a backup, in case of data unavailability. A peak in oil supply is predicted by Campbell, and projected production figures of e.g. the IEA and the EIA have been revised downwards. Since the Atlas only provides figures for the years 2010, 2020 and 2030, the 2035 production figures have been constructed by dividing the decrease/increase in production between 2020 and 2030 by 2 and subtracting/adding this number from/to the 2030 figure. The net oil import figures can then be constructed for each year, for each supplier - see Appendix 7 for the production-, demand- and net oil import figures for each year for each supplier. Since *Campbell's Atlas of Oil and Gas Depletion* only takes into account *Regular Conventional Oil,* the bulk of the supplier countries in the world will become net energy importers in the future, see table 12.

Table 12: Countries with Negative NOI in 2020-2035 with Regular Conventional Oil Production

Year	Country
2020	Venezuela, Argentina, Brazil*, Canada*, Mexico, Vietnam*, Egypt*, Tunisia*, US*, Malaysia, Indonesia*, Australia*, Thailand*
2030	Ecuador, Colombia, Cameroon, Sudan, Yemen
2035	Russian Federation

Note: **Countries which are currently net importers of oil*

It becomes apparent in the model projections that increasing reliance has to be placed on OPEC members who all have positive net oil exports figures up to 2035, who focus primarily on conventional oil production (excluding Venezuela). The Atlas excludes, Arctic oil (Canada and Russia), tar sands (Canada), heavy-oil (Canada and US), extra-heavy oil (Venezuela), shale oil (US), deepwater oil (Brazil, US), so the projected production figures for unconventional oil, as examined in Chapter IV have to be added to the production figures of regular conventional oil, for reasons of comparability with the three IEA Climate Scenarios. The following figures are used for the production of unconventional oil in the projected period - see table 13 (based on Chapter IV).

Table 13: Unconventional Oil Production in the Uppsala Scenario 2011-2035

Oil Type	Country/Region	Production 2011 [Mb/yr]	Production 2020 [Mb/yr]	Production 2030 [Mb/yr]	Production 2035 [Mb/yr]
LTO	Russia	0.00	0.20	0.40	0.45
	Argentina	0.00	0.08	0.17	0.22
	China	0.00	0.08	0.17	0.21
	US	1.00	3.00	4.30	4.00
	Canada	0.00	0.30	0.60	0.50
Tar Sands	Canada	1.80	2.90	3.90	3.90
Extra-Heavy Oil	Venezuela	0.70	1.30	2.00	2.30
Deepwater*	Brazil	1.40	2.00	2.70	3.00
CTL	China	0.10	0.20	0.35	0.50
GTL	Qatar	0.10	0.20	0.30	0.32
	US	0.10	0.20	0.30	0.32

Notes: *CTL production in South Africa is excluded from this report since the country is no supplier for the countries investigated.*
For reasons of data unavailability and simplicity, the divisions for CTL- and GTL production have been 50/50. The intermediate production volumes for a given year have been estimates around figures given in Chapter IV.
**Deepwater oil production is considered as an unconventional oil type, since it requires different technical procedures and economic conditions than conventional oil production. This opposes the stance of the IEA, who classifies deepwater oil as conventional oil for no clear reason in their WEO.*

In *Campbell's Atlas of Oil and Gas Depletion* (Campbell, 2013), natural gas liquids production, as well as processing gains have been excluded from investigation. However, for reasons of comparability with the three Climate Scenarios, the percentage of NGL's and processing gains in total world oil supply (as given in table 4) will be added to the production figures in the Uppsala Scenario for every oil-supplier, which amounts to an increase of 16% in total oil production for each year, for each supplier.

When the unconventional oil, and NGLs and processing gains figures are added to the regular conventional oil production figures, the following countries have negative net oil imports and become net oil importers in the future, see table 14:

Table 14: Countries with Negative NOI in 2020-2035 Accounting for Total Oil Production

Year	Country
2020	Argentina, Brazil*, Mexico, Vietnam*, Egypt*, Tunisia*, US*, Malaysia, Indonesia*, Australia*, Thailand*
2030	Ecuador, Colombia, Cameroon, Sudan, Yemen
2035	-

Note: **Countries which are currently net importers of oil*

It is assumed in this report that estimated petroleum net exports of supplier countries (Campbell, 2008; Campbell, 2013) equals the share in total world oil trade. Total world oil trade is assumed to be the same percentage of world oil production as given by BP (2014), 64.2% in 2012, and is assumed to be constant over time, and also applicable to the Uppsala Scenario. Therefore, the total volume of oil traded globally in 2030 is projected to be 48.5Mb/d, as opposed to an expected 63.6Mb/d in 2030 by the IEA (IEA, 2013b), and 55.3Mb/d in 2012 (BP, 2014). The decrease in total world oil trade is assumed to be proportional throughout the projection period up to 2035. The share of each supplier in total world trade can then be constructed for the projection period. On the basis of the figures mentioned above, the decrease of total global world oil trade will be -0.38Mb/d per year, from which the following world trade figures are derived: 2020 - 52.3Mb/d; 2030 - 48.5Mb/d; 2035 - 46.6Mb/d.

Since the countries mentioned in table 14 have a negative share in total world oil trade, based on the negative net oil exports, their potential exports figures will also be negative. For reasons of simplicity, these figures will be adjusted to a minimum value of 0.000. These nations will be excluded from the calculations of the $OSRI\text{-}PE_i$ and $OSRI\text{-}RE_i$, and the percentage that these nations represent in terms of volume imported in total imports for a given nation will be added to these OSRI indices, assuming that these countries have the same average external oil supply risk as the other countries within the supplier portfolio (see the correction factor in the *'Notes'* under Appendices 8-12). For the countries with a negative R/P ratio in the projection period (Cameroon, Columbia, Thailand, Argentina and Indonesia), the *potential exports* variable will be negative, and will therefore be corrected to 1.0.

When the projected production figures of *Campbell's Atlas of Oil and Gas Depletion* are used in combination with the projected growth figures of the IEA WEO 2012 to construct the potential net oil exports of the supplier countries within this research, and the sum of these net oil exports is taken, only a fraction of the expected total world oil trade is met by these suppliers. It is unclear whether this is due to the fact that future world oil trade is significantly lower in terms of decreased oil volumes, or which countries, that are currently not a supplier of oil for the countries/regions investigated will fill this 'gap' in total future global oil trade. Growth in oil demand could also be lower than the figures given in the IEA WEO 2012. However, this seems highly unlikely since the IEA already revised their growth figures downwards in their WEO 2012 (for reasons that are unclear and not described in any detail, see Chapter IV) in order to keep future oil demand being met by declining production volumes of oil. By using these input figures for the share in total global oil trade, total net oil exports of the suppliers within this research become negative in 2035. This means that nations outside the supplier portfolio of the five countries/regions investigated would have to increase their production of oil to unrealistically high production volumes, at unprecedented rates of increased production capacity. This situation seems highly unlikely, since no supplier outside the suppliers investigated in this research has any oil production of significance at present. Even the share of OPEC member countries decreases in this scenario, while these nations are expected to have increased influence in total global oil production in the coming decades since these nations are able to provide low-cost oil (regular conventional oil, see table 12) far into this century (except Ecuador, Angola and Venezuela). Therefore, the shares in total world oil trade will be kept constant in this research for reasons of simplicity and data availability. When the shares of the supplier countries investigated in total global world trade of 2012 are summed, almost 95% of total trade is covered with this supplier portfolio. It can be concluded from these figures that future oil production will remain a challenge in terms of meeting future, increasing demand, and it remains unclear how, and by which suppliers this growing (or maybe decreasing) demand will be met. Appendix 7 provides a more detailed description for each supplier in this report individually, in the Uppsala Scenario.

Table 15: Input data of Oil Consumption, Production, Net Oil Imports and Dependency Factors in the Uppsala Scenario

		EU	US	China	Japan	India
Oil Demand [Mb/a]	**2020**	3,379	5,586	4,393	1,221	1,600
	2030	2,850	4,786	5,014	1,014	2,321
	2035	2,621	4,386	5,186	936	2,714
Oil Production [Mb/a]	**2020**	814	1,975	1,175	45	158
	2030	447	2,135	857	38	113
	2035	263	1,862	698	31	90
Net Oil Imports [Mb/a]	**2020**	2,565	3,611	3,218	1,176	1,442
	2030	2,403	2,651	4,157	976	2,208
	2035	2,358	2,524	4,488	905	2,624
Oil Dependency Factors		**EU**	**US**	**China**	**Japan**	**India**
	2020	0.759	0.646	0.733	0.963	0.901
	2030	0.843	0.554	0.829	0.963	0.951
	2035	0.900	0.575	0.865	0.967	0.967

Table 15 provides an overview of the input data for composing the dependency factors for the countries investigated in the Uppsala Scenario. The consumption figures are derived from the IEA WEO 2012 (IEA, 2013b) and are assumed to be equal to the figures in the NPS Scenario of the IEA.

Production figures were derived from *Campbell's Atlas of Oil and Gas Depletion* (Campbell, 2013) and adjusted for unconventional oil production, processing gains and NGLs production. Production figures for Japan were not available and the figure of 2012 (EIA, 2014b) was revised downwards to 2030 with 25%, being the same overall downward revision of the Uppsala Group's oil production projections for that year in comparison to the IEA WEO 2012 figures. Appendices 8-12 provide an overview of all the input figures for the Uppsala Scenario for each country individually. The R/P ratio is only given for the years 2012 and 2035 but have been revised downwards proportionally in between. All the input figures for presenting the external oil supply risk indices are given, and the results will be presented in the next chapter.

This chapter will present all the results based on data from the previous chapter, for the model provided by Yang et al (2010). The following paragraphs will present the main findings for the external oil supply risk indices (OSRIs) for the three IEA Climate Scenarios and the Uppsala Scenario, where the indices will be compared over time in figures 23 to 26. First, the traditional oil import diversification index is modified by considering oil supplier's differences in country risks and potential oil exports. Secondly, based on the modified diversification index, external oil supply risk is further evaluated for the five countries/regions by introducing oil import dependency.

7.1 Results of the Modified Oil Import Diversification Indices

Based on the traditional oil import diversification index (HHI), three modified diversification indexes are presented in this research by taking into account oil suppliers' differences in country risk and potential exports. Each index highlights a different side of diversification and can provide more details on the evolution of oil import policy (Yang et al, 2014). Table 16 presents the results for the modified oil import diversification indices in the different scenarios for the countries/regions investigated in this report.

Table 16: Results for the Modified Oil Import Diversification Indices in the IEA Climate- and Uppsala Scenario(s)

IEA Climate Scenarios				
	HHI	**HHI-CR_i**	**HHI-PE_i**	**HHI-RE_i**
European Union	0.141	4.028	0.093	2.255
United States	0.171	3.823	0.097	2.806
China	0.118	3.360	0.103	3.238
Japan	0.181	4.339	0.050	1.189
India	0.102	3.084	0.046	1.381
Uppsala Scenario - 2035				
European Union	0.141	5.204	0.534	13.247
United States	0.171	4.979	0.690	27.038
China	0.118	4.483	0.290	11.944
Japan	0.181	6.008	0.081	2.664
India	0.102	4.085	0.127	4.900

The traditional oil import diversification index (HHI) reflects the number of suppliers and the share assigned to the different sources of oil import. Since this research assesses the potential risks for the five largest oil-importing nations in the world for their current supplier portfolio up to 2035, this index remains constant over time. It can be concluded that import diversification is the highest for India (53% of total imports from Iran, Iraq, Kuwait and Saudi Arabia), followed by China (61% from Saudi Arabia, Angola, Iran and Russia), the EU (41% from Russia and Norway) and the US, respectively (62% from Canada, Saudi Arabia and Mexico). Japan has the lowest diversification of oil imports, with over 68% of total imports coming from only three suppliers, Saudi Arabia, the United Arab Emirates and Qatar.

When the country risk for each oil supplier is taken into account in the HHI-CR_i, larger differences can be detected. This factor has also been assumed to be constant over time in the Climate Scenarios, with a downward revision ('worst-case') in the Uppsala scenario. The same ranking in oil diversification can be seen when country risk is taken into account in the Climate Scenarios. However, in the Uppsala Scenario, the differences become larger and risks higher, with Japan having the highest overall risk in their oil import portfolio. Some supplier countries have a major impact on the total HHI-CR_i index, mainly Venezuela for China, and Russia for the EU, due to excessive reliance of these importing nations on suppliers with relatively higher country risk.

When the potential of delivering oil for suppliers in the future is taken into account, Japan ranks second, behind India. Japan relies heavily on countries with large oil reserves (mainly OPEC), having high R/P ratios and large shares in total world oil trade at present. Japan is followed by the EU and the US respectively (with Ecuador having a large influence on the total HHI-PE_i, having a low R/P ratio). China has the lowest oil import diversification with this index, mainly caused by relying on imports from Angola and Yemen, which both have a low R/P ratio and share in total world trade. The EU is heavily reliant on Norway and Russia for their oil supplies, and these oil suppliers have lower PE-values than e.g. the oil suppliers of the Persian Gulf, which makes the EU more vulnerable when potential exports of oil suppliers are taken into account.

The HHI-RE_i reflects the oil import diversification when taking oil suppliers' country risk as well as potential exports into consideration. By using this modified index, Japan has the highest oil import diversification, as the positive influence of large potential exports of their suppliers outweighs their reliance on a small set of suppliers with relatively high country risk. India ranks second, the EU third and the US fourth. China has the lowest oil import diversification, mainly determined by the low potential exports of Angola and Yemen, and high country risk of Russia.

Appendix 13 shows all the modified diversification indices in the Uppsala Scenario. These HHI's change over time as the R/P ratio of the oil suppliers is revised downward. By combining the HHI indices with the countries/regions' dependency factors of oil import, the external oil supply risks can be evaluated. The following paragraph will outlay the dependency factors for the economies investigated.

7.2 Oil-Dependency Factors

The higher the oil import dependency of an oil-importing nation, the more important oil import diversification is, in terms of external oil supply risks. Figures 21 and 22 show the oil import dependencies for the five economies in the Uppsala Scenario and the 450 (2DS) Scenario. These two scenarios are presented below since these values represent the extremes in the dependency factors for the economies investigated. The figures for the NPS (4DS) and CPS (6DS) can be found in Table 9. Appendix 19 provides an overview of all the dependency factors in the different scenarios.

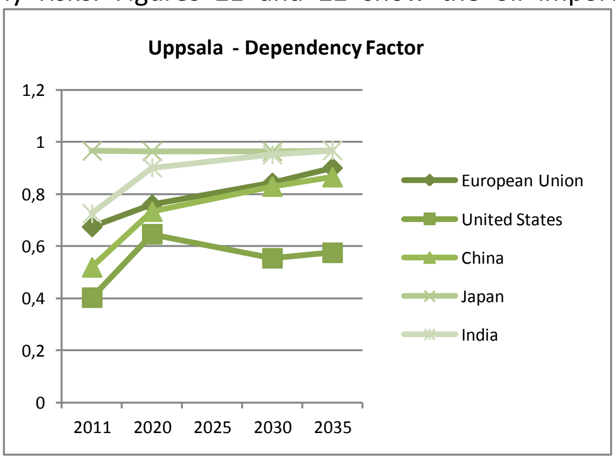


Figure 21: Oil Dependency Factors for the Five Countries/Regions Investigated in the Uppsala Scenario

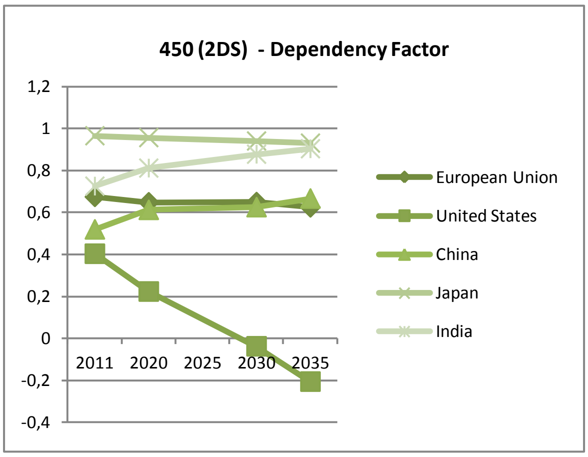


Figure 22: Oil Dependency Factors for the Five Countries/Regions Investigated in the 450 (2DS) Scenario

Figure 21 shows that the oil dependency is the lowest in the United States in the Uppsala Scenario, who increased their domestic production in the 'light tight oil boom'. China, the EU and India rank second, third and fourth respectively. Japan has the highest dependency factor, being almost 100% due to a lack of any oil production of significance. Japan's reliance on external oil supply remains high over the projection period, whereas the oil import dependency of India and the EU approach Japan's figures in 2035. China is the country which makes the largest leap in increased dependency, being unable to meet future domestic oil demand with their oil production, becoming almost 84% reliant on external supplies in 2035. The picture in the 450 Scenario is completely different. While Japan still has the highest dependency on foreign supplies over the projection period, figures for the EU and China are around 20% lower, and the US even becomes a net exporter of oil, being self-sufficient from the year 2030. These effects are mainly due to the IEA's higher production forecasts over the projection period, predominantly from unconventionals (like LTO in the US) and lower demand for oil in the coming decades due to fuel switching for environmental reasons, and efficiency improvements in transport (IEA, 2013b).

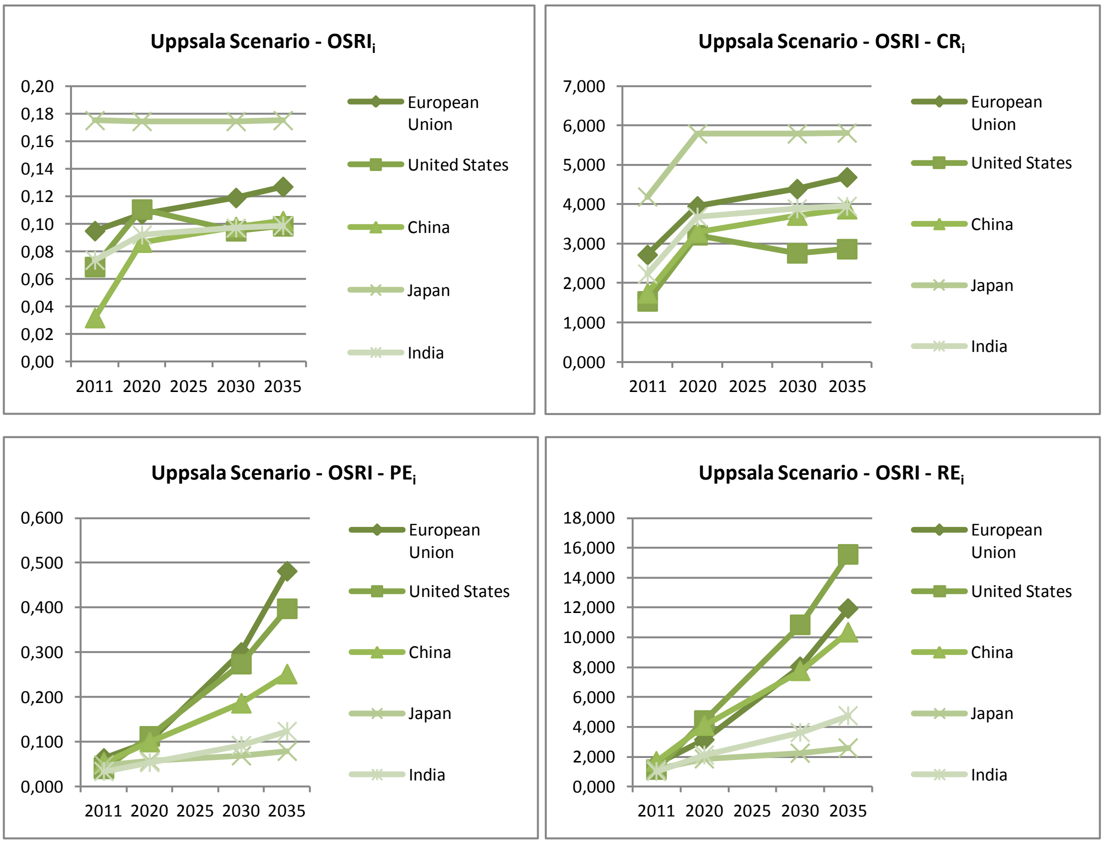
Since diversification is strongly correlated with import dependency in terms of external supply risks, these will be combined to form the external oil supply risk indices in the following paragraph for the five countries/regions investigated.

7.3 The Measurement of External Oil Supply Risks

Figures 23 to 26 present the OSRI indices for the five economies in the four different scenarios. Appendices 14-18 elaborate on the OSRI indices for each country/region individually. In general, it can be seen that EOSRs are higher for any country and any index in the Uppsala Scenario, followed by the CPS, NPS and 450 respectively. This is mainly due to higher dependency factors in the Uppsala Scenario, as a consequence of lower, less optimistic projections of future oil production for the five economies. These differences in the extent of risks become larger when country risk is considered, and more prominently, when potential exports are taken into account (with the impacting factor being the reduced R/P ratio).

In all the scenarios, Japan has the lowest oil import diversification ($OSRI_i$) and also when country risk is considered. China faces the lowest risks in terms of oil import diversification in all scenarios, except the 450 (2DS) scenario, in which the United States become oil-independent, thereby facing 'negative' risks. In the Uppsala Scenario, Japan is followed by the EU, with a worsening oil import diversification due to an increasing dependency factor. The US ranks third, and India second. China, India and the US's trends in the $OSRI_i$ converge over the projection period as China is facing increasing oil import diversification risks due to an increasing dependency factor over time. When country risk is taken into account, China's risks increase and the US surpasses China with having the lowest risks. The picture changes completely when potential exports are taken into account. Japan faces lower external oil supply risks, by relying on suppliers (mainly OPEC) with high R/P ratios and large shares in total world oil trade. Japan has the lowest OSRI-PE_i and OSRI-RE_i values, followed by India, China and the EU respectively. The US faces high risks when potential exports are taken into account in the Uppsala Scenario, as it relies on exporters with low R/P ratios (e.g. Ecuador and Mexico) for their imports. For the EU, these figures are highly influenced by Russia, accounting for 31.7% of total imports (see also the Sensitivity Analysis - Section 8.2), and to a lesser extent Norway (11%).

Figure 23: OSRI Indices in the Uppsala Scenario



In the Climate Scenarios, the US has the highest import diversification (OSRI$_i$) and a positive trend in this risk is observed over time. This effect is mainly caused by the IEA's expectations of LTO production in the future in the US, which are highly optimistic. China ranks second with this index, followed by India, the EU and Japan (the only nation with a downward trend, except the US). This ranking is also observed for the OSRI-CR_i. China has the lowest country risk in 2011 in the Climate Scenarios, however quickly surpassed by the US from 2020 onwards in all three scenarios. When potential exports are taken into account, China becomes the nation with the highest risks, followed by the EU and the stable Japan. India remains at a relatively stable level of external oil supply risks when potential exports are concerned, relying for 87% on imports from OPEC countries. When country risk and potential exports are both taken into account, the same ranking remains, with the differences increasing for China and the EU. The sharply increasing dependency factor of China in the projection period is not matched by the increase in dependency for the EU, which causes the main difference, as well as China being reliant on countries with a lower country risk on average. The US approach 'zero risk' in all three Climate Scenarios, mainly due to the projected 'LTO boom' in the coming decades. India and Japan remain relatively stable over the projection period.

Figure 24: OSRI Indices in the CPS (6DS) IEA Climate Scenario

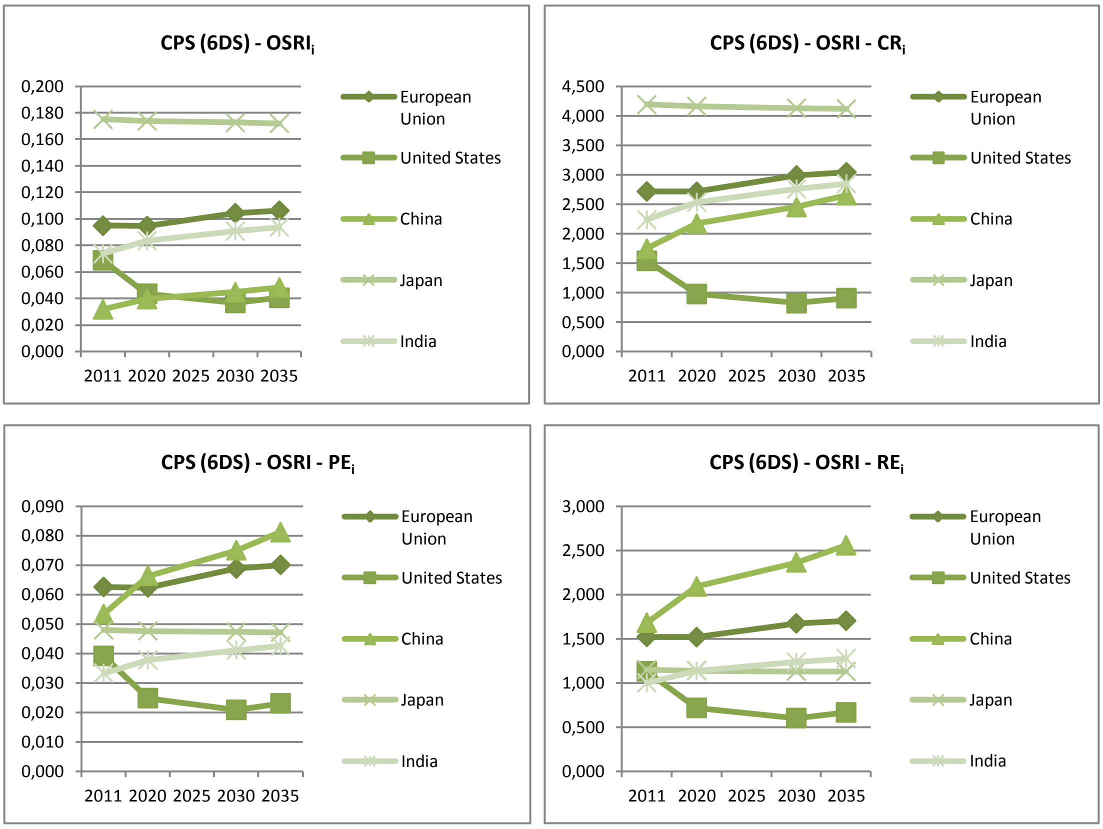
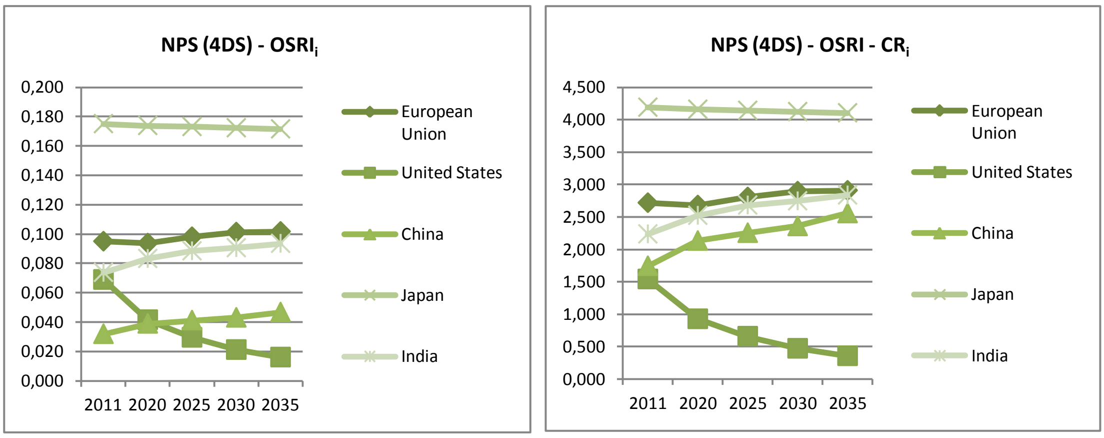


Figure 25: OSRI Indices in the NPS (4DS) IEA Climate Scenario



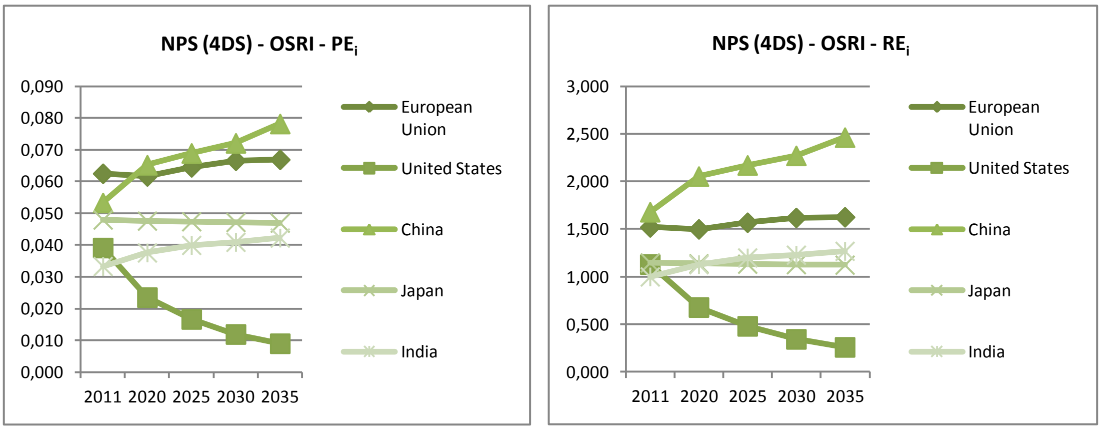
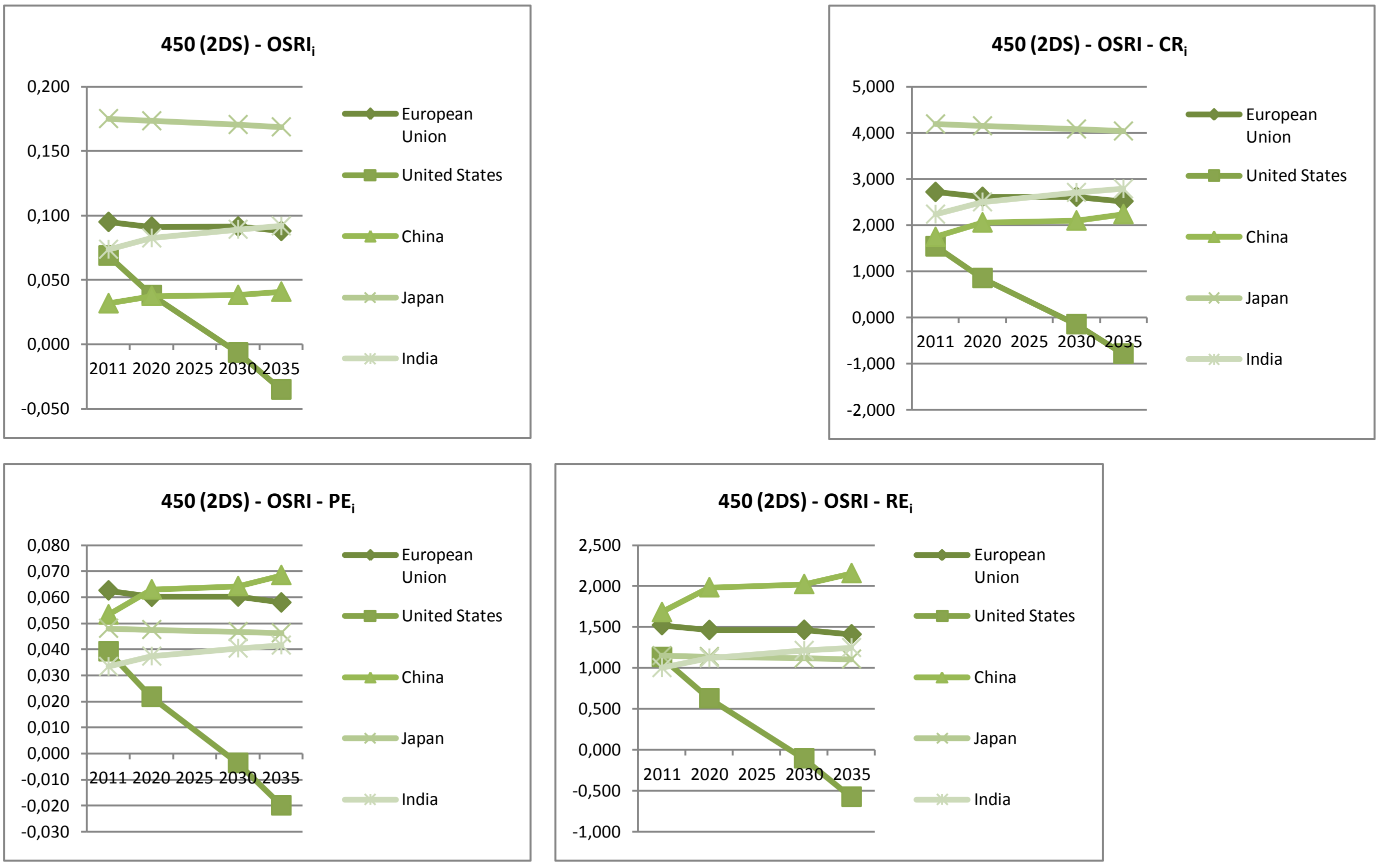


Figure 26: OSRI Indices in the 450 (2DS) IEA Climate Scenario



Some supplier countries have major influence on the results for specific oil-importing economies. Table 17 provides an overview of the suppliers with the largest impact on the OSRI indices for the five economies investigated, and the cause for this influence.

It becomes clear that the EU is heavily dependent on Russia and Norway, which increases the risks for this region significantly. This facts also holds for Japan, for which the dependence on three major suppliers is the cause of higher OSRI indices. However, Japan relies on suppliers with large potential

Table 17: Oil-Suppliers with (Decreasing) Major Influence on OSRI Indices

Oil-Importing Nation	Oil-Supplier	Cause of Major Influence
European Union	Russia	High w_{ij}, high CR_j
	Norway	High w_{ij}, low R/P (PE)
	Azerbaijan	Low s_j, low R/P (PE)
	Cameroon	High CR_j, low R/P (PE)
	Algeria	High CR_j, low R/P (PE)
United States	Mexico	High w_{ij}, low R/P (PE)
	Colombia	Low s_j, low R/P (PE)
	Canada	Very high w_{ij}
	Ecuador	High CR_j, low s_j (PE)
	Saudi Arabia	Very high w_{ij}
China	Angola	High w_{ij}, low R/P (PE) and high CR_j
	Yemen	Very low s_j
	Oman	Low s_j, low R/P (PE)
	Cameroon	High CR_j, low R/P (PE)
	Congo-Br.	High CR_j, low R/P (PE)
Japan	Qatar	Very high w_{ij}
	UAE	Very high w_{ij}
	Saudi Arabia	Very high w_{ij}
	Russia	High w_{ij}, high CR_j
	Malaysia	Low s_j, low R/P (PE)
India	Malaysia	Low s_j, low R/P (PE)
	Iraq	High w_{ij}, high CR_j
	Nigeria	High CR_j
	Angola	High CR_j, low R/P (PE)
	Iran	High w_{ij}, high CR_j

exports, which reduces the risks in the indices where this variable is included. The United States relies on imports mainly from Canada, Mexico and Saudi Arabia, and to a lesser extent on Ecuador and Colombia (low potential exports - low R/P ratio). The main risk for China, is that their oil imports are mainly from countries with low R/P ratio's. If China succeeds to diversify its sources more from OPEC countries, risks could be significantly reduced. India predominantly imports their oil resources from countries with a higher country risk level, being heavily reliant on imports from Iran and Iraq.

The following chapter will elaborate on the shortcomings of the model, and the input figures used, to determine the EOSRs in this research. A sensitivity analysis will assess the robustness and reliability of the findings above, followed by a discussion on the main shortcomings.

The results in the previous chapter are subject to uncertainties in the parameters used in the model by Yang et al (2010). Data unavailability, assumptions made in this research, and simplifications of a complex system of risks in a global oil market, are all arguments to be cautious with regards to the results in this report. The modified diversification indices proposed in this research provide different insights on external oil supply risks for the five economies investigated. This can then be used to form different, and more specified policies in order to reduce external oil supply risks in the future. However, some uncertainties in the variables and input data used for this report have had a major influence on the results. This section starts with a sensitivity analysis of the R/P ratio, followed by an examination of the impact of Russian oil supplies within the supply portfolio of the EU. The EU relies on Russian oil supplies for 31% of their total imports, therefore having a major influence on the OSRI indices within this research for the EU. At the same time, international tensions in Ukraine have caused the EU and the US to impose sanctions on Russia, with Russia countering with 'energy-related sanctions'. This sensitivity analysis shows the impact of a Russian boycott of oil supplies to Europe. Then, the country risk factor will be discussed, as well as the stable supplier portfolio, and the composition of *net oil exports* and *net oil imports.*

8.1 Sensitivity Analysis Variable R/P-Ratio

When the external oil supply risks for the five economies in this research are determined, the R/P ratio of the oil-supplier countries plays an important role. More specifically, in the OSRI-PE$_i$ and OSRI-RE$_i$, where the R/P ratio determines the potential exports for a supplier country, combined with the share in total world oil trade. In order to assess the impact of the assumptions made in this research in the IEA Climate Scenarios, the R/P ratio of the supplier countries for India and the United States will be revised downward with 0.5 yr/yr in the NPS Scenario (being the same downward revision as in the Uppsala Scenario). The results of this sensitivity analysis are presented in figure 27.

It becomes clear that the R/P ratio of the supplier countries has a significant impact on the outcomes of the OSRI-PE$_i$ and OSRI-RE$_i$, where the potential exports are incorporated in the calculation. The OSRI$_i$ and OSRI-CR$_i$ are not different from the regular NPS figures and are therefore not given in this section. As can be seen in figure 25, when the R/P ratio is revised downward with 0,5 yr/yr, in this case for India and the United States, in the NPS, the OSRI indices where the r_j variable is introduced approach the Uppsala Scenario figures. This is especially true for the OSRI-PE$_i$ for India, and to a lesser extent for the OSRI-RE$_i$, where the country risk variable 'stabilizes' the impact of the decreasing R/P ratio for the supplier countries. It can be concluded that the assumption made in the Climate Scenarios - with the R/P ratio held constant - has a significant impact on the results in these scenarios. This is predominantly visible in the OSRI-PE$_i$, where an increase of around 280% is measured in 2035 for India. For the OSRI-RE$_i$, this increase amounts to almost 250%. For the United States, the impact of lowering the R/P ratios of the supplier countries is far lower, mainly due to lower dependency factors. However, EOSR is still higher in this case.

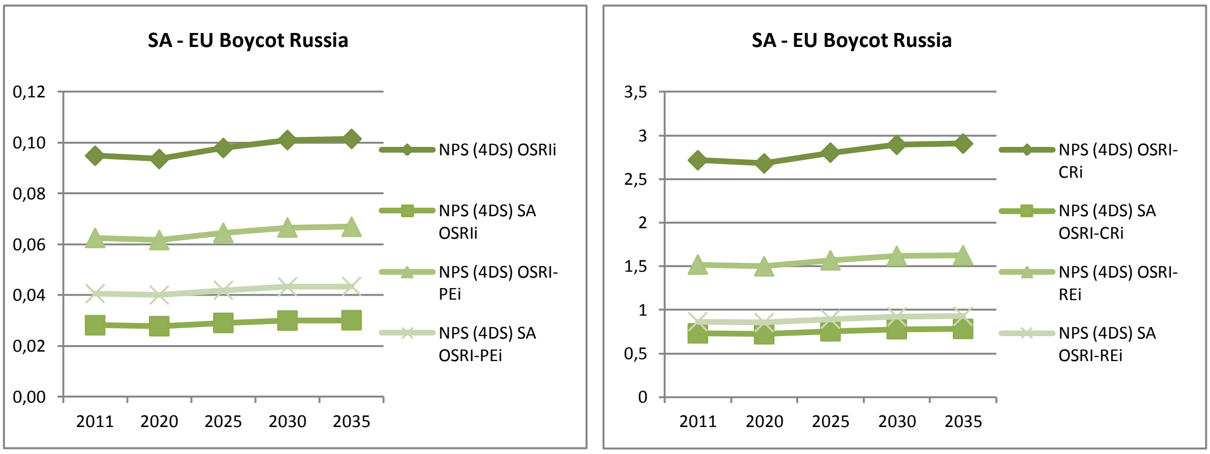
Figure 27: Sensitivity Analysis of the R/P ratio of Supplier Countries in the NPS Climate Scenario for India and the United States

8.2 Sensitivity Analysis of the Impact of Russia on EOSRs for the European Union

Some supplier countries have a major influence on external oil supply risks for a given economy, due to excessive reliance on these major supplier countries. A prominent example is the oil-supplier Russia for the European Union. The EU relies on Russian oil supplies for 31% of their total imports, therefore having a major influence on the OSRI indices within this research for the This sensitivity analysis shows the impact of a Russian boycott of oil supplies to Europe. The imports from Russia will be evenly divided over the other suppliers (which is very unlikely) of the EU. The impact of a Russian boycott of their oil delivery to the EU in terms of external oil supply risks is given in figure 28.

Figure 28 shows the impact of Russia on EOSRs for the European Union. When Russian supplies are subdivided over the other suppliers, the HHI is reduced with 75% and thus, oil imports diversification increases significantly for the EU. Considering country risk, the external oil supply risk becomes 2.5 times lower, and the OSRI-PE_i is reduced with around 65%. The overall external oil supply risks for the EU, taking into account both potential exports and country risk, is reduced with 75%, when Russia is excluded from the regions' supplier portfolio. It becomes clear that excessive reliance on a single oil-supplier has a significant effect on the results for the OSRI indices in this research. However, it can be seen as a highly unlikely situation in which all supplies from one major supplier are evenly distributed over the other supplier countries in the import portfolio. The OSRI indices in this case are highly dependent on the way the oil supplies are subdivided over the other suppliers, and the country risks and potential exports that these suppliers have.

Figure 28: Sensitivity Analysis (SA-scenarios) of the Impact of a Russian Oil Boycott to the European Union (Note: dependency actors derived from the NPS Scenario)



In figure 28, the 'SA-Indices' show the impact of a Russian boycott on the OSRI indices in the NPS Scenario.

8.3 Discussion

In this research, the current (2011) supplier portfolio of the oil-importing economies is investigated for potential risks in the coming decades. This portfolio is held constant throughout the projection period. This situation is highly unlikely, as oil-importing nations will always switch suppliers when necessary. However, these switching practices can only be considered when reviewing the past, like in the research of Yang et al, (2010), and future changes in the supplier portfolio are difficult to predict. This means that this is a major uncertainty in this report.

Other important variables in this research are the country risk factor and the net oil exports, which determine the share in total world oil trade. As mentioned in Chapter V, the country risk factor does not account for any trade/political relationships between a supplier and an importing nation. This could potentially reduce risks significantly. A prominent example is the relationship between the US and Saudi Arabia, or the overseas relationships of China and Japan with mainly African and Middle Eastern states, where direct acquisitions of equity and financial loans in exchange for oil supplies secure oil supplies in the future. The opposite is true for countries like Vietnam, the Philippines and China who all have an interest in offshore deepwater oil deposits, disputing their maritime borders, which increases tensions between these nations (EIA, 2014b). The country risk factor does not consider these relationships, whether they are positive or negative. this could have an impact on the OSRI-CR_i results in this research. However, the CR-value of the supplier countries has been varied in this research in the different scenarios, partly tackling this shortcoming.

The share in total world oil trade is computed by taking the value of a supplier countries *net oil exports* from the EIA (2014b), and it is assumed that these values equal their share in total world oil trade. However, these figures fail to address the share in world oil trade for countries which are net importers of oil, e.g. Canada or Brazil. Figures that were available in the *inter-area movements* section of the *BP Statistical Review of World Energy* were used to consider this shortcoming. However, only the largest economies were mentioned in this report. A more thorough, country-by-country analysis could overcome this lack of data. Then again, the figures that were available in the

BP Review are subject to intense debate, likewise for the IEA Climate Scenario projections. So, the input data for this research is based on reports that have been criticized for their accuracy and reliability. Projections are always subject to uncertainties, as future developments are uncertain and unpredictable to a certain degree. However, detailed modelling of future trends, based on historical trends and expected developments in the future could provide a detailed description of - in this report - the risks associated with external oil supply.

The share in total world oil trade is also held constant in the Uppsala Scenario, which was a consequence of the fact that the shares in total world oil trade - in the case of using the regular method for calculating the net oil exports and share in total world oil trade - were unable to meet projected world oil trade figures - see section 6.4. Risks became too high to be captured by the model used in this report, and therefore these figures are only of limited value for the conclusions. However, it can be concluded from this part of the research that risks will become extremely high in this scenario, which would almost certainly cause major supply-disruptions in the future.

A final discussion point for this research would be the influence of emergency stocks, or Strategic Petroleum Reserves (SPRs), on energy security and external oil supply risks. Emergency stocks are not considered in the model used in this report, but have a significant impact on the buffering of oil shocks, and therefore on shocks to the economy for an importing nation. For example, in the overall index ($OSRI\text{-}RE_i$) in the Uppsala Scenario, the US faces the highest risks. However, the US has a SPR of 58 days of oil imports. India, however has a SPR of only 37Mb, but plans to enlarge the emergency stocks to 132Mb. This process is very capital intensive and it remains to be seen that these increases can be achieved. The same holds for China, having an SPR of 25 days of oil imports, and planning to increase this volume to 90 days of imports in 2020. Japan has the largest SPR - 169 days of oil imports (Yang et al, 2014; EIA, 2014b). The extent of the decrease in risks by having these strategic reserves is hard to quantify and modelling this effect is a subject of further scientific research.

CHAPTER IX - CONCLUSIONS

This report focussed on the following question: *What is the impact of different climate- and oil supply scenarios on external oil supply risks for major oil-importing countries up to 2035?* In order to answer this question, four energy futures were constructed in which oil demand and supply are modelled up to 2035. The EOSR indices from this model will change during the projection period as different climate policies (or the extent of implementation of these policies) are taken into account in the Climate Scenarios, and when supply of oil reaches a peak in the fourth, 'Uppsala' scenario.

It can be concluded from this research that risks associated with external oil supply in the Climate Scenarios, are higher for all five economies investigated in the CPS Scenario, followed by the NPS and the 450 respectively. Thus, the extent of implementation of more stringent climate policies has a significant effect on external oil supply risks for the five largest oil-importing nations in the world. When the OSRI indices are compiled for the IEA Climate Scenarios, the US has the highest import diversification ($OSRI_i$) and a positive trend in this risk is observed over time. China ranks second with this index, followed by India, the EU and Japan. China has the lowest country risk in 2011 in the Climate Scenarios, however, China is quickly surpassed by the US from 2020 onwards in all three scenarios. When potential exports are taken into account, China becomes the nation with the highest risks, followed by the EU and the stable Japan. India remains at a relatively stable level of external oil supply risks when potential exports are concerned. When country risk and potential exports are both taken into account, the same ranking remains, with the differences increasing between China and the EU. The US approaches 'zero risk' in the CPS and NPS, and even becomes oil-independent in the 450 Scenario. It becomes clear that the largest impact on falling overall external oil supply is caused by oil import reliance on OPEC members, with Japan being the most prominent example. However, it can be concluded from the sensitivity analysis that (assumptions for) the R/P ratio has a significant impact on the results in these scenarios. When investigating the exclusion of Russia from the EU's supplier portfolio, it becomes clear that excessive reliance on a single oil-supplier also has a significant effect on the results for the OSRI indices in this report. Another important risk factor is the variable of country risk. The dependency factor is also a major determinant for the OSRI indices. Dependency of oil imports increase for the EU in the CPS and NPS, with a stable 450 Scenario. For China and India, the dependency factor increases in each scenario. Japan, and more prominently the US, have decreasing dependency factors over time, which has a major impact on the OSRIs for the US, and to a lesser extent Japan.

The abovementioned results, based on figures of the IEA, have been revised to account for problems in recoverability and availability of oil resources in the world, since these figures are widely criticized in scientific literature. These problems are particularly present in the case of unconventional oil production. However, global oil supply is expected to become increasingly reliant on unconventionals as crude oil supply falls over time (IEA, 2013b). However, numerous technical- (low EROEI), economic- (higher marginal costs of production) and environmental constraints (higher carbon intensity) make a rapid expansion of non-conventional oil production extremely challenging. Most of the factors mentioned above are likely to continue to hamper unconventional oil production in the foreseeable future and it is therefore also possible that global oil production may peak or plateau in a relatively near future. This pessimistic context is modelled in the Uppsala Scenario.

In general, it can be seen that EOSRs are higher for any country and any index in the Uppsala Scenario, followed by the CPS, NPS and 450 respectively. This is mainly due to higher dependency factors in the Uppsala Scenario, as a consequence of lower, less optimistic projections of future oil production for the five economies. These differences in the extent of risks become larger when country risk is considered, and more prominently, when potential exports are taken into account (with the impacting factor being the reduced R/P ratio). In the Uppsala Scenario, Japan has the lowest oil import diversification, followed by the EU. The US ranks third, and India second. China is exposed to the lowest level of risk in this context. When country risk is taken into account, China's EOS risks increase and the US surpasses China with having the lowest risks. The picture changes completely when potential exports are taken into account. Japan faces lower external oil supply risks, by relying on suppliers with high R/P ratios and large shares in total world oil trade. Japan is followed by India, China and the EU respectively. The US is exposed to the highest risks when potential exports are taken into account.

When production figures are adjusted for a future peak in global oil supply, in combination with the projected growth figures of the IEA WEO 2012, to construct the potential net oil exports of the supplier countries within the Uppsala Scenario, only a fraction of the projected total world oil trade is met by these suppliers. It is unclear whether this is due to the fact that future world oil trade is significantly lower in terms of decreased oil volumes, or which countries, that are currently not a supplier of oil for the economies investigated, will fill this 'gap' in total future global oil trade. It can be concluded that future oil production will remain a challenge in terms of meeting increasing demand, and it remains unclear how, and by which suppliers, this growing demand will be met. It becomes apparent that risks will become extremely high in this scenario, which would almost certainly cause major supply-disruptions in the future. It is therefore essential for substitutes of oil (mainly in transport) to be developed rapidly and implemented on a large-scale. However, a proper chance of achieving this requires functional markets with transparent information. When information on falling oil-supply is not available and publicly criticized by the oil-incumbency, and government policies on energy are completely reliant on information from unreliable and inaccurate reports from e.g. the IEA and BP, this realization will come too late. This could potentially cause a new oil-crisis for which the world was (intentionally) not prepared.

There is a growing realisation that peak oil should be acknowledged as part of a complex energy situation with the realisation that cheap fuel is no longer available and we now face circumstances where prices will increase. The constructed scenarios, and the oil-supply risk indices derived from these scenarios, present a picture of increased risks for the five largest oil-importing nations in the world, when more stringent climate policies are prevented from being implemented (or implemented too slowly). When a peak of oil supply is considered in the model, an even more pessimistic outlook is provided for the five economies in this research, with increased risks in all indices. The final conclusion of this research will be that - based on the abovementioned arguments - high energy-based economic growth will be limited and harder to achieve, and come at an increasingly higher financial-, energetic- and environmental cost, causing increased external oil-supply risks for oil-importing nations.

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Appendix 1a: Input Data for European Union for HHI-Indices in the IEA Climate Scenarios

European Union												
Supplier Country	w_{ij}	w_{ij}^2	$ICRG_j$	CR_j	$w_{ij}^2 x CR_j$	Oil Trade [tbbl/d]	s_j	r_j	PE_j	$1/PE_j$	$w_{ij}^2 x1/PE_j$	$w_{ij}^2 xCR_j x1/PE_j$
Iraq	0,034	0,001	57	43	0,050	2235	0,04	131,9	5,60	0,18	0,000	0,009
Kuwait	0,010	0,000	78	22	0,002	2414	0,05	88,7	4,07	0,25	0,000	0,001
Oman	0,001	0,000	79	21	0,000	779	0,01	16,3	0,24	4,14	0,000	0,000
Qatar	0,001	0,000	77	23	0,000	1843	0,04	33,2	1,16	0,86	0,000	0,000
Saudi Arabia	0,091	0,008	76	24	0,197	8865	0,17	63	10,62	0,09	0,001	0,019
Algeria	0,041	0,002	69	31	0,052	1547	0,03	20	0,59	1,70	0,003	0,089
Angola	0,028	0,001	69	31	0,024	1737	0,03	19,4	0,64	1,56	0,001	0,038
Cameroon	0,005	0,000	63	37	0,001	34	0,00	8,8	0,01	175,80	0,004	0,132
Congo (DR)	0,001	0,000	52	48	0,000	280	0,01	16,1	0,09	11,67	0,000	0,000
Egypt	0,010	0,000	62	38	0,004	0	0,00	0	0,00	0,00	0,000	0,000
Gabon	0,004	0,000	70	30	0,001	226	0,00	22,3	0,10	10,44	0,000	0,005
Libya	0,057	0,003	72	28	0,091	1313	0,02	86,9	2,17	0,46	0,002	0,042
Nigeria	0,083	0,007	64	36	0,249	2254	0,04	42,1	1,80	0,55	0,004	0,138
Tunisia	0,002	0,000	63	37	0,000	0	0,00	0	0,00	0,00	0,000	0,000
Azerbaijan	0,043	0,002	68	32	0,058	847	0,02	21,9	0,35	2,84	0,005	0,165
Kazakhstan	0,059	0,003	69	31	0,108	1355	0,03	47,4	1,22	0,82	0,003	0,089
Russia	0,317	0,101	70	30	3,018	7201	0,14	22,4	3,07	0,33	0,033	0,984
Ukraine	0,000	0,000	64	36	0,000	0	0,00	0	0,00	0,00	0,000	0,000
Norway	0,109	0,012	87	13	0,155	1680	0,03	10,7	0,34	2,93	0,035	0,454
Brazil	0,004	0,000	72	28	0,000	0	0,00	0	0,00	0,00	0,000	0,000
Canada	0,005	0,000	81	19	0,000	3056	0,06	127,4	7,40	0,14	0,000	0,000
Colombia	0,010	0,000	66	34	0,003	682	0,01	6,4	0,08	12,05	0,001	0,042
Ecuador	0,000	0,000	63	37	0,000	292	0,01	44,6	0,25	4,04	0,000	0,000
Mexico	0,018	0,000	72	28	0,009	1366	0,03	10,7	0,28	3,60	0,001	0,033
United States	0,001	0,000	76	24	0,000	2680	0,05	10,7	0,55	1,83	0,000	0,000
Venezuela	0,009	0,000	61	39	0,003	1712	0,03	299	9,73	0,10	0,000	0,000

Appendix 1b: Results Oil Import Diversification Indices for the European Union in the IEA Climate Scenarios

European Union	
Index	**Results**
Traditional Oil Import Diversification Index (HHI)	**0.141**
Modified Oil Import Diversification Index with Country Risk (HHI-CR)	**4.028**
Modified Oil Import Diversification Index with Potential Exports (HHI-PE)	**0.093**
Modified Oil Import Diversification Index with both Country Risk and Potential Exports (HHI-RE)	**2.255**
Imports from OPEC Countries	**35.4%**

Note: *1.6% of import volume not taken into account in HHI-PE_i and HHI-RE_i due to Egypt. Brazil. Ukraine and Tunisia being net importers of oil. so s_j equals 0.*

Sources: *w_{ij} - European Commission. 2013; CR_j - ICRG. 2012; s_j - EIA. 2014b; BP. 2014; r_j - BP. 2014*

Appendix 2a: Input Data for United States for HHI-Indices in the IEA Climate Scenarios

United States													
Supplier Country	% of Total Oil Imports	w_{ij}	w_{ij}^2	$ICRG_j$	CR_j	wij^2xCR_j	Oil Trade [tbbl/d]	s_j	r_j	PE_j	$1/PE_j$	w_{ij}^2x1/PE_j	$w_{ij}^2xCR_jx1/PE_j$
Algeria	0,38	0,004	0,000	69	31	0,000	1547	0,03	20	0,59	1,70	0,000	0,001
Libya	0,56	0,006	0,000	72	28	0,001	1313	0,02	86,9	2,17	0,46	0,000	0,000
Angola	2,62	0,026	0,001	69	31	0,021	1737	0,03	19,0	0,63	1,59	0,001	0,034
Ecuador	2,95	0,030	0,001	63	37	0,032	292	0,01	44,6	0,25	4,04	0,004	0,130
Iraq	4,42	0,044	0,002	57	43	0,084	2235	0,04	131,9	5,60	0,18	0,000	0,015
Kuwait	4,22	0,042	0,002	78	22	0,039	2414	0,05	88,7	4,07	0,25	0,000	0,010
Nigeria	3,10	0,031	0,001	64	36	0,035	2254	0,04	42,1	1,80	0,55	0,001	0,019
Saudi Arabia	17,17	0,172	0,029	76	24	0,707	8865	0,17	63,0	10,62	0,09	0,003	0,067
Venezuela	9,78	0,098	0,010	61	39	0,373	1712	0,03	299,0	9,73	0,10	0,001	0,038
Argentina	0,17	0,002	0,000	71	29	0,000	24	0,00	10,0	0,00	219,17	0,001	0,018
Azerbaijan	0,38	0,004	0,000	68	32	0,000	847	0,02	21,9	0,35	2,84	0,000	0,001
Brazil	1,41	0,014	0,000	72	28	0,006	0	0,00	0,0	0,00	0,00	0,000	0,000
Canada	33,28	0,333	0,111	81	19	2,105	3056	0,06	127,4	7,40	0,14	0,015	0,284
Chad	0,86	0,009	0,000	60	40	0,003	103	0,00	40,0	0,08	12,77	0,001	0,037
Colombia	4,75	0,048	0,002	66	34	0,077	682	0,01	6,4	0,08	12,05	0,027	0,926
Gabon	0,31	0,003	0,000	70	30	0,000	226	0,00	22,3	0,10	10,44	0,000	0,003
Mexico	11,01	0,110	0,012	72	28	0,340	1366	0,03	10,7	0,28	3,60	0,044	1,222
Norway	0,22	0,002	0,000	87	13	0,000	1680	0,03	10,7	0,34	2,93	0,000	0,000
Russia	0,58	0,006	0,000	70	30	0,001	7201	0,14	22,4	3,07	0,33	0,000	0,000
Vietnam	0,17	0,002	0,000	65	35	0,000	0	0,00	0,0	0,00	0,00	0,000	0,000

Appendix 2b: Results Oil Import Diversification Indices for the United States in the IEA Climate Scenarios

United States	
Index	**Results**
Traditional Oil Import Diversification Index (HHI)	**0.171**
Modified Oil Import Diversification Index with Country Risk (HHI-CR)	**3.823**
Modified Oil Import Diversification Index with Potential Exports (HHI-PE)	**0.097**
Modified Oil Import Diversification Index with both Country Risk and Potential Exports (HHI-RE)	**2.806**
Imports from OPEC Countries	**45.2%**

Note: *1.6% of import volume not taken into account in HHI-*PE_i *and HHI-*RE_i *due to Brazil and Vietnam being net importers of oil. so* s_j *equals 0.*

Sources: w_{ij} *- EIA. 2014b;* CR_j *- ICRG. 2012;* s_j *- EIA. 2014b; BP. 2014;* r_j *- BP. 2014*

Appendix 3a: Input Data for China for HHI-Indices in the IEA Climate Scenarios

China													
Supplier Country	% of Total Oil Imports	w_{ij}	w_{ij}^2	$ICRG_j$	CR_j	$w_{ij}^2xCR_j$	Oil Trade [tbbl/d]	s_j	r_j	PE_j	$1/PE_j$	w_{ij}^2x1/PE_j	$w_{ij}^2xCR_jx1/PE_j$
Saudi Arabia	22,6	0,226	0,051	76	24	1,226	8865	0,17	63,0	10,618	0,094	0,005	0,115
Angola	17,3	0,173	0,030	69	31	0,928	1737	0,03	19,4	0,641	1,561	0,047	1,448
Iran	12	0,120	0,014	63	37	0,533	1880	0,04	116,9	4,178	0,239	0,003	0,128
Russia	9,1	0,091	0,008	70	30	0,248	7201	0,14	22,4	3,067	0,326	0,003	0,081
Oman	6,6	0,066	0,004	79	21	0,091	779	0,01	16,3	0,241	4,142	0,018	0,379
Venezuela	6	0,060	0,004	61	39	0,140	1712	0,03	299,0	9,732	0,103	0,000	0,014
Kazakhstan	4,7	0,047	0,002	69	31	0,068	1355	0,03	47,4	1,221	0,819	0,002	0,056
Libya	3,8	0,038	0,001	72	28	0,040	1313	0,02	86,9	2,169	0,461	0,001	0,019
Kuwait	2,5	0,025	0,001	78	22	0,014	2414	0,05	88,7	4,071	0,246	0,000	0,003
UAE	2,4	0,024	0,001	77	23	0,013	2595	0,05	79,1	3,902	0,256	0,000	0,003
Yemen	1,9	0,019	0,000	57	43	0,016	34	0,00	45,4	0,029	34,076	0,012	0,529
Congo-Br.	1,8	0,018	0,000	52	48	0,016	280	0,01	14,8	0,079	12,693	0,004	0,197
Australia	1,4	0,014	0,000	78	22	0,004	0	0,00	0,0	0,000	0,000	0,000	0,000
Iraq	1,3	0,013	0,000	57	43	0,007	2235	0,04	131,9	5,604	0,178	0,000	0,001
Brazil	1,2	0,012	0,000	72	28	0,004	0	0,00	0,0	0,000	0,000	0,000	0,000
Nigeria	1,2	0,012	0,000	64	36	0,005	2254	0,04	42,1	1,804	0,554	0,000	0,003
Eq. Guinea	0,6	0,006	0,000	52	48	0,002	308	0,01	16,5	0,097	10,350	0,000	0,018
Congo	0,5	0,005	0,000	68	32	0,001	280	0,01	16,1	0,086	11,668	0,000	0,009
Cameroon	0,5	0,005	0,000	63	37	0,001	34	0,00	8,8	0,006	175,802	0,004	0,163
Colombia	0,5	0,005	0,000	66	34	0,001	682	0,01	6,4	0,083	12,051	0,000	0,010
Brunei	0,4	0,004	0,000	82	18	0,000	144	0,00	19,0	0,052	19,225	0,000	0,006
Canada	0,3	0,003	0,000	81	19	0,000	3056	0,06	127,4	7,402	0,135	0,000	0,000
Qatar	0,3	0,003	0,000	77	23	0,000	1843	0,04	33,2	1,163	0,860	0,000	0,000
Thailand	0,3	0,003	0,000	68	32	0,000	0	0,00	0,0	0,000	0,000	0,000	0,000
Malaysia	0,2	0,002	0,000	75	25	0,000	45	0,00	15,6	0,013	74,929	0,000	0,007
Mongolia	0,1	0,001	0,000	67	33	0,000	0	0,00	0,0	0,000	0,000	0,000	0,000

Appendix 3b: Results Oil Import Diversification Indices for China in the IEA Climate Scenarios

China	
Index	**Results**
Traditional Oil Import Diversification Index (HHI)	**0.118**
Modified Oil Import Diversification Index with Country Risk (HHI-CR)	**3.360**
Modified Oil Import Diversification Index with Potential Exports (HHI-PE)	**0.103**
Modified Oil Import Diversification Index with both Country Risk and Potential Exports (HHI-RE)	**3.238**
Imports from OPEC Countries	**69.4%**

Note: *3.0% of import volume not taken into account in HHI-PE$_i$ and HHI-RE$_i$ due to Brazil. Australia. Thailand and Mongolia being net importers of oil. so s_j equals 0.*

Sources: *w_{ij} - Reuters. 2012a; CR_j - ICRG. 2012; s_j - EIA. 2014b; BP. 2014; r_j - BP. 2014*

Appendix 4a: Input Data for Japan for HHI-Indices in the Climate Scenarios

Japan													
Supplier Country	% of Total Oil Imports	w_{ij}	w_{ij}^2	$ICRG_j$	CR_j	$w_{ij}^2 x CR_j$	Oil Trade [tbbl/d]	s_j	r_j	PE_j	$1/PE_j$	$w_{ij}^2 x1/PE_j$	$w_{ij}^2 xCR_j x1/PE_j$
Kazakhstan	0,1	0,001	0,000	69	31	0,000	1355	0,03	47,4	1,22	0,82	0,000	0,000
Vietnam	1,5	0,015	0,000	65	35	0,008	0	0,00	34,5	0,00	0,00	0,000	0,000
Malaysia	0,5	0,005	0,000	75	25	0,001	45	0,00	15,6	0,01	74,93	0,002	0,047
Brunei	0,2	0,002	0,000	82	18	0,000	144	0,00	19,0	0,05	19,23	0,000	0,001
Indonesia	3,2	0,032	0,001	65	35	0,036	0	0,00	11,1	0,00	0,00	0,000	0,000
Iran	4,6	0,046	0,002	63	37	0,078	1880	0,04	116,9	4,18	0,24	0,001	0,019
Iraq	1,6	0,016	0,000	57	43	0,011	2235	0,04	131,9	5,60	0,18	0,000	0,002
Saudi Arabia	30,7	0,307	0,094	76	24	2,262	8865	0,17	63,0	10,62	0,09	0,009	0,213
Kuwait	7,2	0,072	0,005	78	22	0,114	2414	0,05	88,7	4,07	0,25	0,001	0,028
Qatar	14,6	0,146	0,021	77	23	0,490	1843	0,04	33,2	1,16	0,86	0,018	0,421
UAE	22,7	0,227	0,052	77	23	1,185	2595	0,05	79,1	3,90	0,26	0,013	0,304
Oman	2,1	0,021	0,000	79	21	0,009	779	0,01	16,3	0,24	4,14	0,002	0,038
Norway	0,1	0,001	0,000	87	13	0,000	1680	0,03	10,7	0,34	2,93	0,000	0,000
Russia	7,2	0,072	0,005	70	30	0,156	7201	0,14	22,4	3,07	0,33	0,002	0,051
Venezuela	0,4	0,004	0,000	61	39	0,001	1712	0,03	299,0	9,73	0,10	0,000	0,000
Ecuador	0,7	0,007	0,000	63	37	0,002	292	0,01	446,0	2,48	0,40	0,000	0,001
Algeria	0,1	0,001	0,000	69	31	0,000	1547	0,03	20,0	0,59	1,70	0,000	0,000
Libya	0,1	0,001	0,000	72	28	0,000	1313	0,02	86,9	2,17	0,46	0,000	0,000
Sudan	0,2	0,002	0,000	52	48	0,000	20	0,00	42,1	0,02	62,47	0,000	0,012
Nigeria	0,1	0,001	0,000	64	36	0,000	2254	0,04	42,1	1,80	0,55	0,000	0,000
Chad	0,2	0,002	0,000	60	40	0,000	103	0,00	40,7	0,08	12,55	0,000	0,002
Gabon	1,2	0,012	0,000	70	30	0,004	226	0,00	22,3	0,10	10,44	0,002	0,045
Angola	0,1	0,001	0,000	69	31	0,000	1737	0,03	19,4	0,64	1,56	0,000	0,000
Australia	0,6	0,006	0,000	78	22	0,001	0	0,00	23,4	0,00	0,00	0,000	0,000

Appendix 4b: Results Oil Import Diversification Indices for Japan in the IEA Climate Scenarios

Japan	
Index	**Results**
Traditional Oil Import Diversification Index (HHI)	**0.181**
Modified Oil Import Diversification Index with Country Risk (HHI-CR)	**4.339**
Modified Oil Import Diversification Index with Potential Exports (HHI-PE)	**0.050**
Modified Oil Import Diversification Index with both Country Risk and Potential Exports (HHI-RE)	**1.183**
Imports from OPEC Countries	**82.3%**

Note: *5.2% of import volume not taken into account in HHI-PE_i and HHI-RE_i due to Vietnam. Indonesia and Australia being net importers of oil. so s_j equals 0.*

Sources: *w_{ij} - Petroleum Association of Japan. 2014; CR_j - ICRG. 2012; s_j - EIA. 2014b; BP. 2014; r_j - BP. 2014*

Appendix 5a: Input Data for India for HHI-Indices in the IEA Climate Scenarios

India													
Supplier Country	Oil Supply [x1000 bbl/dy]	w_{ij}	w_{ij}^2	$ICRG_j$	CR_j	$w_{ij}^2xCR_j$	Oil Trade [tbbl/d]	s_j	r_j	PE_j	$1/PE_j$	w_{ij}^2x1/PE_j	$w_{ij}^2xCR_jx1/PE_j$
Iran	363	0,106	0,011	63	37	0,412	1880	0,04	116,9	4,18	0,24	0,003	0,099
Iraq	483	0,140	0,020	57	43	0,848	2235	0,04	131,9	5,60	0,18	0,004	0,151
Kuwait	355	0,103	0,011	78	22	0,234	2414	0,05	88,7	4,07	0,25	0,003	0,058
Oman	52	0,015	0,000	79	21	0,005	779	0,01	16,3	0,24	4,14	0,001	0,020
Qatar	130	0,038	0,001	77	23	0,033	1843	0,04	33,2	1,16	0,86	0,001	0,028
Saudi Arabia	651	0,189	0,036	76	24	0,860	8865	0,17	63,0	10,62	0,09	0,003	0,081
UAE	316	0,092	0,008	77	23	0,194	2595	0,05	79,1	3,90	0,26	0,002	0,050
Yemen	26	0,008	0,000	57	43	0,002	34	0,00	45,4	0,03	34,08	0,002	0,084
Brazil	76	0,022	0,000	72	28	0,014	0	0,00	0,0	0,00	0,00	0,000	0,000
Colombia	18	0,005	0,000	66	34	0,001	682	0,01	6,4	0,08	12,05	0,000	0,011
Equador	6	0,002	0,000	63	37	0,000	292	0,01	44,6	0,25	4,04	0,000	0,000
Mexico	46	0,013	0,000	72	28	0,005	1366	0,03	10,7	0,28	3,60	0,001	0,018
Venezuela	191	0,056	0,003	61	39	0,120	1712	0,03	299,0	9,73	0,10	0,000	0,012
Australia	13	0,004	0,000	78	22	0,000	0	0,00	0,0	0,00	0,00	0,000	0,000
Brunei	22	0,006	0,000	82	18	0,001	144	0,00	19,0	0,05	19,23	0,001	0,014
Malaysia	47	0,014	0,000	75	25	0,005	45	0,00	15,6	0,01	74,93	0,014	0,350
Algeria	42	0,012	0,000	69	31	0,005	1547	0,03	20,0	0,59	1,70	0,000	0,008
Angola	181	0,053	0,003	69	31	0,086	1737	0,03	19,4	0,64	1,56	0,004	0,134
Cameroon	10	0,003	0,000	63	37	0,000	34	0,00	8,8	0,01	175,80	0,001	0,055
Congo	11	0,003	0,000	52	48	0,000	280	0,01	14,8	0,08	12,69	0,000	0,006
Egypt	57	0,017	0,000	62	38	0,010	0	0,00	0,0	0,00	0,00	0,000	0,000
Eq. Guinea	18	0,005	0,000	52	48	0,001	308	0,01	16,5	0,10	10,35	0,000	0,014
Nigeria	283	0,082	0,007	64	36	0,244	2254	0,04	42,1	1,80	0,55	0,004	0,135
Sudan	14	0,004	0,000	52	48	0,001	21	0,00	50,0	0,02	50,10	0,001	0,040
Azerbaijan	21	0,006	0,000	68	32	0,001	847	0,02	21,9	0,35	2,84	0,000	0,003
Norway	13	0,004	0,000	87	13	0,000	1680	0,03	10,7	0,34	2,93	0,000	0,001

Appendix 5b: Results Oil Import Diversification Indices for India in the IEA Climate Scenarios

India	
Index	**Results**
Traditional Oil Import Diversification Index (HHI)	**0.102**
Modified Oil Import Diversification Index with Country Risk (HHI-CR)	**3.084**
Modified Oil Import Diversification Index with Potential Exports (HHI-PE)	**0.046**
Modified Oil Import Diversification Index with both Country Risk and Potential Exports (HHI-RE)	**1.381**
Imports from OPEC Countries	**87.3%**

Note: *4.3% of import volume not taken into account in HHI-PE$_i$ and HHI-RE$_i$ due to Australia. Brazil and Egypt being net importers of oil. so s_j equals 0.*

Sources: *w_{ij} - Reuters. 2012b; CR_j - ICRG. 2012; s_j - EIA. 2014b; BP. 2014; r_j - BP. 2014*

Appendix 6: Input Data for Net Oil Imports Calculation in Different Climate Scenarios (*Source: IEA. 2013b*)

		NPS					CPS					450				
	Year	**US**	**China**	**India**	**EU**	**Japan**	**US**	**China**	**India**	**EU**	**Japan**	**US**	**China**	**India**	**EU**	**Japan**
Consumption [Mb/yr]	**2011**	5621	3186	1193	3921	1471										
	2020	5586	4393	1600	3379	1221	5686	4529	1636	3457	1236	5450	4143	1543	3214	1157
	2025	5200	4764	1950	3121	1114										
	2030	4786	5014	2321	2850	1014	5343	5536	2414	3107	1057	4043	3986	2079	2286	850
	2035	4386	5186	2714	2621	936	5214	5886	2857	2979	1000	3300	3714	2250	1943	729
Production [Mb/d]	**2011**	9,20	4,20	0,90	3,50	0,14	9,20	4,20	0,90	3,50	0,14	9,20	4,20	0,90	3,50	0,14
	2020	11,60	4,40	0,80	3,10	0,14	11,60	4,40	0,80	3,10	0,14	11,60	4,40	0,80	3,10	0,14
	2025	11,80	4,30	0,70	2,60	0,14	11,80	4,30	0,70	2,60	0,14	11,80	4,30	0,70	2,60	0,14
	2030	11,50	4,10	0,70	2,20	0,14	11,50	4,10	0,70	2,20	0,14	11,50	4,10	0,70	2,20	0,14
	2035	10,90	3,40	0,60	2,00	0,14	10,90	3,40	0,60	2,00	0,14	10,90	3,40	0,60	2,00	0,14
Production [Mb/yr]	**2011**	3358	1533	329	1278	51	3358	1533	329	1278	51	3358	1533	329	1278	51
	2020	4234	1606	292	1132	51	4234	1606	292	1132	51	4234	1606	292	1132	51
	2025	4307	1570	256	949	51	4307	1570	256	949	51	4307	1570	256	949	51
	2030	4198	1497	256	803	51	4198	1497	256	803	51	4198	1497	256	803	51
	2035	3979	1241	219	730	51	3979	1241	219	730	51	3979	1241	219	730	51
Net Oil Imports [Mb/yr]	**2011**	2263	1653	865	2644	1420										
	2020	1352	2787	1308	2248	1170	1452	2923	1344	2326	1185	1216	2537	1251	2083	1106
	2025	893	3195	1695	2172	1063										
	2030	589	3518	2066	2047	963	1146	4040	2159	2304	1006	-155	2490	1824	1483	799
	2035	408	3945	2495	1891	885	1236	4645	2638	2249	949	-679	2473	2031	1213	678

Appendix 7a: Input Data Uppsala Scenario of Oil Production, R/P Ratio, Country Risk Factor, Consumption and the Compound Average Annual Growth Factor of Consumption of Supplier Countries

	Adjusted Production [Mb/d]			R/P Ratio [yr]				CRj	Oil Consumption [Mb/d]				CAAGR	
	2020	2030	2035	2012	2020	2030	2035		2012	2020	2030	2035	[#/yr]	[%/yr]
Algeria	1.26	0.79	0.56	20.0	16.0	11.0	8.5	55.5	0.33	0.37	0.42	0.44	1.013	1.3
Libya	1.45	1.19	1.07	86.9	82.9	77.9	75.4	60.5	0.17	0.19	0.21	0.23	1.013	1.3
Angola	0.39	0.22	0.14	19.4	15.4	10.4	7.9	59.0	0.09	0.10	0.11	0.12	1.013	1.3
Ecuador	0.33	0.20	0.13	44.6	40.6	35.6	33.1	53.3	0.21	0.23	0.26	0.27	1.011	1.1
Iraq	4.53	4.10	3.88	131.9	127.9	122.9	120.4	45.8	0.75	0.85	1.00	1.08	1.016	1.6
Kuwait	2.42	2.15	2.02	88.7	84.7	79.7	77.2	69.5	0.38	0.43	0.51	0.55	1.016	1.6
Nigeria	1.40	1.17	1.06	42.1	38.1	33.1	30.6	53.0	0.27	0.30	0.34	0.36	1.013	1.3
Saudia Arabia	9.53	7.79	6.92	63.0	59.0	54.0	51.5	66.8	2.86	3.25	3.81	4.12	1.016	1.6
Venezuela	2.15	2.76	3.01	110.0	106.0	101.0	98.5	50.5	0.78	0.85	0.95	1.00	1.011	1.1
Argentina	0.53	0.45	0.41	10.2	6.2	1.2	0.1	60.8	0.70	0.76	0.85	0.90	1.011	1.1
Azerbaijan	1.09	0.73	0.56	21.9	17.9	12.9	10.4	57.3	0.09	0.10	0.12	0.13	1.016	1.6
Brazil	2.15	2.82	2.41	19.5	15.5	10.5	8.0	63.3	2.81	3.04	3.36	3.53	1.010	1.0
Canada	3.77	4.81	4.58	41.1	37.1	32.1	29.6	75.8	2.28	2.17	2.05	1.99	0.994	-0.6
Chad	0.16	0.11	0.08	40.7	36.7	31.7	29.2	51.0	0.01	0.01	0.01	0.01	1.013	1.3
Colombia	0.53	0.33	0.23	6.4	2.4	0.1	0.1	56.5	0.29	0.32	0.35	0.37	1.011	1.1
Gabon	0.15	0.08	0.05	22.3	18.3	13.3	10.8	60.5	0.02	0.02	0.03	0.03	1.013	1.3
Mexico	1.49	0.74	0.37	10.7	6.7	1.7	0.1	62.0	2.11	2.30	2.57	2.71	1.011	1.1
Norway	1.16	0.62	0.35	10.7	6.7	1.7	0.1	82.0	0.22	0.20	0.18	0.17	0.988	-1.2
Russia	7.04	5.03	3.98	22.4	18.4	13.4	10.9	61.8	3.20	3.30	3.44	3.51	1.004	0.4
Vietnam	0.36	0.21	0.14	34.5	30.5	25.5	23.0	56.5	0.39	0.47	0.59	0.66	1.023	2.3
Cameroon	0.05	0.03	0.02	8.0	4.0	0.1	0.1	52.5	0.03	0.03	0.04	0.04	1.013	1.3
Congo (DR)	0.30	0.26	0.24	14.8	10.8	5.8	3.3	40.0	0.01	0.01	0.01	0.01	1.013	1.3
Egypt	0.39	0.25	0.18	16.1	12.1	7.1	4.6	53.3	0.76	0.84	0.96	1.02	1.013	1.3
Tunisia	0.06	0.04	0.04	17.9	13.9	8.9	6.4	54.3	0.09	0.10	0.11	0.12	1.013	1.3
Kazakhstan	2.38	2.16	2.05	47.4	43.4	38.4	35.9	59.8	0.25	0.26	0.28	0.29	1.006	0.6
United States	5.41	5.85	5.10	10.7	6.7	1.7	0.1	69.8	18.49	17.20	15.71	15.02	0.991	-0.9
Oman	0.58	0.34	0.22	16.3	12.3	7.3	4.8	70.3	0.14	0.16	0.18	0.19	1.013	1.3
Qatar	1.50	1.60	1.62	40.9	36.9	31.9	29.4	69.3	0.19	0.22	0.25	0.27	1.016	1.6
Malaysia	0.43	0.29	0.21	15.6	11.6	6.6	4.1	66.0	0.60	0.72	0.90	1.01	1.023	2.3
Brunei	0.10	0.06	0.04	19.0	15.0	10.0	7.5	75.5	0.02	0.02	0.03	0.03	1.023	2.3
Indonesia	0.72	0.48	0.35	11.1	7.1	2.1	-0.4	57.0	1.60	1.92	2.41	2.70	1.023	2.3
Iran	4.40	3.62	3.22	116.9	112.9	107.9	105.4	52.8	1.71	1.94	2.28	2.46	1.016	1.6
UAE	3.18	2.70	2.46	79.0	75.0	70.0	67.5	67.0	0.62	0.70	0.83	0.89	1.016	1.6
Sudan	0.12	0.10	0.10	50.0	46.0	41.0	38.5	41.3	0.09	0.10	0.11	0.12	1.013	1.3
Australia	0.10	0.25	0.33	23.4	19.4	14.4	11.9	70.8	1.13	1.00	0.86	0.80	0.985	-1.5
Yemen	0.21	0.13	0.10	45.4	41.4	36.4	33.9	48.5	0.14	0.16	0.19	0.20	1.016	1.6
Eq. Guinea	0.03	0.03	0.02	16.5	12.5	7.5	5.0	39.9	0.01	0.01	0.01	0.01	1.015	1.5
Thailand	0.25	0.22	0.21	2.7	0.1	0.1	0.1	56.8	1.01	1.21	1.52	1.70	1.023	2.3

Appendix 7b: Input Data Uppsala Scenario of Net Oil Exports, Share in World Oil Trade and Potential Exports of Supplier Countries

	Net Oil Exports [Mb/d]			Sj			PE		
	2020	2030	2035	2020	2030	3035	2020	2030	2035
Algeria	0.89	0.37	0.11	0.017	0.008	0.002	0.239	0.050	0.007
Libya	1.26	0.98	0.84	0.024	0.020	0.018	1.945	1.484	1.256
Angola	0.29	0.11	0.02	0.006	0.002	0.000	0.075	0.013	0.001
Ecuador	0.10	-0.06	-0.14	0.002	-0.001	-0.003	0.077	-0.038	-0.083
Iraq	3.68	3.10	2.80	0.070	0.064	0.060	8.860	7.572	6.897
Kuwait	1.99	1.65	1.47	0.038	0.034	0.032	3.142	2.552	2.255
Nigeria	1.10	0.83	0.70	0.021	0.017	0.015	0.759	0.491	0.371
Saudia Arabia	6.29	3.98	2.80	0.120	0.082	0.060	6.852	4.066	2.746
Venezuela	1.30	1.81	2.01	0.025	0.037	0.043	2.582	3.602	3.994
Argentina	-0.23	-0.40	-0.49	-0.004	-0.008	-0.011	-0.019	-0.001	-0.001
Azerbaijan	0.99	0.61	0.43	0.019	0.013	0.009	0.300	0.106	0.043
Brazil	-0.89	-0.54	-1.12	-0.017	-0.011	-0.024	-0.230	-0.067	-0.054
Canada	1.60	2.76	2.59	0.031	0.057	0.056	1.072	1.573	1.328
Chad	0.15	0.10	0.07	0.003	0.002	0.001	0.098	0.054	0.035
Colombia	0.21	-0.02	-0.14	0.004	0.000	-0.003	0.002	0.000	0.000
Gabon	0.13	0.06	0.02	0.002	0.001	0.000	0.040	0.010	0.002
Mexico	-0.81	-1.83	-2.34	-0.016	-0.038	-0.050	-0.073	-0.004	-0.005
Norway	0.96	0.44	0.18	0.018	0.009	0.004	0.086	0.001	0.000
Russia	3.74	1.59	0.47	0.071	0.033	0.010	1.172	0.292	0.052
Vietnam	-0.11	-0.37	-0.52	-0.002	-0.008	-0.011	-0.059	-0.162	-0.192
Cameroon	0.01	-0.01	-0.02	0.000	0.000	0.000	0.001	0.000	0.000
Congo (DR)	0.28	0.25	0.23	0.005	0.005	0.005	0.048	0.007	0.000
Egypt	-0.45	-0.71	-0.84	-0.009	-0.015	-0.018	-0.087	-0.038	-0.002
Tunisia	-0.04	-0.07	-0.08	-0.001	-0.001	-0.002	-0.009	-0.006	-0.001
Kazakhstan	2.12	1.88	1.76	0.041	0.039	0.038	1.679	1.314	1.138
United States	-11.79	-9.86	-9.92	-0.225	-0.203	-0.213	-1.060	-0.020	-0.021
Oman	0.43	0.16	0.03	0.008	0.003	0.001	0.085	0.009	0.000
Qatar	1.28	1.35	1.35	0.025	0.028	0.029	0.857	0.761	0.683
Malaysia	-0.29	-0.62	-0.80	-0.006	-0.013	-0.017	-0.053	-0.027	-0.002
Brunei	0.07	0.03	0.01	0.001	0.001	0.000	0.019	0.003	0.000
Indonesia	-1.20	-1.93	-2.34	-0.023	-0.040	-0.050	-0.117	-0.004	-0.005
Iran	2.46	1.34	0.76	0.047	0.028	0.016	5.223	2.859	1.623
UAE	2.47	1.87	1.57	0.047	0.039	0.034	3.453	2.530	2.074
Sudan	0.02	-0.01	-0.02	0.000	0.000	0.000	0.015	-0.007	-0.016
Australia	-0.90	-0.61	-0.47	-0.017	-0.013	-0.010	-0.298	-0.124	-0.062
Yemen	0.05	-0.05	-0.10	0.001	-0.001	-0.002	0.036	-0.035	-0.063
Eq. Guinea	0.02	0.01	0.01	0.000	0.000	0.000	0.003	0.001	0.000
Thailand	-0.96	-1.30	-1.50	-0.018	-0.027	-0.032	-0.002	-0.003	-0.003
Totals World	52.3	48.5	46.6						

Appendix 8: Input Data for the European Union for the HHI-Indices in the Uppsala Scenario

European Union											
Supplier Country	wij^2	$ICRG_j$	CR_j	$w_{ij}^2xCR_j$	s_j	r_j 2012	r_j 2035	PE_j	$1/PE_j$	w_{ij}^2x1/PE_j	$w_{ij}^2xCR_j$ $x1/PE_j$
Iraq	0,001	45,8	54,2	0,063	0,04	131,9	120,4	5,12	0,20	0,000	0,012
Kuwait	0,000	69,5	30,5	0,003	0,05	88,7	77,2	3,54	0,28	0,000	0,001
Oman	0,000	70,3	29,7	0,000	0,01	16,3	4,8	0,07	14,07	0,000	0,000
Qatar	0,000	69,3	30,7	0,000	0,04	33	21,5	0,75	1,33	0,000	0,000
Saudi Arabia	0,008	66,8	33,2	0,273	0,17	63	51,5	8,68	0,12	0,001	0,031
Algeria	0,002	55,5	44,5	0,075	0,03	20	8,5	0,25	4,00	0,007	0,301
Angola	0,001	59,0	41,0	0,032	0,03	19	7,5	0,25	4,04	0,003	0,131
Cameroon	0,000	52,5	47,5	0,001	0,00	8	1	0,00	1547,06	0,031	1,491
Congo	0,000	40,0	60,0	0,000	0,01	14,8	3,3	0,02	56,93	0,000	0,016
Congo (DR)	0,000	52,0	48,0	0,000	0,01	16	4,5	0,02	41,75	0,000	0,002
Egypt	0,000	53,3	46,7	0,005	0,00	0	0	0,00	0,00	0,000	0,000
Gabon	0,000	60,5	39,5	0,001	0,00	22,3	10,8	0,05	21,55	0,000	0,014
Libya	0,003	60,5	39,5	0,129	0,02	86,9	75,4	1,88	0,53	0,002	0,069
Nigeria	0,007	53,0	47,0	0,325	0,04	42,1	30,6	1,31	0,76	0,005	0,248
Tunisia	0,000	54,3	45,7	0,000	0,00	0	0	0,00	0,00	0,000	0,000
Azerbaijan	0,002	57,3	42,7	0,078	0,02	21,9	10,4	0,17	5,97	0,011	0,464
Kazakhstan	0,003	59,8	40,2	0,140	0,03	47,4	35,9	0,92	1,08	0,004	0,152
Russia	0,101	61,8	38,2	3,843	0,14	22,4	10,9	1,49	0,67	0,067	2,575
Norway	0,012	82,0	18,0	0,215	0,03	10,7	1	0,03	31,31	0,373	6,719
Brazil	0,000	63,3	36,7	0,000	0,00	0	0	0,00	0,00	0,000	0,000
Canada	0,000	75,8	24,2	0,001	0,06	127,4	115,9	6,73	0,15	0,000	0,000
Colombia	0,000	56,5	43,5	0,004	0,01	6,4	1	0,01	77,13	0,008	0,340
Ecuador	0,000	53,3	46,7	0,000	0,01	44,6	33,1	0,18	5,44	0,000	0,000
Mexico	0,000	62,0	38,0	0,012	0,03	10,7	1	0,03	38,51	0,012	0,473
United States	0,000	69,8	30,2	0,000	0,05	10,7	1	0,05	19,63	0,000	0,000
Venezuela	0,000	50,5	49,5	0,004	0,03	299	287,5	9,36	0,11	0,000	0,000

***Note**: Supplier countries given in red are net oil importing nations; countries given in blue have a negative R/P ratio over/during the projection period - figure revised to +1. For the European Union, a correction factor was used for the OSRI-PE_i and OSRI-RE_i to account for countries with no share in total world oil trade (sj = 0), and equal risk is assumed in comparison with other supplier countries. For the European Union the correction factor was +1.6% - representing total import volume of oil in supplier portfolio left out.*

Appendix 9: Input Data for the United States for the HHI-Indices in the Uppsala Scenario

United States

Supplier Country	wij^2	$ICRG_j$	CR_j	$w_{ij}^2xCR_j$	s_j	r_j 2012	r_j 2035	PE_j	$1/PE_j$	w_{ij}^2x1/PE_j	$w_{ij}^2xCR_j$ $x1/PE_j$
Algeria	0,000	55,5	31,0	0,000	0,03	20	8,5	0,25	4,00	0,000	0,002
Libya	0,000	60,5	28,0	0,001	0,02	86,9	75,4	1,88	0,53	0,000	0,000
Angola	0,001	59,0	41,0	0,028	0,03	19,0	7,5	0,25	4,04	0,003	0,113
Ecuador	0,001	53,3	46,7	0,041	0,01	44,6	33,1	0,18	5,44	0,005	0,222
Iraq	0,002	45,8	54,2	0,106	0,04	131,9	120,4	5,12	0,20	0,000	0,021
Kuwait	0,002	69,5	30,5	0,054	0,05	88,7	77,2	3,54	0,28	0,001	0,015
Nigeria	0,001	53,0	47,0	0,045	0,04	42,1	30,6	1,31	0,76	0,001	0,034
Saudia Arabia	0,029	66,8	33,2	0,978	0,17	63,0	51,5	8,68	0,12	0,003	0,113
Venezuela	0,010	50,5	49,5	0,474	0,03	299,0	287,5	9,36	0,11	0,001	0,051
Argentina	0,000	60,8	39,2	0,000	0,00	10,0	1	0,00	2191,67	0,006	0,244
Azerbaijan	0,000	57,3	42,7	0,001	0,02	21,9	10,4	0,17	5,97	0,000	0,004
Brazil	0,000	63,3	36,7	0,007	0,00	0,0	0	0,00	0,00	0,000	0,000
Canada	0,111	75,8	24,2	2,681	0,06	127,4	115,9	6,73	0,15	0,016	0,398
Chad	0,000	51,0	49,0	0,004	0,00	40,0	28,5	0,06	17,92	0,001	0,064
Colombia	0,002	56,5	43,5	0,098	0,01	6,4	1	0,01	77,13	0,174	7,584
Gabon	0,000	60,5	39,5	0,000	0,00	22,3	10,8	0,05	21,55	0,000	0,008
Mexico	0,012	62,0	38,0	0,461	0,03	10,7	1	0,03	38,51	0,467	17,743
Norway	0,000	82,0	18,0	0,000	0,03	10,7	1	0,03	31,31	0,000	0,003
Russia	0,000	61,8	38,2	0,001	0,14	22,4	10,9	1,49	0,67	0,000	0,001
Vietnam	0,000	56,5	43,5	0,000	0,00	0,0	0	0,00	0,00	0,000	0,000

***Note**: Supplier countries given in red are net oil importing nations; countries given in blue have a negative R/P ratio over/during the projection period - figure revised to +1. For the United States, a correction factor was used for the OSRI-PE$_i$ and OSRI-RE$_i$ to account for countries with no share in total world oil trade (sj = 0), and equal risk is assumed in comparison with other supplier countries. For the United States the correction factor was +1.58% - representing total import volume of oil in supplier portfolio left out.*

Appendix 10: Input Data for China for the HHI-Indices in the Uppsala Scenario

China											
Supplier Country	wij^2	$ICRG_j$	CR_j	$w_{ij}^2xCR_j$	s_j	r_j 2012	r_j 2035	PE_j	$1/PE_j$	w_{ij}^2x1/PE_j	$w_{ij}^2xCR_j$ $x1/PE_j$
Saudi Arabia	0,051	66,8	33,2	1,696	0,17	63,0	51,5	8,680	0,115	0,006	0,195
Angola	0,030	59,0	41,0	1,227	0,03	19,0	7,5	0,248	4,038	0,121	4,955
Iran	0,014	52,8	47,2	0,680	0,04	116,9	105,4	3,767	0,265	0,004	0,180
Russia	0,008	61,8	38,2	0,316	0,14	22,4	10,9	1,492	0,670	0,006	0,212
Oman	0,004	70,3	29,7	0,129	0,01	16,3	4,8	0,071	14,067	0,061	1,820
Venezuela	0,004	50,5	49,5	0,178	0,03	299,0	287,5	9,357	0,107	0,000	0,019
Kazakhstan	0,002	59,8	40,2	0,089	0,03	47,4	35,9	0,925	1,081	0,002	0,096
Libya	0,001	60,5	39,5	0,057	0,02	86,9	75,4	1,882	0,531	0,001	0,030
Kuwait	0,001	69,5	30,5	0,019	0,05	88,7	77,2	3,543	0,282	0,000	0,005
UAE	0,001	67,0	33,0	0,019	0,05	79,0	67,5	3,330	0,300	0,000	0,006
Yemen	0,000	48,5	51,5	0,019	0,00	45,4	33,9	0,022	45,636	0,016	0,848
Congo-Brazzaville	0,000	40,0	60,0	0,019	0,01	14,8	3,3	0,018	56,926	0,018	1,107
Australia	0,000	70,8	29,2	0,006	0,00	0,0	0,0	0,000	0,000	0,000	0,000
Iraq	0,000	45,8	54,2	0,009	0,04	131,9	120,4	5,116	0,195	0,000	0,002
Brazil	0,000	63,3	36,7	0,005	0,00	0,0	0,0	0,000	0,000	0,000	0,000
Nigeria	0,000	53,0	47,0	0,007	0,04	42,1	30,6	1,311	0,763	0,000	0,005
Eq. Guinea	0,000	39,9	60,1	0,002	0,01	16,5	5,0	0,029	34,156	0,001	0,074
Congo	0,000	40,0	60,0	0,002	0,01	16,0	4,5	0,024	41,746	0,001	0,063
Cameroon	0,000	52,5	47,5	0,001	0,00	8,0	1,0	0,001	1547,059	0,039	1,837
Colombia	0,000	56,5	43,5	0,001	0,01	6,4	1,0	0,013	77,126	0,002	0,084
Brunei	0,000	75,5	24,5	0,000	0,00	19,0	7,5	0,021	48,704	0,001	0,019
Canada	0,000	75,8	24,2	0,000	0,06	127,4	115,9	6,734	0,149	0,000	0,000
Qatar	0,000	69,3	30,7	0,000	0,04	33,0	21,5	0,753	1,327	0,000	0,000
Thailand	0,000	56,8	43,2	0,000	0,00	0,0	0,0	0,000	0,000	0,000	0,000
Malaysia	0,000	66,0	34,0	0,000	0,00	15,6	4,1	0,004	285,095	0,001	0,039
Mongolia	0,000	60,0	40,0	0,000	0,00	0,0	0,0	0,000	0,000	0,000	0,000

***Note**: Supplier countries given in red are net oil importing nations; countries given in blue have a negative R/P ratio over/during the projection period - figure revised to +1. For China, a correction factor was used for the OSRI-PE_i and OSRI-RE_i to account for countries with no share in total world oil trade (sj = 0), and equal risk is assumed in comparison with other supplier countries. For China, the correction factor was +3% - representing total import volume of oil in supplier portfolio left out.*

Appendix 11: Input Data for Japan for the HHI-Indices in the Uppsala Scenario

Japan											
Supplier Country	wij^2	$ICRG_j$	CR_j	$w_{ij}^2xCR_j$	s_j	r_j 2012	r_j 2035	PE_j	$1/PE_j$	w_{ij}^2x1/PE_j	$w_{ij}^2xCR_j$ $x1/PE_j$
Kazakhstan	0,000	59,8	40,2	0,000	0,03	47,4	35,9	0,92	1,08	0,000	0,000
Vietnam	0,000	56,5	43,5	0,010	0,00	34,5	23,0	0,00	0,00	0,000	0,000
Malaysia	0,000	66,0	34,0	0,001	0,00	15,6	4,1	0,00	285,09	0,007	0,242
Brunei	0,000	75,5	24,5	0,000	0,00	19,0	7,5	0,02	48,70	0,000	0,005
Indonesia	0,001	57,0	43,0	0,044	0,00	11,1	1,0	0,00	0,00	0,000	0,000
Iran	0,002	52,8	47,2	0,076	0,04	116,9	105,4	3,77	0,27	0,000	0,020
Iraq	0,000	45,8	54,2	0,014	0,04	131,9	120,4	5,12	0,20	0,000	0,003
Saudi Arabia	0,094	66,8	33,2	3,129	0,17	63,0	51,5	8,68	0,12	0,011	0,361
Kuwait	0,005	69,5	30,5	0,158	0,05	88,7	77,2	3,54	0,28	0,001	0,045
Qatar	0,021	69,3	30,7	0,654	0,04	33,0	21,5	0,75	1,33	0,028	0,869
UAE	0,052	67,0	33,0	1,700	0,05	79,0	67,5	3,33	0,30	0,015	0,511
Oman	0,000	70,3	29,7	0,013	0,01	16,3	4,8	0,07	14,07	0,006	0,184
Norway	0,000	82,0	18,0	0,000	0,03	10,7	1,0	0,03	31,31	0,000	0,001
Russia	0,005	61,8	38,2	0,198	0,14	22,4	10,9	1,49	0,67	0,003	0,133
Venezuela	0,000	50,5	49,5	0,001	0,03	299,0	287,5	9,36	0,11	0,000	0,000
Ecuador	0,000	53,3	46,7	0,002	0,01	46,6	35,1	0,19	5,13	0,000	0,012
Algeria	0,000	55,5	44,5	0,000	0,03	20,0	8,5	0,25	4,00	0,000	0,000
Libya	0,000	60,5	39,5	0,000	0,02	86,9	75,4	1,88	0,53	0,000	0,000
Sudan	0,000	41,3	58,7	0,000	0,00	42,1	30,6	0,01	85,95	0,000	0,020
Nigeria	0,000	53,0	47,0	0,000	0,04	42,1	30,6	1,31	0,76	0,000	0,000
Chad	0,000	51,0	49,0	0,000	0,00	40,0	28,5	0,06	17,92	0,000	0,004
Gabon	0,000	60,5	39,5	0,006	0,00	22,3	10,8	0,05	21,55	0,003	0,123
Angola	0,000	59,0	41,0	0,000	0,03	19,0	7,5	0,25	4,04	0,000	0,000
Australia	0,000	70,8	29,2	0,001	0,00	23,4	11,9	0,00	0,00	0,000	0,000

***Note**: Supplier countries given in red are net oil importing nations; countries given in blue have a negative R/P ratio over/during the projection period - figure revised to +1. For Japan, a correction factor was used for the OSRI-PE_i and OSRI-RE_i to account for countries with no share in total world oil trade (sj = 0), and equal risk is assumed in comparison with other supplier countries. For Japan the correction factor was +5.3% - representing total import volume of oil in supplier portfolio left out.*

Appendix 12: Input Data for India for the HHI-Indices in the Uppsala Scenario

India

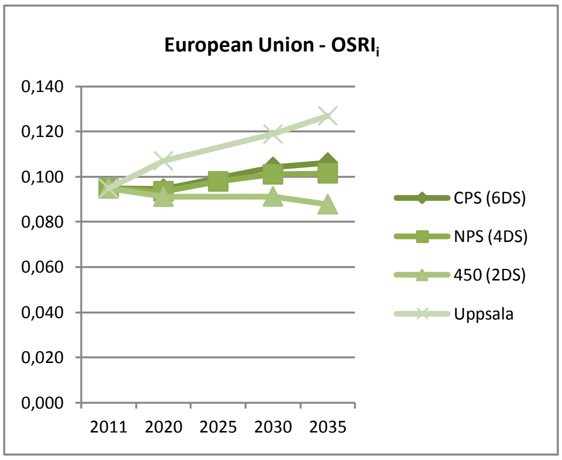
Supplier Country	wij^2	$ICRG_j$	CR_j	$w_{ij}^2xCR_j$	s_j	r_j 2012	r_j 2035	PE_j	$1/PE_j$	w_{ij}^2x1/PE_j	$w_{ij}^2xCR_j$ $x1/PE_j$
Iran	0,011	52,8	47,2	0,526	0,036	116,9	105,4	3,767	0,265	0,003	0,140
Iraq	0,020	45,8	54,2	1,069	0,042	131,9	120,4	5,116	0,195	0,004	0,209
Kuwait	0,011	69,5	30,5	0,325	0,046	88,7	77,2	3,543	0,282	0,003	0,092
Oman	0,000	70,3	29,7	0,007	0,015	16,3	4,8	0,071	14,067	0,003	0,096
Qatar	0,001	69,3	30,7	0,044	0,035	33,0	21,5	0,753	1,327	0,002	0,058
Saudi Arabia	0,036	66,8	33,2	1,190	0,169	63,0	51,5	8,680	0,115	0,004	0,137
UAE	0,008	67,0	33,0	0,279	0,049	79,0	67,5	3,330	0,300	0,003	0,084
Yemen	0,000	48,5	51,5	0,003	0,001	45,4	33,9	0,022	45,636	0,003	0,134
Brazil	0,000	63,3	36,7	0,018	0,000	0,0	0,0	0,000	0,000	0,000	0,000
Colombia	0,000	56,5	43,5	0,001	0,013	6,4	1,0	0,013	77,126	0,002	0,092
Equador	0,000	53,3	46,7	0,000	0,006	44,6	33,1	0,184	5,442	0,000	0,001
Mexico	0,000	62,0	38,0	0,007	0,026	10,7	1,0	0,026	38,507	0,007	0,262
Venezuela	0,003	50,5	49,5	0,153	0,033	299,0	287,5	9,357	0,107	0,000	0,016
Australia	0,000	70,8	29,2	0,000	0,000	0,0	0,0	0,000	0,000	0,000	0,000
Brunei	0,000	75,5	24,5	0,001	0,003	19,0	7,5	0,021	48,704	0,002	0,049
Malaysia	0,000	66,0	34,0	0,006	0,001	15,6	4,1	0,004	285,095	0,053	1,811
Algeria	0,000	55,5	44,5	0,007	0,029	20,0	8,5	0,250	4,000	0,001	0,027
Angola	0,003	59,0	41,0	0,114	0,033	19,0	7,5	0,248	4,038	0,011	0,459
Cameroon	0,000	52,5	47,5	0,000	0,001	8,0	1,0	0,001	1547,05	0,013	0,621
Congo	0,000	40,0	60,0	0,001	0,005	14,8	3,3	0,018	56,926	0,001	0,035
Egypt	0,000	53,3	46,7	0,013	0,000	0,0	0,0	0,000	0,000	0,000	0,000
Eq. Guinea	0,000	39,9	60,1	0,002	0,006	16,5	5,0	0,029	34,156	0,001	0,056
Nigeria	0,007	53,0	47,0	0,318	0,043	42,1	30,6	1,311	0,763	0,005	0,243
Sudan	0,000	41,3	58,7	0,001	0,000	50,0	38,5	0,015	65,059	0,001	0,063
Azerbaijan	0,000	57,3	42,7	0,002	0,016	21,9	10,4	0,167	5,971	0,000	0,010
Norway	0,000	82,0	18,0	0,000	0,032	10,7	1,0	0,032	31,310	0,000	0,008

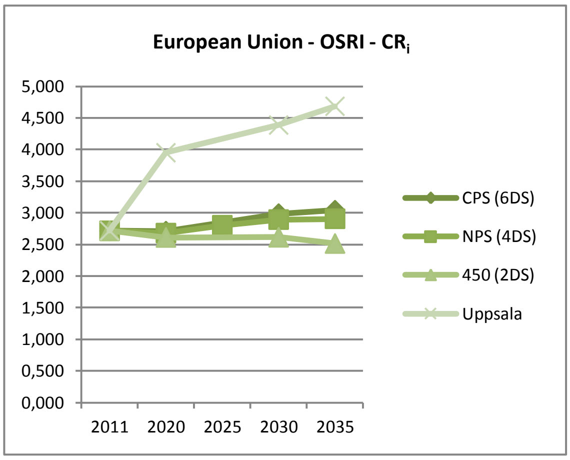
***Note**: Supplier countries given in red are net oil importing nations; countries given in blue have a negative R/P ratio over/during the projection period - figure revised to +1. For India, a correction factor was used for the OSRI-PE_i and OSRI-RE_i to account for countries with no share in total world oil trade (sj = 0), and equal risk is assumed in comparison with other supplier countries. For India, the correction factor was +4.25% - representing total import volume of oil in supplier portfolio left out.*

Appendix 13: HHI Indices and OSRI Indices for the Five Countries/Regions Investigated in the Uppsala Scenario 2011-2035

		HHI Indices				OSRI Indices			
		HHI	$HHI\text{-}CR_i$	$HHI\text{-}PE_i$	$HHI\text{-}RE_i$	OSRI-HHI	$OSRI\text{-}CR_i$	$OSRI\text{-}PE_i$	$OSRI\text{-}RE_i$
European Union	**2011**	0,141	4,028	0,093	2,255				
	2020	0,141	5,204	0,133	4,114	0,107	3,950	0,101	3,123
	2030	0,141	5,204	0,355	9,513	0,119	4,387	0,299	8,019
	2035	0,141	5,204	0,534	13,247	0,127	4,684	0,481	11,922
United States	**2011**	0,171	3,823	0,097	2,806				
	2020	0,171	4,979	0,173	6,834	0,110	3,216	0,112	4,415
	2030	0,171	4,979	0,493	19,545	0,095	2,758	0,273	10,828
	2035	0,171	4,979	0,690	27,038	0,098	2,863	0,397	15,547
China	**2011**	0,118	3,360	0,103	3,238				
	2020	0,118	4,483	0,135	5,559	0,086	3,286	0,099	4,075
	2030	0,118	4,483	0,224	9,344	0,098	3,716	0,186	7,746
	2035	0,118	4,483	0,290	11,944	0,102	3,878	0,251	10,332
Japan	**2011**	0,181	4,339	0,050	1,183				
	2020	0,181	6,008	0,059	1,917	0,174	5,786	0,057	1,846
	2030	0,181	6,008	0,071	2,313	0,174	5,786	0,068	2,227
	2035	0,181	6,008	0,081	2,664	0,175	5,810	0,078	2,576
India	**2011**	0,102	3,084	0,046	1,381				
	2020	0,102	4,085	0,059	2,336	0,092	3,681	0,053	2,105
	2030	0,102	4,085	0,096	3,800	0,097	3,885	0,091	3,614
	2035	0,102	4,085	0,127	4,900	0,099	3,950	0,123	4,738

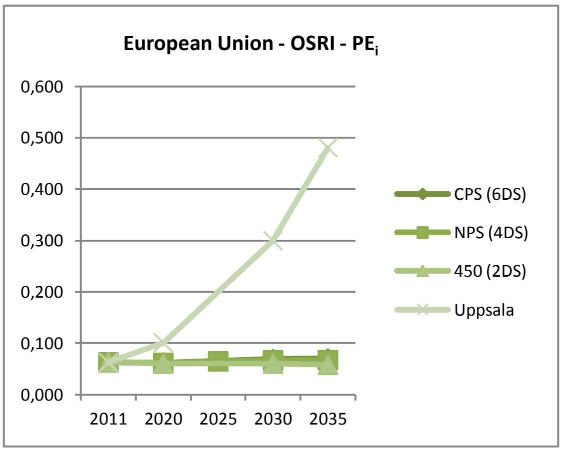
Appendix 14: OSRI Indices for the European Union in the Four Scenarios 2011-2035

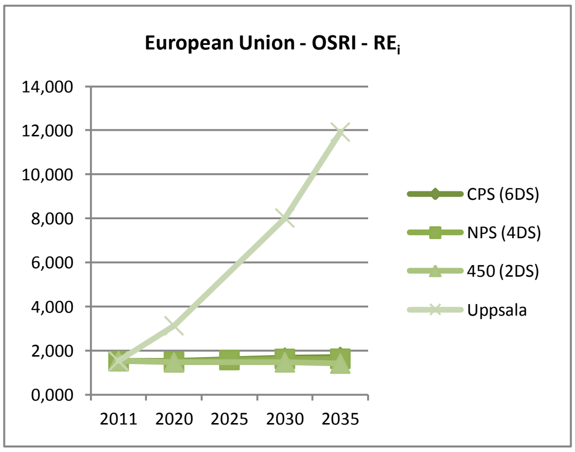




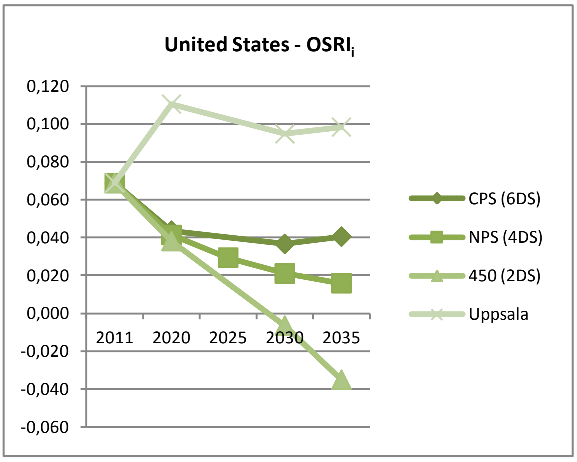
OSRI-Indices for the European Union in the Three Climate Scenarios 2011-2035

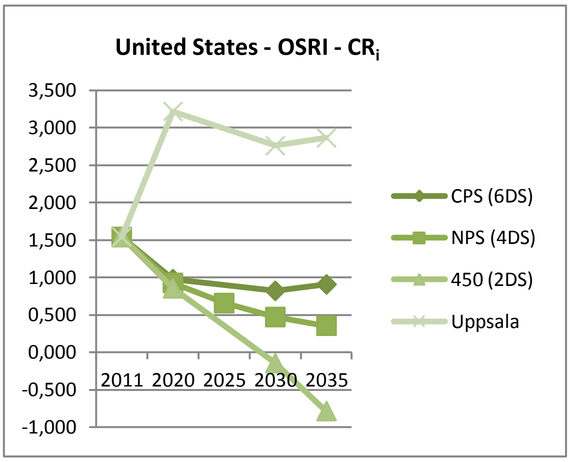
European Union												
	NPS				CPS				450			
	OSRI-HHI	OSRI-CR$_i$	OSRI-PE$_i$	OSRI-RE$_i$	OSRI-HHI	OSRI-CR$_i$	OSRI-PE$_i$	OSRI-RE$_i$	OSRI-HHI	OSRI-CR$_i$	OSRI-PE$_i$	OSRI-RE$_i$
2011	0.095	2.715	0.063	1.520								
2020	0.094	2.679	0.062	1.500	0.095	2.709	0.062	1.517	0.091	2.610	0.060	1.461
2025	0.098	2.803	0.065	1.569								
2030	0.101	2.893	0.067	1.619	0.104	2.987	0.069	1.672	0.091	2.613	0.060	1.463
2035	0.101	2.906	0.067	1.627	0.106	3.041	0.070	1.702	0.088	2.514	0.058	1.408





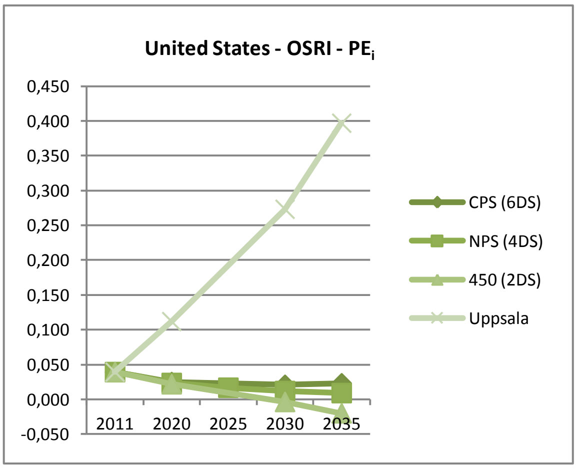
Appendix 15: OSRI Indices for the United States in the Four Scenarios 2011-2035

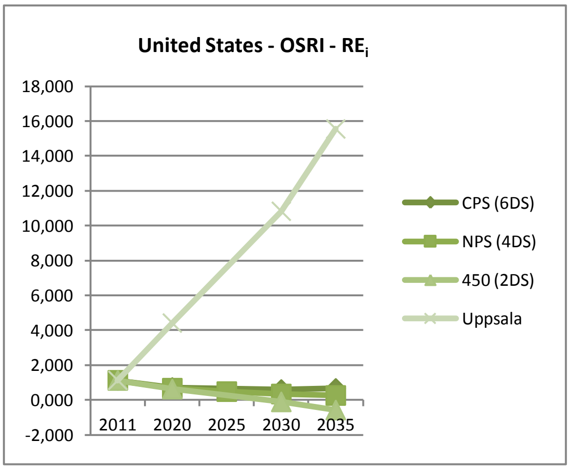




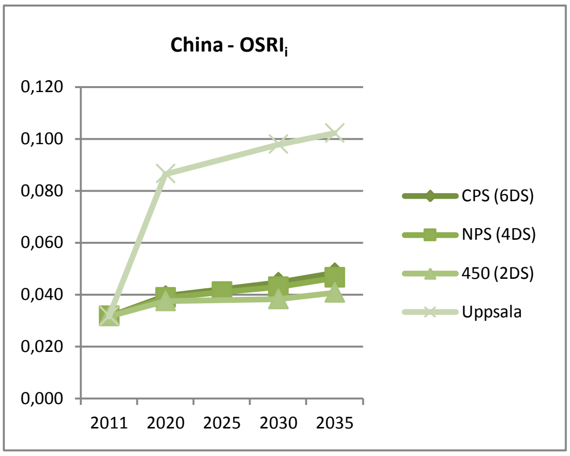
OSRI-Indices for the United States in the Three Climate Scenarios 2011-2035

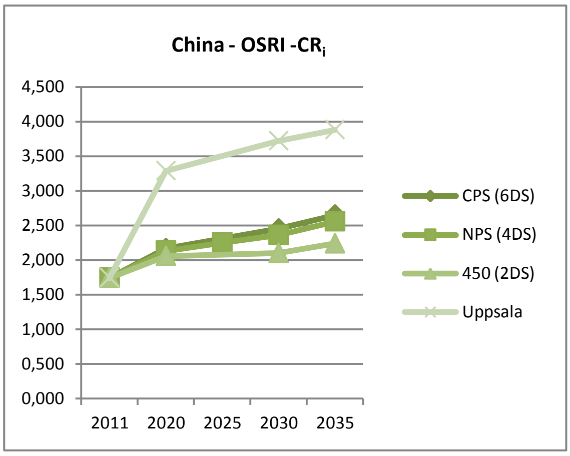
United States												
	NPS				CPS				450			
	OSRI-HHI	OSRI-CR$_i$	OSRI-PE$_i$	OSRI-RE$_i$	OSRI-HHI	OSRI-CR$_i$	OSRI-PE$_i$	OSRI-RE$_i$	OSRI-HHI	OSRI-CR$_i$	OSRI-PE$_i$	OSRI-RE$_i$
2011	0.069	1.539	0.039	1.129								
2020	0.041	0.925	0.024	0.679	0.044	0.976	0.025	0.716	0.038	0.853	0.022	0.626
2025	0.029	0.657	0.017	0.482								
2030	0.021	0.470	0.012	0.345	0.037	0.820	0.021	0.601	-0.007	-0.146	-0.004	-0.107
2035	0.016	0.355	0.009	0.261	0.040	0.906	0.023	0.665	-0.035	-0.786	-0.020	-0.577





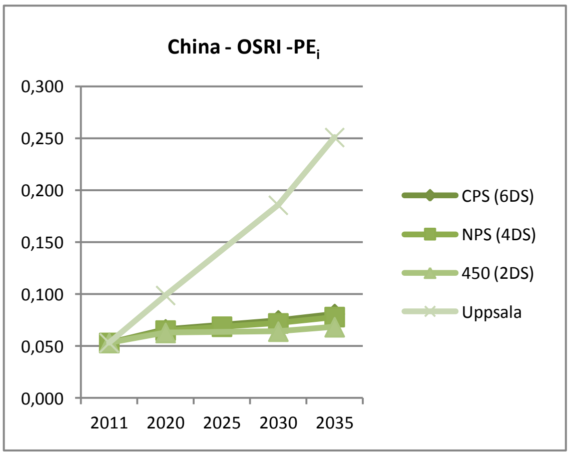
Appendix 16: OSRI Indices for China in the Four Scenarios 2011-2035

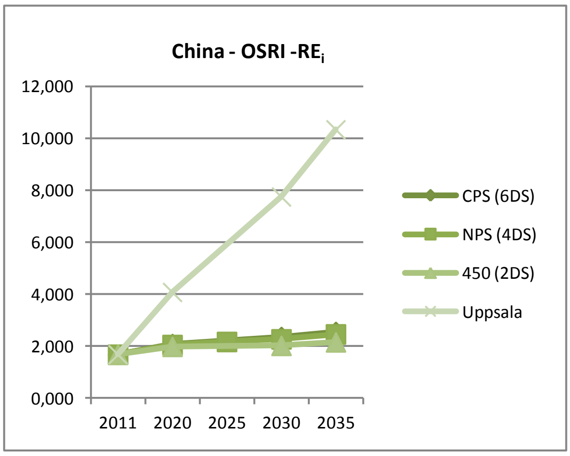




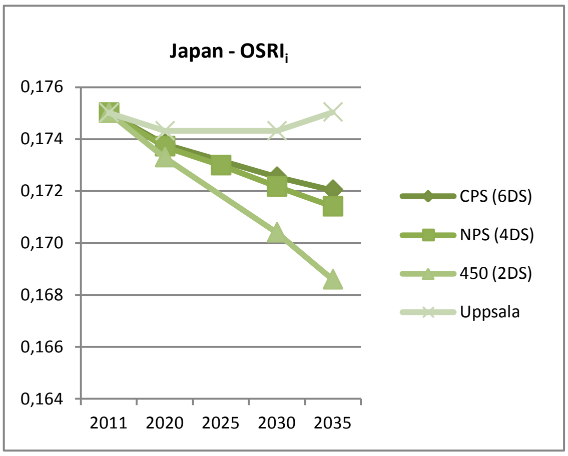
OSRI-Indices for China in the Three Climate Scenarios 2011-2035

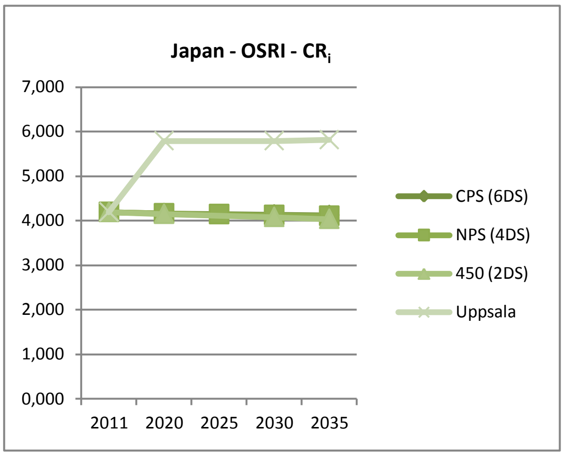
China												
	NPS				CPS				450			
	OSRI-HHI	OSRI-CR$_i$	OSRI-PE$_i$	OSRI-RE$_i$	OSRI-HHI	OSRI-CR$_i$	OSRI-PE$_i$	OSRI-RE$_i$	OSRI-HHI	OSRI-CR$_i$	OSRI-PE$_i$	OSRI-RE$_i$
2011	0.032	1.743	0.053	1.680								
2020	0.039	2.132	0.065	2.054	0.040	2.168	0.066	2.090	0.037	2.057	0.063	1.983
2025	0.041	2.253	0.069	2.171								
2030	0.043	2.357	0.072	2.271	0.045	2.452	0.075	2.363	0.038	2.098	0.064	2.022
2035	0.047	2.556	0.078	2.463	0.048	2.651	0.081	2.555	0.041	2.237	0.068	2.156





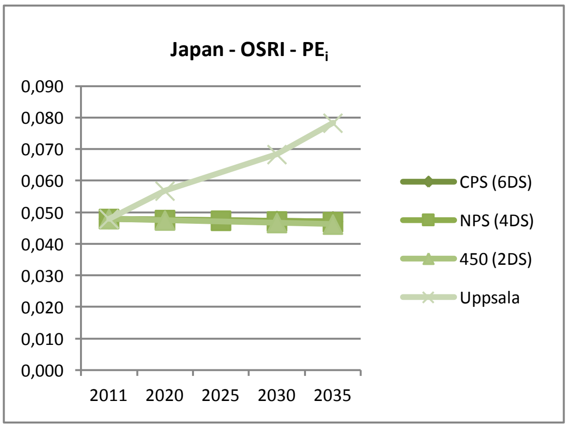
Appendix 17: OSRI Indices for Japan in the Four Scenarios 2011-2035

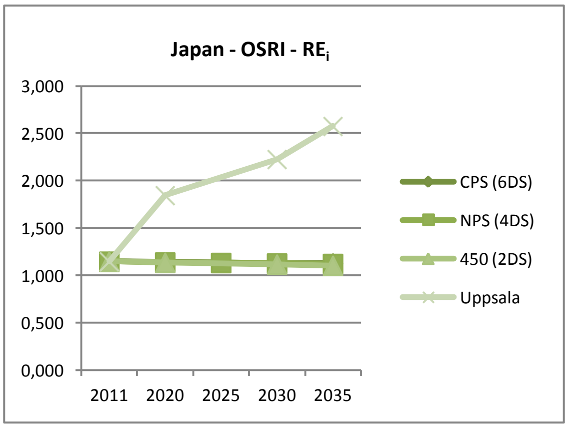




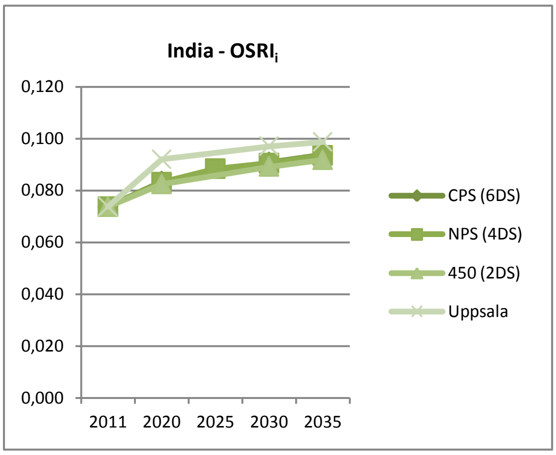
OSRI-Indices for Japan in the Three Climate Scenarios 2011-2035

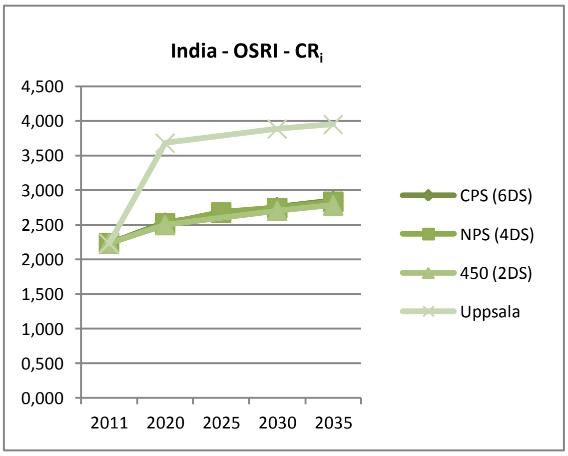
Japan												
	NPS				**CPS**				**450**			
	OSRI-HHI	**OSRI-CR_i**	**OSRI-PE_i**	**OSRI-RE_i**	**OSRI-HHI**	**OSRI-CR_i**	**OSRI-PE_i**	**OSRI-RE_i**	**OSRI-HHI**	**OSRI-CR_i**	**OSRI-PE_i**	**OSRI-RE_i**
2011	0.175	4.188	0.048	1.142								
2020	0.174	4.157	0.047	1.133	0.174	4.160	0.047	1.134	0.173	4.147	0.047	1.130
2025	0.173	4.140	0.047	1.128								
2030	0.172	4.120	0.047	1.123	0.173	4.129	0.047	1.126	0.170	4.078	0.047	1.112
2035	0.171	4.102	0.047	1.118	0.172	4.117	0.047	1.122	0.169	4.035	0.046	1.100





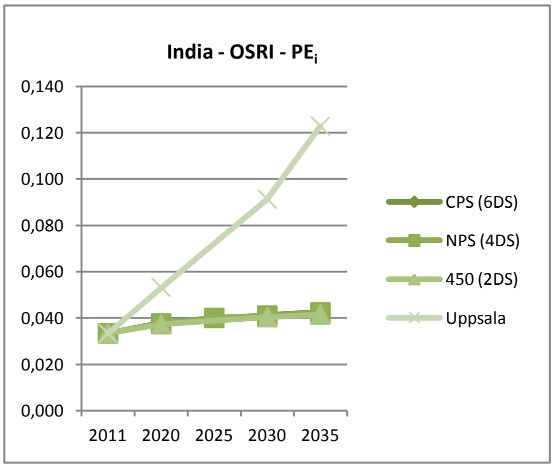
Appendix 18: OSRI Indices for India in the Four Scenarios 2011-2035

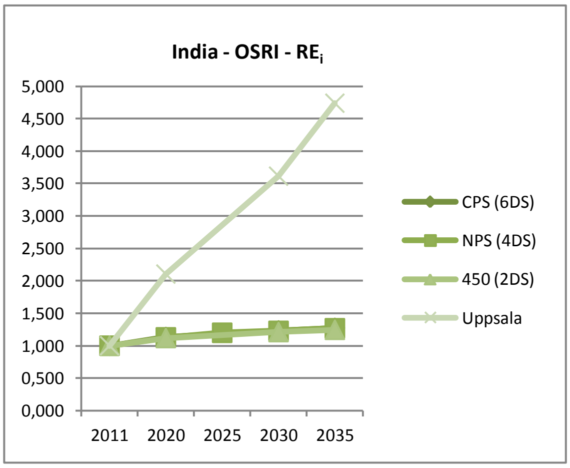




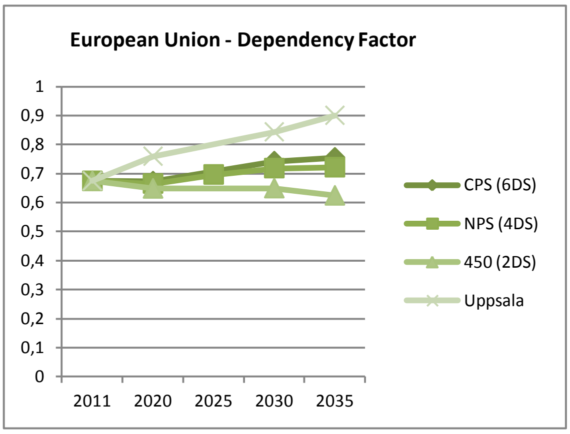
OSRI-Indices for India in the Three Climate Scenarios 2011-2035

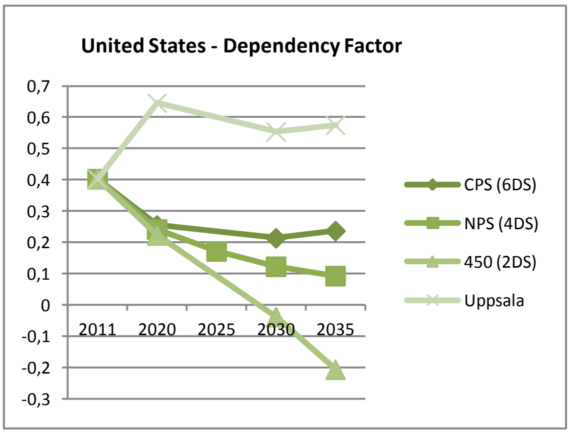
India												
	NPS				CPS				450			
	OSRI-HHI	OSRI-CR$_i$	OSRI-PE$_i$	OSRI-RE$_i$	OSRI-HHI	OSRI-CR$_i$	OSRI-PE$_i$	OSRI-RE$_i$	OSRI-HHI	OSRI-CR$_i$	OSRI-PE$_i$	OSRI-RE$_i$
2011	0.074	2.235	0.033	1.000								
2020	0.083	2.521	0.038	1.129	0.083	2.534	0.038	1.134	0.082	2.500	0.037	1.119
2025	0.088	2.680	0.040	1.200								
2030	0.090	2.744	0.041	1.229	0.091	2.758	0.041	1.234	0.089	2.705	0.040	1.211
2035	0.093	2.835	0.042	1.269	0.094	2.848	0.042	1.275	0.092	2.784	0.042	1.246

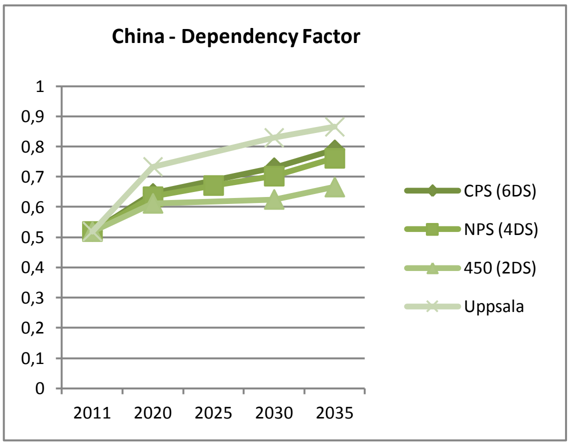


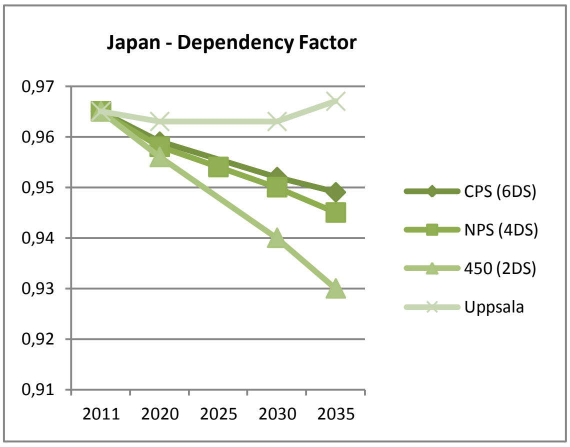


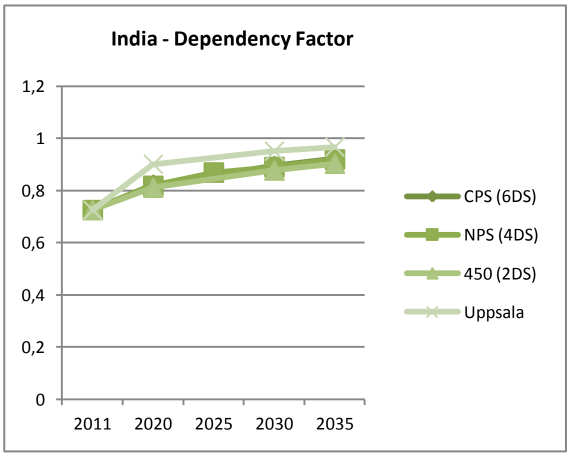
Appendix 19: Dependency Factors for the Five Countries Investigated in the Four Scenarios











Appendix 20: Classification of All Liquid Fuels (*Source: IEA. 2013b*)