Modelling the Effects of Greening of Society due to Climate Change: Fossil Fuel Pricing in the Kingdom of Saudi Arabia and Petroleum Industry

By

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Abstract

Climate change (CC) was first declared a pressing global issue in 1992 and is currently associated with impacting on fossil fuel (FF) prices. In many ways, the dynamics of CC and international political responses thereof, appear to have affected significantly the supply and demand chains of FF companies. In 1997, the Kyoto Protocol (KP) of the United Nations Framework Convention on Climate Change (UNFCCC) was adopted in an attempt to mitigate global greenhouse gas (GHG) emissions. National and international responses to CC have targeted FF use and as a result have led to reductions in the amount of energy supplied by these sources, in favour of low carbon renewable alternatives such as wind and solar. Concomitantly, this in turn has influenced negatively the revenues of FF-producing countries and in particular, the Kingdom of Saudi Arabia’s (KSA) petroleum sector. In recent times, countries that rely on FF production for economic stability have experienced highs and lows with the pricing of their commodities. Clearly, the changing circumstances of oil rich countries is an important issue for the future development of KSA and as such there is a need for research in this area.

This thesis examines how CC specifically, and ‘greening of the world’ in general, are in fact influencing the production and pricing of FF rich countries. This study aims to derive a better understanding of the relationships between FF prices, environmental policies, and CC which is intimately related to, and caused by, the GHG emissions from the burning of FF around the world. More specifically, this research qualitatively explores the nature of the KSA management and their policies over time given the wider context of CC and its impacts on FF prices. The second part of the research employs a
quantitative approach by investigating the dynamic effects of CC and green energy prices — representing the changing nature of FF uptake around the world in response to environmental policy objectives — on FF pricing. This study identifies the relationship between FF prices and CC through the analysis of secondary data. The variable set FF return includes global and KSA oil prices together with global natural gas (NG) and coal prices; whereas the variable set CC comprises a green energy index, global [carbon dioxide (CO₂), temperature, and precipitation] and KSA [temperature and precipitation]. The sample spans 1 January 1978–30 June 2016 (Period 3) is divided into two sub-periods, as follows: Period 1 (1 January 1978–28 February 1997) and Period 2 (1 March 1997–30 June 2016).

To determine the effect of CC and the impact of greening our society on stock equity returns of the FF industry, advanced time-series conditional variance approaches are used herein. This research analyses dynamic interdependencies allowing for serial autocorrelation in a vector autoregressive framework. To explore and estimate systemic relationships, the impulse response, variance decompositions and Granger causality tests are applied. In addition, to examine the weight and links between CC-related variables and their influence on the pricing of FF, the canonical correlation analysis (CCA) is employed.

The results suggest that CC is value relevant for FF stock and that stockholders incorporate this information in their index valuation processes. Further, the results indicate similarly that the FF industry is value relevant for the green energy index and could affect the demand for renewable energy. A highly significant relationship is found
both between global CO\textsubscript{2} emissions and FF returns (Period 2) and between the oil market and global NG (Period 2 and 3). A moderate to low significant relationship between the green energy index and global variables is revealed (CO\textsubscript{2} and temperature). Significant canonical correlations were established between FF and CC variable sets and one set of canonical variates. FF returns contributed most heavily to the relationship, whereas the CC variables played a lesser role.

This research suggests that FF investors have become concerned recently about the influences of GHG emissions on CC, perhaps viewing a clean energy future as desirable. The study contributes to the emerging field of environmental finance by providing further insights into the role of environmental information in finance models. In academic and practical terms, the analysis advances the understandings of how financial markets could be prompted to channel more resources towards environmental concerns.
**Statement of originality**

This work has not previously been submitted for a degree or diploma in any university. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the thesis itself.

Tareq Saeed
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<tr>
<td>ADF</td>
<td>Augmented Dickey-Fuller</td>
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<tr>
<td>AIC</td>
<td>Akaike Information Criteria</td>
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<tr>
<td>Aramco</td>
<td>Arabian American Oil Company</td>
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<tr>
<td>ARCH</td>
<td>Autoregressive Conditional Heteroskedasticity</td>
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<td>ARIMA</td>
<td>Autoregressive Integrated Moving Average</td>
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<tr>
<td>BP</td>
<td>British Petroleum</td>
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<td>CASOC</td>
<td>California Arabian Standard Oil Company</td>
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<td>CC</td>
<td>Climate Change</td>
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<td>CCA</td>
<td>Canonical Correlation Analysis</td>
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<td>CCS</td>
<td>Carbon Capture and Storage</td>
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<td>CMP</td>
<td>Carbon-Mitigation Policies</td>
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<tr>
<td>CO₂</td>
<td>Carbon Dioxide</td>
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<tr>
<td>COP</td>
<td>Conference of the Parties</td>
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<tr>
<td>CPS</td>
<td>Current Policies Scenario</td>
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<tr>
<td>CT</td>
<td>Carbon Tax</td>
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<tr>
<td>EGARCH</td>
<td>Exponential GARCH</td>
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<tr>
<td>EIA</td>
<td>Energy Information Administration</td>
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<tr>
<td>ETS</td>
<td>Emission Trading Scheme</td>
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<tr>
<td>EU</td>
<td>European Union</td>
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<tr>
<td>FF</td>
<td>Fossil Fuel</td>
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<tr>
<td>FPE</td>
<td>Final Prediction Error</td>
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<tr>
<td>GARCH</td>
<td>Generalised Autoregressive Conditional Heteroskedasticity</td>
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<td>GCA</td>
<td>Granger Causality Analyses</td>
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<td>GCC</td>
<td>Gulf Corporation Council</td>
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<td>GDP</td>
<td>Gross Domestic Product</td>
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<td>GHG</td>
<td>Greenhouse Gas</td>
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<td>Abbreviation</td>
<td>Full Form</td>
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<tr>
<td>HFC</td>
<td>Hydrofluorocarbons</td>
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<td>HQ</td>
<td>Hannan-Quinn</td>
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<td>IEA</td>
<td>International Energy Agency</td>
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<td>Intergovernmental Panel on Climate Change</td>
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<td>IRA</td>
<td>Impulse Response Analyses</td>
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<td>KP</td>
<td>Kyoto Protocol</td>
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<td>KSA</td>
<td>Kingdom of Saudi Arabia</td>
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<tr>
<td>LGN</td>
<td>Liquefied Natural Gas</td>
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<tr>
<td>LM</td>
<td>Lagrange Multiplier</td>
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<tr>
<td>LR</td>
<td>Likelihood Ratio</td>
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<tr>
<td>MAE</td>
<td>Mean Absolute Error</td>
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<td>Mean Squared Error</td>
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<td>NP</td>
<td>Ng and Perron</td>
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<tr>
<td>OECD</td>
<td>Organisation for Economic Co-operation and Development</td>
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<td>OPEC</td>
<td>Organisation of Petroleum Exporting Countries</td>
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<td>PARCH</td>
<td>Power ARCH</td>
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<tr>
<td>PP</td>
<td>Philips-Perron</td>
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<tr>
<td>REP</td>
<td>Renewable Energy Programme ( )</td>
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<td>RMSE</td>
<td>Root-Mean-Square Error</td>
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<td>RQ</td>
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<td>SD</td>
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<td>SIC</td>
<td>Schwarz Information Criteria</td>
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<td>Standard Oil Company of California</td>
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<td>Threshold GARCH</td>
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<td>UK</td>
<td>United Kingdom</td>
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<td>Acronym</td>
<td>Full Form</td>
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<tr>
<td>UN</td>
<td>United Nations</td>
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<td>UNFCCC</td>
<td>United Nations Framework Convention on Climate Change</td>
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<td>US</td>
<td>United States</td>
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<td>VAR</td>
<td>Vector Autoregressive</td>
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<td>VDA</td>
<td>Variance Decomposition Analyses</td>
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<td>Variance Inflation Factor</td>
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<td>WB</td>
<td>World Bank</td>
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<td>WG</td>
<td>Working Groups</td>
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<td>WTO</td>
<td>World Trade Organization</td>
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Publications during candidature


Keywords

Fossil fuel, climate change; qualitative and quantitative analyses; stationarity; stochastic volatility models; vector autoregressive; impulse response; variance decomposition analysis; Granger causality test; canonical correlation; loading; redundancy.
Chapter 1

Introduction
1.1 Statement of the problem

It is expected that the ‘Fossil Fuel Age’ will come to an end sooner rather than later and thus influencing the production and pricing of oil, natural gas (NG) and coal. The changing climatic conditions that have been recorded are likely to create further concern towards fossil fuels (FF) commodities. Increased global awareness related to conserving energy around the world is also likely to help lower future demand for FF in favour of alternative-energy sources. However, the above actions seem to display some inconsistencies and are a direct reflection of the climate change (CC) policies being implemented in countries worldwide. Countries that seem to have a poor uptake of energy efficiency measures often seem to contribute greatly towards the deteriorating global climate via increased greenhouse gas (GHG) contributions. The major source of emissions are, in general, a result of burning FF, the main product of the oil, NG and coal industries and this is a significant contributor to CC (Anderson., 2007). Since the price for FF are generally dictated by demand, some important market factors that influence the consumption rate are supply and demand activities (because alternatives to the commodities are limited presently, but future changes in supply or demand chains may result in large price changes) (Halsnæs, 1996).

For more than 150 years, the scientific community has recognised the environmental threat posed by GHG emissions. However, the threat perception has risen following public attention, along with the global business community and world governments following the United Nations Framework Convention on CC (UNFCCC) held in Rio de Janeiro (1992). Subsequently, the 1997 Kyoto Protocol (KP), former United States (US) Vice President Al Gore’s book An Inconvenient Truth: The Crisis of Global Warming
(2007) and the recent UNFCCC (2009), known as the Copenhagen global climate summit (Tokar and Dietz, 2013), have all underscored the need for political and economic leaders to take immediate action to reduce GHG emissions. While scientists remain uncertain about how CC will play out, there is little doubt that it will impose significant economic costs (Heal and Millner, 2014).

The assessment emphasis is being placed on the carbon content of fuel since the carbon content is directly linked to the quantity of carbon dioxide (CO$_2$) emissions and policies are aimed at reducing such emissions based on agreements made in the KP (18% below 1990 levels in the period from 2013 to 2020). Emissions will potentially affect the growth and development of economies that are heavily reliant on FF (Ghanem et al., 1999). The biggest challenge for FF-producing countries is the constant threat they face in terms of the reduced demand for their export commodities as a direct result of implementation of such global policies.

The International Energy Agency (IEA) and most scientists believe that the world needs to make an immediate and revolutionary change in energy sources to limit GHG emissions to a level that will avert catastrophic global warming. Some scientists believe that the word is nearing a point of no return if GHG emissions are not reduced considerably in the next 30 years (Maslin, 2014). Additionally, worldwide public protests have raised awareness on CC and dependence on FF’s and thus requires the global business and economic community to formulate solutions. As a response, emission trading programs and carbon-mitigation policies, such as the European Union (EU) Emission Trading Scheme (ETS) in 2005, New Zealand ETS and others have been developed at global, national and local levels to encourage reductions in global GHG emissions.
emissions. Nevertheless, efforts to reduce the global reliance on carbon-polluting activities may well be the biggest single challenge and opportunity for business and/or governments since the industrial revolution.

Carbon reduction involves a massive investment in a new energy infrastructure and essential changes in the global economy as nations switch from high- to low-carbon sources of energy or renewable energy. Rifkin (2016) has asserted that the third industrial revolution will promote a green economy. These revolutionary changes mean that every economy, country and nearly every sector of the economy will be influenced by CC and carbon risks (Paul, 2007). Since the industrial revolution, which began in Great Britain in the late 1700s, the level of GHG emissions has risen by 30%. Most of these GHG emissions are CO$_2$ emissions from carbon dioxide-emitting industrial processes (Garnaut, 2008). The main source of global CO$_2$ is the burning of FF, making it a significant contributor to CC.

Besides supply and demand, factors such as taxes, events such as a war and policies that govern the development of clean and green energy amongst others all appear to influence the levels of FF production and pricing. It can be expected that a drop in the consumption rate of FF may have a negative influence on FF prices. As a result, the producing countries such as the Kingdom of Saudi Arabia (KAS) stand to face sharp revenue drops since their economies are largely dependent on ‘petro’ dollars; reduced use of FF is essentially a direct threat to their existence. The key for KSA’s survival seems to be the knowledge it can gain regarding the nature of the relationships between CC and the FF prices well in advance of the changes that may be forthcoming. Such an
understanding will allow sufficient time for the KSA to prepare and respond to sharply changing events that may otherwise come as a surprise.

Carbon-mitigation policies (CMP) and global public processes could alter the economies of entire industries and could significantly affect the survivability and profitability of the FF sector. In extreme cases, the continued existence of numerous FF-producing countries are at stake (Wellington and Sauer, 2005). Addressing the risks from CC poses profound opportunities and challenges for the FF industry. Moreover, how these challenges are addressed will influence FF-exporting nations ability to maintain and create shareholder wealth and their own market values (Pinkse, 2006).

This study analyses and examines the effects of global CC and greener energy use on the market value of producing countries’ FF industries arising from an interdependent relationship among CC, polluting oil, NG and the coal industry. This research empirically explores the value relevance of green energy and GHG emissions in the context of the FF industry.

1.2 Research aims, objectives and questions

The FF industry is subject to a greater degree of climate risks and potentially significant variance in profits and hence, market value (Wellington and Sauer, 2005). Climatic conditions are critical to FF markets; for instance, an unusually hot summer or extremely cold winter can significantly impact demand (for heating and cooling), production, prices and securities values (Knight and Pretty, 1996). On the other hand, the FF industry produces dangerous hydrocarbons and contributes greatly to
atmospheric pollution associated with a substantial proportion of environmental degradation and CC (McGeachie et al., 2005).

In addition, this sector is also a source of risks from leaks, spills and explosions. Recently, a California gas leak became the worst environmental disaster (23 October 2015) since the British Petroleum (BP) oil spill. The leak released almost 97 metric tonne (mt) of heat-trapping methane over 112 days, equal to the yearly GHG emissions of over half a million cars, according to a scientific paper published in Science (Conley et al., 2016). Moreover, on 21 April 2010, a BP oil rig off the coast of Louisiana exploded, killing 11 and injured 17 workers and causing an enormous oil leak that threatened the ecosystem and marine life of the Gulf Coast. BP estimated the Gulf of Mexico oil spill to be at almost 5 thousand barrels per day (Mbbl/d) of oil. New official estimates place that number at around 53–62 Mbbl/d, officially making it the worst oil spill in history (Roach et al., 2010). Toxic fly ash is a by-product of the burning of coal for generating electricity; thus the Kingston fossil plant coal fly ash slurry spill (on 22 December 2008) heavily polluted the Emory river and surrounding area in Tennessee, causing considerable damage to the fishery in the downstream lake (Burch, 2015).

Since FF companies are affected by CC and responsible for the GHG emissions, the capital market’s perception of and behaviour towards the industry could have an enormous impact on the market value of the FF sector based on their role in CC. Environmental and CC information may lead capital markets to revise their expectations regarding the performance of polluting FF companies. The FF industry has always been an important segment of investors’ portfolios, but the issue of CC, now at centre stage
globally, raises the question: How, and to what extent, does market value respond to this vital issue? How investors respond can greatly impact the sector.

A significant amount of academic study on how market values of FF respond to environmental catastrophes and CC has focused on meteorological and financial issues. Considerable scientific attention has been paid to the relationship between financial performance and the environment – e.g. Filbeck and Gorman (2004), Pintea et al. (2014) and Nor et al. (2016). Some studies have looked at the potential impact of CC, risks and opportunities for businesses – e.g. Ihlen (2009) and Lash and Wellington (2007). Other empirical studies investigated the relationship between shareholder value and catastrophic events – e.g. Knight and Pretty (1996) and CERES (2002).

Climate is often expressed as the synthesis of weather reports covering a long span of time. It is defined regarding long-term averages and other statistics of climate conditions, including frequencies of extreme events. Climate is popularly thought of as comprising temperature, precipitation and other meteorological phenomena. As distinguished from climate, severe and extreme weather is the most accepted measure of CC. Severe weather refers to any meteorological phenomena with the potential to cause damage to both communities and individuals and have social, economic and environmental consequences.

A number of the empirical literatures have explored the relationship between CC variables such as temperature and other variables such as electricity demand (Vu et al., 2014), energy and NG consumption (Timmer and Lamb, 2007; Alessandro and Fabio, 2015) and FF production and prices (Covert et al., 2016). Only some qualitative,
forecasting and scenario-building research has focused on the value relevance of the world’s leading FF companies (Wellington and Sauer, 2005). Thus, on a broad scale, existing academic research on the climate and environmental issues has investigated first, the impact of CC variables on returns of FF, and second, the impact of pollution on environment and the consequential impact on market value of the FF companies.

Presently no comprehensive, empirical, multiyear analysis has examined the value relevance of CC in the context of countries’ or governments’ FF industries. Moreover, none have investigated these reinforcing relations in the KSA context. The KSA FF industry is highly critical and relevant to the Saudi economy. Therefore, the present study fills this gap.

The goal of this research is to analyse and examine the effects of global CC and greener energy use on the market value of KSA and other producing countries’ FF industries that arise from an interdependent relationship among CC, polluting oil, NG and the coal industry. In particular, this research empirically explores the value relevance of green energy and GHG emissions in the context of the KSA and non-KSA FF industry (the global FF market). The three specific aims of this study are as follows:

1. Investigate KSA’s management structure in the petroleum industry and its influence on the global market of FF and CC;

2. Investigate the behaviour of each time series of the FF variable set [oil (global and KSA), NG and coal prices] and the CC variable set [global variables (green energy index, CO₂ emissions, temperature and precipitation) and KSA variables (temperature and precipitation)]; and
3. Investigate the overall dynamic relationships among FF, CC and the combined set variables.

To achieve these aims, this study determines the value market reaction. Accordingly, this research explores the effects of CC and GHG emissions before and after a CMP (KP) was introduced by the UN. For more informative results, the present research compares the KSA FF sector, which operates globally and is affected by different climate policies, and the increase in renewable energy. The objectives of this research are as follows:

1. Examine the historical significance of KSA’s structure and management in relation to the FF industry;
2. Examine the impacts of CC policies and shifts to a greener future through the management structure of KSA and other producing countries’ FF prices;
3. Examine the impact of CC on the FF industry and its consequent influence on the market value of the FF industry;
4. Examine the inter-relationships between KSA’s FF production and pricing and those of other producer countries;
5. Examine the relationships among KSA’s climate variables and those among global climate variables; and
6. Examine the influence of CC variables on FF variables following the introduction of the UNFCCC for KP GHG mitigation policies.

To achieve the objectives, the following questions are considered and answered using qualitative and quantitative methods in a univariate and multivariate manner:

1. What is the KSA policies’ response for FF energy crises and CC?
2. What are the influences of global CC policies on the FF pricing mechanism?

3. How did FF investors consider CO₂ emissions and green energy information following the UNFCCC and KP?

4. What are the effects of the CC variables on the market value of the FF industry?

5. Is the financial market concerned with the environmental aspects of investments?

6. What are the linear combinations of the FF and CC variables that maximise the correlation coefficients between them?

1.3 Significance and contribution of the research

The findings of this study will help to provide a deeper understanding of KSA’s highly adaptable management structure that has proven in the past to have quick response times. The results of the present study also allow other organisations and countries to more clearly understand the dilemma and position of KSA in relation to developments on one hand and negative effects of CC variables on the other. Furthermore, models may help to explain how KSA may quickly respond and return the world FF back to normal economic conditions, when KSA could possibly experience extreme financial events such as a global financial crisis or the harsh reality of conflicts and wars.

This study is also significant because of the importance of FF production in the growth patterns of most countries. This is one of the first studies of this type to examine links between the effects of CC caused by continuous activities related to the use of FF consumption (causing GHG emissions) as well as production and pricing of KSA’s and other producing countries’ FF levels. This study will attempt to establish the effects of CC policies on the production and pricing of KSA and other FF-producing countries.
A significant contribution of this study is the establishment of relationships between green index, CO₂ emissions, temperature change and production and pricing levels of FF, including their economic impact on KSA. Additionally, the study will develop mathematical models that allow a deeper understanding of the association between KSA and other countries in relation to the above variables.

The findings of this study may furnish the global business community with broader information about the influence of CC on energy prices. This will help KSA and other FF-producing countries to understand the implications of CC variables in relation to global oil, NG and coal prices and, as a consequence, will lead to more critical longer-term planning and scenario analyses by the economies that rely on FF revenue.

In addition, the mathematical models developed in this thesis will benefit FF companies and governments by enabling them to understand the nature of relationships amongst the variables and how they correlate with the environmental policies that will in turn become major business risks over time. As a result, the companies and governments will possess the required knowledge and tools to respond to the policies (aimed at curbing CC) that are likely to impact the oil, NG and coal industry. Ultimately, the findings will allow the financial community (when dealing with FF-producing nations) to build more accurate investment plans that includes the risk of CC and its impact on oil, NG, coal production and prices.

Therefore, this study contributes to academic research by

1. Confirming the direct effect of KSA management structure on FF production and prices globally;
2. Determining the impact of CC policies on the FF industry’s market value;
3. Determining the influence of increasing green/renewable energy on FF returns;
4. Determining the value relevance of CC variables in the context of the FF market by applying a combination of econometric models and approaches;
5. Determining the relation of FF return and CC variables globally and in the KSA;
6. Determining and comparing the impact of CC variables on prices returns of FF sectors as well as the entire FF market before and after implementation of the 1997 KP policies; and
7. Determining the value relevance of CC variables as environmental variables in financial models.

1.4 Research motivation

The motivation behind this research topic lies the inadequate information regarding the effects of CC variables on KSA’s economy. There have been unresolved issues in international effort to achieve a sustainable climate regime by determining the extent to which developed nations’ emissions reduction will impact FF prices and how these influences can be minimised. Increasing concerns about climate mitigation policies that significantly affect FF markets, especially KSA’s, as well as determine people’s behaviour in using these products and emitting GHG, makes it necessary for this matter to be looked into keenly by the KSA and other affected countries. For instance, the response of the UNFCCC regarding KSA is expected to affect the implementation of existing and new CC mitigation policies, either in a positive or negative manner.

According to the findings of some previous researches, policies that advocate for the KP and other CC policies on ways to mitigate emissions will reduce the demand for fossil-
based fuels like oil and significantly affect the cost of FF from KSA. It is stipulated that the required reduction in FF, in an attempt to adhere to emissions curbs, would affect KSA and other FF-producing countries’ economies by reducing the revenue received by these nations. For instance, the FF sector provides almost all of the Saudi government’s revenues.

1.5 Ethical considerations

Ethical considerations are normally involved to ascertain the originality and credibility of the research. If the ethical issues will not be effectively considered, this could affect the study by reducing the accuracy of the information to be presented. This study considers originality as an important element of ethical concerns. The appropriate ethical issues will be strongly considered by the researcher when conducting this study. By appropriately considering all ethical issues, the study will easily demonstrate the dependability and trustworthiness of the information presented in this research.

The ethical aspects of the proposed study will be addressed by implementing several measures. One such measure is that the respondents, especially those involved as sources of data, will participate in the survey voluntarily and will have been fully informed about the study objectives and aims. The researcher will ensure that the questionnaires do not contain any discriminating, degrading or unacceptable language that may be offensive to any member of the sampled population. Moreover, the researcher has ensured that the questionnaires are designed to collect information directly related to the research questions; as such, no personal or private questions will be asked from the respondents.
In addition, participants in the research should not be exposed to harm in any manner whatsoever. Researcher should prioritise respect for and self-respect of participants. Full consent should also be obtained from the participants before the study. Moreover, participant confidentiality should be ensured. Satisfactory confidentiality of individuals’ data should be ensured. Also, any dishonesty or overstatement about the study’s objectives and aims should be avoided. Affiliations, sources of funding and any conflicts of interest must be declared. Any communication relative to the study should be carried out with transparency and honesty. Above all, any type of misleading information, particularly in depictions of primary data, is considered bias and must be avoided.

### 1.6 Thesis structure

The thesis is organised into five parts consisting of eight chapters (Figure 1.1). The second and third chapters present an institutional background of the FF industry and CC, respectively. These chapters review both theoretical and empirical literatures and develop new research questions that these findings suggest and similarly recognise gaps and contractions. Moreover, Chapters 2 and 3 examine studies relating to the relevant issues in FF prices, including the relevance of CC policies, green energy and carbon risks.

Chapter 4 presents the methods applied in the empirical analyses. The data are described, together with the statistical techniques and models used to analyse them. Industries and criteria for green energy company selections, as well as sample size, also are presented. Based on the general and specific objectives and the different
methodologies in this thesis, the analyses of empirical results are discussed in four chapters (5, 6, 7 and 8).

The rationale for the design and structure of the thesis is as follows. Figure 1.1 indicates that the thesis is designed such that Chapters 1, 2, 3, 4 and 9 relate to the whole thesis, whereas Chapters 5, 6, 7 and 8 present and discuss the empirical results. Chapters 5, 6, 7 and 8 are structured similarly; each of these self-contained chapters has its own methodology, results and discussion but with same data. This procedure is intentionally done for the purpose of facilitating the publication of these chapters as journal articles. Chapter 9 concludes the thesis by presenting the major findings and provides recommendations for future study.
Figure 1.1: Thesis organisation.
Chapter 2

Fossil Fuel
2.1 Introduction

One popular perception holds that current FF stores of will remain able to supply more than half of the world’s principal energy for years to come (BP, 2016a). Global dominance in the energy industry has long been held by one of the world’s primary natural resources: crude oil. Even with all the many advancements in the energy industry, oil remains the planet’s primary fuel source (IEA, 2015). Given the steady trend in population growth across the globe and the marked increase in motorised transportation and vehicle tenure, experts predict that there will be similar growth in oil prices as well as a sustained market value (Rickwood, 2010). However, since FFs are non-renewable resources and will someday run out, the need for alternative sources increases.

Such alternatives include forms of clean energy, or methods that do not produce harmful by-products and damage the environment by increasing emissions. Clean energy can be produced by hydroelectric plants and renewable sources such as nuclear power plants or other alternative technologies. These non-conventional methods have been gaining popularity and have slowly been overtaking segments of the energy market. In the 35 years between 1973 and 2008, clean energy sources increased their market footprint from 12.4% up to 18.7%. Given the heavy reliance on FF sources, this more than 6% jump is a testament to the efficiency of alternative fuel sources. Furthermore, the majority of that increase is attributable to advances in the hydro and nuclear fields alone (IEA, 2009). These increases identify effective changes in policies across the globe to incorporate clean energy sources (Haug, 2011).
Despite the generally accepted beliefs on current energy development, however, the impact of global CCs poses a starkly different outcome. Efforts around the globe attempted to reduce emissions by lowering pollution in the early twentieth century (Fouquet, 2012). In order for that goal to be reached and steadily maintained, the global consumption of FFs would have to be cut completely in half (Haug, 2011). Such a decrease would impact all energy-related activities around the world, because the global population is highly dependent on this natural resource as its primary energy source. Currently, economic growth has slowed around the world in comparison to previous decades. Nonetheless, global FF emissions have maintained constant growth and have reached alarming heights (Le Quéré et al., 2015). Without changes in global energy and climate policies, this growth is having serious consequences on the environment.

Historically, movements in the global energy industry can be predicted by monitoring trends in FF prices, specifically the oil price. Such changes are visible indicators of changes actively taking place as well as forerunners for upcoming changes in the market. For instance, the global financial crisis hit the economy and drove oil prices back down ($34), and temporary shifted attention to the immediate threat to human welfare and prosperity (Ragheb, 2016). Although the financial market was experiencing severe losses, oil prices crept back up and settled near $100 per barrels (/bbl) by early 2011 until the recent decline in the price below $60/bbl in 2015 (IEA, 2016). Along with the increase/decrease in price, the energy industry began to realise concerns for their future security and possible losses or alternatives. That realisation led to discussions about a breaking point in oil production and sales. Experts then were forced to accept that at some point there will either be no more oil to mine for consumption, or the price will become so high that it will no longer be economic to utilise (Smith, 2009;
Kutasovic, 2012). At that point, research into sustainable and renewable energy was increased.

In this Chapter 2, the researcher will discuss how oil prices and other FF sources may impact the energy industry’s transition into an alternative and sustainable economic system. Since this is an exceptionally wide-ranging and comprehensive issue, discussions will be detailed in order to provide an ample foundation of knowledge on factors that influence market trends in FFs as well as the various processes that can lead to energy transition. More specifically, this chapter will outline a path along which an unparalleled worldwide energy transformation can be choreographed through policies and technologies. Because oil is generally focused on more than other FFs, this chapter will attempt to address the reason for such a focus as well as provide background on its historical trends.

This chapter will continue to focus more on oil and its subsequent price trends in both historical and current markets as well as NG and coal. Supply and demand factors will be incorporated as influences on price fluctuations, and recent movements will be scrutinised more closely. Recessions and macro-economic events most often associated with the upset in oil prices will be reviewed too. Moreover, this chapter will explore the possible future of FFs and associated markets. It also provides relevant background information on the FF industry in KSA. Besides documents, the stylised facts of FF production and prices for KSA will be considered. Chapter 2 illustrates the essential need for, and the importance of, this study for KSA. A summary of the purpose and significance of the research is provided at the end of this chapter.
2.2 Resource price theory and evidence

2.2.1 Resource price theory

It is commonly accepted that the resources found naturally on this Earth are finite. However, when analysed from an economic standpoint, resources may be considered to be unlimited if the amount being extracted is negligible compared to the overall supply. With most economic markets functioning along competitive dynamics, prices will trend towards the lowest average cost in order to remain dominant in demand. If resources are unlimited, then capital and labour can subsequently match demand. Thus, any increase will result in supply adjustments and any variation in price will only be temporary. Furthermore, technological improvements and operational streamlining reduces cycle times and result in an overall downward tendency (Frank, 2009).

Similarly, a competitive economy ensures that resources that are limited but renewable will only be extracted at such a rate as the natural replenishment will restore supply before the demand consumes all stock. Such resources can be forests, livestock farms or fisheries (Erickson, 2009). In economic terms, the replenishment rate must equal its return on investment. With the replenishment rate predetermined, suppliers can support a steady flow of product at a rate that the environment can sustain. Subsequently, if the demand for these resources increases, then without any technological improvements for production or replenishment, the only other factor to rise is the price.

It has been theorised that limited but renewable resources will be the defining factor in the rate of resource production and prices. In theory, over a span of time, these factors influence the competitive market such to maximise economic welfare through a
particular pattern of exploitation (Gaudet, 2007). Producers are incentivised to only produce enough of the limited resource so as to meet the expected return on investment in the future after deducting extraction costs. If the resources are left undisturbed, producers can expect prices to rise in the future when demand increases. The opportunity for profit is compared to the investment of revenues at the current rate of interest. Due to this balance of supply versus demand and the profitability of resource price potential, the market for these products maintains a perfect competition and subsequently allows time for the renewable resources to be replenished. The balance comes from immediate versus future consumption of these materials. Still, in an economy with stagnant growth and no increase in demand, resource prices will gradually increase as the supply subsequently decreases. A growing economy suggests a growing population and thus growing demand and this trend will also increase prices.

A similar trend can be found in other industries such as technology. For example, as new advances are made, industries focus greater attraction on the new possibilities and are motivated to pay higher prices. Interestingly, new resource developments also lead to vastly different price paths while still depleting resources (Livernois, 2009). If technology provides advances in extraction methods of FF’s and thus reduce operating costs, the initial benefit would be a drop-in price extended to the consumer. However, eventually that rate at which the price increases will also rise as time progresses. Conversely, if new sources are discovered or created, the rate at which the price increases will be reduced, as well as its corresponding range. In a perfectly competitive market, price profiles such as these would be highly sought. There are also factors of defective market arrangements that can vary price points and property welfare. Though
in theory, there are innumerable outcomes to the various resource price trajectories in
the economy.

2.2.2 Price path indications

The concern over finite resources being completely consumed have long since plagued
economists around the world to the early 19th century by the British classical
economists, particularly Malthus and Ricardo. They predicted a dismal future where the
world’s non-renewable fuels would be depleted (Ruttan, 2002). Throughout the years,
experts have repeatedly examined price and consumption trends in commodities,
resources and energy to monitor their availability and predict how long they will last.
The first of these studies of long-term market prices trends include those directed by
Kendrick (1961), Potter and Christy (1962) and Barnett and Morse (1963). They studied
real prices for natural and renewable resources in the US for the period 1870–1957.
Their research concluded that prices since the 1870s have either been steadily
maintained or exhibited a declining long-run trend despite quite large short-run
fluctuations (Tilton, 2003).

Many studies were also conducted on non-renewable resources and findings were quite
comparable when analysed over periods more than a century (Smith, 1979; Berck and
Roberts, 1996). Further research conducted later by Pindyck (1999) reviewed the past
price history of FF going back almost 130 years. Pindyck modelled FF price trend and
found that it fit nicely into a U-shape, particularly after the oil crisis in the 1970s. In the
last two decades of 19th century, the price of oil dropped continuously between 1900
and 1970 then rose again in 1970s. Though overall, the price of oil in 2000s has
generally remained lower than the peak in 1920 (Dvir and Rogoff, 2009). Interestingly,
advancements in technology, alternative developments and new source discoveries have been able to provide a constant supply of ‘even’ finite resources (Livernois, 2009). Another misconception about the availability of these exhaustible resources is that their supply is still so great compared to their rates of consumption that they can be perceived as being unlimited (Hamilton, 2012). This is because the quantity is vast enough to push depletion dates far into the future.

In general, studies on resource price trends have been conducted for periods of around 100 years. It is possible that these ranges are not long enough to develop a comprehensive picture of resource scarcity. Procedurally speaking, it is extremely difficult to manipulate information, let alone collect it, for such long-periods. However, it has been reported by Hausman (1995) that both production and sales prices for fuel, between 1450 and 1988, maintained a steady rate over the ‘very’ long-run; and when individual fuel prices have increased, consumers have switched to less expensive fuel. A study by Fouquet and Pearson (2003) validated these findings and reported little variation or substantial rises in the average energy price from 1500 to 2000. On this scale, they found that the 20th century was attributed to drastically different energy structures and a vast transition to alternative fuel sources or higher quality and higher priced sources. Fouquet and Pearson suggested that this transformation was result of rising value associated with developing higher quality energy services.

2.2.2.1 Emphasis on energy service prices

A different perspective to consider in regard to the energy industry is the price of energy services rather than of the fuel sources themselves. Although the sources are undoubtedly a major factor in prices, particularly when supply and demand is
considered, they are also necessary inputs for services and thus introduce a new question of whether or not this relationship drives those services to be more expensive. Energy consumption is completely dependent on the demand for its uses, such as electric power, heating and transportation. Energy resources are mined, refined and combined with various technologies to provide energy services and improve lifestyles (Fouquet, 2014).

The possibility also exists that service prices drop with increased technological efficiencies even if the raw price of the resource remains unchanged. Efficiency improvements make energy services cheaper, which may led to increase demand for those services. However, several researchers have revealed that increased energy efficiency does not necessarily reduce energy consumption, because of the limit role of energy efficiency in determining total FF’s consumption (Schipper and Grubb, 2000; Schettkat, 2011). For example, if a factory uses energy more efficiently, it becomes more profitable, thereby encouraging further investment and greater levels of output. This is termed the direct ‘rebound effect’ (see Schettkat (2011) and Gillingham et al. (2016) for more literature on the rebound effect). Over long-periods of time, price trends between the fuel source and the service may diverge substantially.

While this revelation is certainly not new, there has not been substantial research into price trends of energy services and why those factors diverge from overall energy costs. Nordhaus (1998) reviewed the difference in overall costs versus the singular price for energy service of a period of 200 years. Nordhaus found that the price of the heating service fell far more than the price of the FF in the long-run. The difference showed a stark discrepancy in the perceived benefits that consumers received as a result of
reduced heating costs. In fact, in the examined case, the average energy price actually rose substantially after the introduction of environmental legislation. Thus, the evidence makes a strong case for focusing on environment policies. An addition to this examination by Fouquet (2016) and Muller (2016) includes all major services in the energy industry over periods of up to 700 years. The purpose of their extension to this line of research was to determine if using the overall cost of energy was underestimating the decline in service prices over the years.

When the energy industry determines the set price for services, equipment efficiency is calculated and then incorporated into the service price. For example, if one unit of gas used to light a gas fireplace costs $500 but it only provides 20% of useful heat, then the actual price for a unit of gas in useful heat is translated into $2,500. But if the efficiency of that unit of gas is increased from 20% to 50%, then the energy cost is reduced to $1,000. This formula can be applied to any service and its related energy source and associated technologies. A simulation of growth progression was developed by Fouquet and Pearson (2006) for each major energy technology that included each sector’s share of the energy market based on usage data. By combining the share price of the market with the cost for each technology, a relatively reliable average service price can be estimated and compared across various waves of technological development.

In terms of heating, efficiencies were implemented when the Rumford fireplace was introduced in the 19th century (Fouquet and Pearson, 2005). Furthering those advancements, NG and electricity presented a cleaner and much more efficient method for heating in the 20th century, and this enhanced energy efficiencies even further. When 1956 saw the passage of the Clean Air Act, efforts to eliminate coal became a primary
focus in the energy industry (Thorsheim, 2006). The available substitutes happened to be more expensive, however, and the industry saw a shift in overall service prices in order to maintain environmental standards set by new policies. However, equipment technology also saw great improvements, which allowed energy prices to continue their downward trend. Still, by only focusing on the price instead of the availability and efficiency in the 20th century gives an inaccurate sense of scarcity in the heating industry. Essentially, researchers and economists have been trying to convey the fact that different results are produced when focusing on price trends in energy services rather than the resources used. These approaches were further corroborated by studies conducted by Haas et al. (2008) and Fouquet (2012) in which additional factors such as environmental constraints (policies) came into play.

Returning to the point of energy transition from a global standpoint, it is prudent to understand that narrowing the price focus to either energy sources or services will not fully provide a reliable solution for a low-carbon energy solution. Still, there must be significant emphasis on efficiency in services powered by FFs in order to reduce their usage overall and sufficiently lower prices. Another factor to consider is the rebound effect once energy services are streamlined and stabilised. This effect demonstrates the increase in demand through increased efficiency. A service may be modified to use less of a finite resource and reduce costs. However, the general effect is then that the demand increases as more people switch to the more efficient service. The higher demand counteracts the decrease in energy source consumption, rendering it insignificant. Thus, the problem with non-renewable resources continues, despite the fact that overall service costs for energy has decreased.
2.2.3 Emphasis on oil

Many excellent justifications exist for focusing on energy service prices. However, the majority of attention has specifically been devoted to oil. At the end 2015, the oil provided 32.9% of the world’s energy consumption with a 1.9% growth in demand. Surprisingly, this is the first increase since 1999 mostly on account of rising consumption in China and India and the drop in the oil market. The last 17 years have witnessed a steady decline in oil usage in favour of alternative sources such as NG and coal, which hold 23.8% and 29.2% of the market, respectively. Global NG consumption rose by 1.7%, with a significant growth from the rather weak increase (+0.6%) seen in 2014; coal consumption fell to 29.2%, the lowest share since 2005 (BP, 2016a). Oil provides a significantly higher energy content than NG or coal and is extremely conventional in multiple stages of production.

Due to its numerous benefits in the energy industry, oil remains the most widely traded product in the world. Though NG and coal are also consumed for energy, even at an increasing rate, these commodities are priced based on regional demand, whereas oil is valued from a global perspective (Mohammadi, 2011). Several industries, such as aviation, still rely completely on the refinement of oil for continued operations (Darbouche and Fattouh, 2011).

Countries that produce oil are almost exclusively dependent on the continued production and refinement of this natural resource, as is the case for KSA. As with the fluctuating prices for oil, local economies in these countries are also vulnerable to instability and prolonged periods of stagnant or negative growth in profits. Similarly, energy markets dependent on oil are also typically attendant to great macro-economic
influences on Organisation for Economic Co-operation and Development (OECD) countries as well as the worldwide economy (Berument et al., 2010). Nonetheless, oil maintains an elevated status in the energy industry due to its sheer dominance within transportation. The heating and power sectors have successfully transitioned much of their resources to alternative-energy sources, but the transport industry remains challenged in transitioning to the desired low-carbon economy, and they are expected to remain the primary reason that oil prices will continue to rise.

As previously stated, NG prices will vary from market to market based on the regional demand. This divergence is generally due to variations in pricing mechanisms, limited options for arbitrage, costs for transport (which ironically requires the consumption of oil), and condition of the local NG market (Ritz, 2014). Recently, the US has seen a steady growth in NG production, which has successfully kept energy prices low. It has also stimulated more diversity in the market on a regional level (Bresciani et al., 2014). However, oil and NG prices continue to be associated through competition within industrial and electricity sectors. Even NG service contracts include price clauses dependent on fluctuating oil indicators so as to remain competitive. This has given rise to a close association between oil and NG prices. In recent contracts, NG delivery services include a clause for coal prices so as to maintain competitiveness in the electricity sector. As time progresses, it is likely that this connection will ebb as fewer capabilities will be switched over from one to the other – oil to NG (Hem et al., 2011) or coal to NG (Salovaara, 2011).

As transport through oceanic cargo shipments increase, NG prices are levelling for various reasons by arbitrage. The US has increased production of unconventional gas,
which has significantly decreased the amounts it imports. Prices in the US dipped so low in 2012 [below $2 per million British Thermal unit (mmbtu)] that they accounted for a mere 12% of costs in Europe and around 18% of Asian spot prices (Henderson, 2012). This huge difference reignited discussions that NG prices should not be set based on the oil index and that it is possible for a worldwide convergence to bring about lower oil prices.

Coal consumption, on the other hand, is less common and therefore is traded in relatively small quantities internationally. Often, the difference in market demand across countries impacts the price, but the interesting fact is that coal is becoming more of a competitor against NG in the power segment (Nalbandian and Dong, 2013). Since the oil shock in the 1970s, the price for coal has not followed the same pattern, rather than become volatile and unpredictable, it has remained relatively stable. Oil and NG services can more easily transition to other fuels, unlike those that rely upon coal. This is possibly the reason for coal’s lack of volatility in price trends. It may also be due to the fact that coal is sold in ‘long-lasting’ contracts, often longer than 30 years. Coal production has been increasing with stable demand, which may also account for its lower prices. In addition, coal is a rather unclean resource, which makes it less desirable to transport as opposed to NG (Bakker et al., 2009).

Coal will partner with NG or oil in price trends only to the extent that energy service providers can use one or the other as a substitute in the open market. Oil is leaving the electricity market as alternative sources become integrated, which will impact its pricing. Although no significant upsets have been identified in the current competitiveness between coal and oil, although the transport industry may very well
experience more of a transition to liquid energy sources. Due to the fact that coal reserves remain large, the market likely will not see an increase in prices in the long-run, despite some potential bursts of change with new transport capabilities (Bakker et al., 2009).

### 2.2.4 Oil price historical trends

Oil was originally embraced as a primary source of fuel and energy because at the time of its discovery, its price was rather modest. It also contains numerous physical characteristics that make it ideal for use. In fact, engineers began designing equipment around oil’s capabilities so as to take full advantage of its properties. The combustion engine is one such invention. Further, policies and investments were modified to support oil consumption. Winston Churchill directed the British Navy to transition from coal exclusively to oil and policy makers directed investment and production efforts into the establishment and development of oil companies (Craig et al., 2013).

Following the huge upset in oil prices in the 1970s, the demand for oil was significantly reduced as consumers became largely disrupted by the gouge. The early 1980s also saw a decrease in the carbon intensity in various countries; in fact, a reduction of approximately 24% (IEA, 2004). This disruption to the industry steered various policies on diversification and efficiency towards attempts to reconcile the energy market. Much greater support for nuclear and NG sources emerged, along with incentives and strict regulations on automobile production. These standards also applied to general appliances and industrial construction. Drastic changes led to oil price declines between 1986 and 1999 (Jochem et al., 2000).
Unfortunately, the 1980s also saw an increase in nuclear accidents, such as the Three Mile Island (US, 1979) and the devastation of Chernobyl (Bri et al., 2012). Oil prices began to rise as nuclear power was no longer being used as a substitute. In 2011, the Fukushima nuclear disaster, as a consequence of a nuclear shutdown, means that electricity customers will pay up to 18% more for electricity, and the rate for industrial consumers will rise by 36% every month on average due to increased energy prices (Vivoda, 2012). IEEJ (2012) predicted that the cost of FF imports will increase by $61 billion if the Fukushima nuclear plant did not resume operations in 2012. Regardless of the alternative-energy source crisis, the market for oil still did not regain its previous footprint. Today, the global demand for oil is approximately half its level in the 1970s.

During the period 2002–2008, the oil market experienced sustained price rises in annual average energy costs every year for nearly a decade. However, these dramatic price rises ended with the 2008 Global Financial Crisis. A different trend emerged than seen previously, and economists attributed the new rising prices to dramatic changes in power structures amongst producers and consumers, such as the overtaking of the pricing system by the Organisation of Petroleum Exporting Countries (OPEC) (Fattouh, 2010). Another contributing factor was a shock to supply stores, such as the devastation brought by the 1979 Iranian revolution. The production of power itself seemed to have no influence over price movements, although OPEC played a major role behind the scenes in determining market specific prices for oil (Fattouh, 2007). Still, non-OECD nations remained the driving force for the unanticipated increase in demand. Much of this demand originated in China and India as their economies sustained steadily increasing growth and industrialisation. As is always the case with supply and demand, the price for oil rose as the demand began to outweigh supply.
Arguments have since been hammered out regarding the increase in oil and other FF demand levels in conjunction with questions concerning the ability of oil supplies to keep pace with demand. Substitutions for oil always generate the majority of conversations when these discussions arise. Since oil essentially dominates the transport industry, many economists and engineers focus on this area to alleviate its dependence on oil (Kahn Ribeiro et al., 2007; Mitchell et al., 2012). Once again, an ‘age of abundance’ approaches where oil stores are plentiful compared to current demand. Additionally, since the need is much lower now than 50 years ago, prices have also dropped to as low as $48 a barrel in 2015 (BP, 2016a). The IEA (2014) suggests that oil prices will continue to reach historical heights based on recent trends. Shale oil and gas play a large part in this projection, but they still will not generate enough supply at a cost low enough to have a significant impact. Figure 2.1 provides an outline of the section.

![Figure 2.1: Summary of a possible assumption process of resources prices.](image)

### 2.3 Factors in oil price trends

Interpreting trends in oil prices or projecting upcoming drifts in market behaviour is an analysis methodology that relies almost exclusively on market principles. Economists monitor supply and demand variables along with factors that affect them. They also study major ‘players’ within the market and analyse their particular buying and selling
behaviours together with any volatility or surprises with oil-related policies and technologies. Multiple factors impact the global market and projected behaviours in future demand trends. These factors include the price of oil, policies that define taxation regulations, competitive energy prices, population growth, strength of the economy and the possibility of technological advancements. When monitoring supply trends, economists consider the physical limitations of the region and geography, technological restraints, prices, exploratory funding and production investments, and the current structure and stability of the market and its associated politics.

### 2.3.1 Variables of demand

#### 2.3.1.1 Demand development

Oil demand is based on a variety of specific determinants. Its demand seems to evolve in a predictable manner dictated by the changing drivers—mainly the price. Primarily, a country’s gross domestic product, or GDP, is a figure used to determine its oil market. An increased rate of energy consumption in general reflects stronger economic growth and increased GDP (Ghalayini, 2011). However, the market has seen drastically changed dynamics in recent years due to increased oil usage in non-OECD countries. Recently, the balance has shifted so much, in fact, that the Asia-Pacific region has accelerated its market dominance to account for nearly 35% of the world’s total 95.01 million barrels per day (MMbbl/d) in 2015, with a 4.1% growth rate between 2014–2015 (BP, 2016a).

Although China is a major driver in this increase, their population increase and growth in energy consumption is not completely responsible. In recent decades, US export and
import controls have eased, as has its undisciplined monetary practices; these have contributed to the surge in oil prices across the global market. Despite the progressing economic recovery, the oil market will experience fiscal consolidations, as evident already in the European market (Helm, 2008). Even still, the continued population growth around the world, expected to reach 9.7 billion by 2050, and an increase in per capita incomes, will inevitably have a rather strong impact on the future of the energy market (Reilly et al., 2015). On the other hand, population growth is fuelled by consuming energy (FF), which may lead to increases in activities that increase pollution (Li and Molina, 2014).

Predictions about the worldwide demand for oil rely on models made for economic stimulation and oil price behaviours. The Energy Information Administration (EIA) in 2016 found that oil demand projections vary with differences in projections between the low-oil-price ($76/bbl) and high-oil-price ($252/bbl) cases standing at 5 MMbbl/d for the year 2040. Similarly, the difference in demand projections between the high-economic-growth and low-economic-growth scenarios is more than $25 billion (2010 dollars) for the year 2040 (EIA, 2016a). The demand for oil has low short-run price elasticity and thus high price inelasticity in the short-run. The demand for oil is responsive to economic activity in the short-run; income elasticity was found to be significant at a value of 0.53 between 1918–1999 (Krichene, 2002).

Notwithstanding, differences in assumptions about oil prices and growth rates are not the main aspects that can explain the divergence between the varied projections. Even assuming similar growth and price trajectories, it is quite possible to reach divergent projections about the future growth of oil demand. A key determining variable that
explains the deciding divergence in projections is the presumption made about price elasticity of oil consumption, mainly in non-OECD countries. Global associations accept assume a low income elasticity in non-OECD countries, ranging between 0.14 and 0.39 (Dargay and Gately, 2010). There are two stylised facts about income elasticity that must be considered. First, it is not constant but tends to adjust with the level of economic improvement, for example when the share of manufacturing relative to non-manufacturing GDP rises (Lo et al., 2007). Second, there is a threshold effect when per capita income reaches a specific certain level so that car ownership increases twice as fast as the growth in incomes (Dargay and Gately, 1997).

2.3.1.2 Transport alternatives

One reason why it is difficult to find an alternative for oil is the transportation industry. Most modes of transport are run completely on oil, and suitable replacements have not yet been found. Economists project the demand for oil to continue to rise as the need for transportation, particularly in China, steadily rises. Unfortunately, based on the current rates of increase, the supply will likely run out before this demand is satisfied, thus drastically increasing prices (Helm, 2011). Alternatives will then be quickly focused on, with the economy able to producing the greatest technological advancements for fuel substitutes dominating the market.

Even as oil prices continue to rise based on demand from the transport industry, the rate of vehicle ownership is highly unlikely to slow. Based on these assumptions and historical trends, fuel prices seem to have little impact on car ownership, although increased costs do encourage consumers to shift towards more compact and efficient vehicles as well as reducing amounts of travelling (Chamon et al., 2008). Technology
also has a great influence on both policy and demand for oil in the transportation industry. Unfortunately, those advances are hard to predict. Unless accompanied by a dramatic change in policy, the classic combustion engine that uses oil will likely remain the most common mode of transport. Developments in hybrid vehicles and electric cars have begun to enter the market, but they will not present any serious competition without governmental support and funding (Haug, 2011).

Regardless, many feel that viable substitutions are already available. Alternatives such as biofuels have already shown suitable potential for functioning in the transport industry in place of oil. Some such biofuels are ethanol and corn ethanol. Unfortunately, their impact is still too small without further technological developments to expand their role in the energy industry. One impressive attempt tried to convert the three primary fuel sources into each other; this would allow FF to be mutually transmutable, offering additional possibilities not only for energy sources but also for price regulation. The downside of such a transaction is that the conversion process is highly toxic in that it emits high levels of pollutants into the atmosphere. Additionally, further exploration into NG and coal power generators in non-OECD nations along with the use of electricity for transport in electric vehicles will help stabilise the market (Allsopp and Fattouh, 2013). Figure 2.2 provides an outline for the role of demand in the FF industry.

Figure 2.2: Summary of a possible assumption process of resources demand.
2.3.2 Variables in supply

2.3.2.1 Recently cycled supply variables

There are multiple explanations for why oil supplies are seen as limited and thus resulted in elevated prices. There have been reductions in mature oil fields that have shown much lower extraction rates. A recent analysis estimated that the weighted decrease of production from all existing world oil fields was about 4.5% in 2006 (Jackson and Eastwood, 2007), which is in line with the 4–6% range estimated by ExxonMobil (2004). However, IEA came to the conclusion that the annual global decline rate is 9.1% (Ragheb, 2016). This led to worries over global reserve quantities and whether oil companies would be able to increase their output at a rate that would not deplete stores. Economists were also concerned that prices for both exploration and development would increase (Allsopp and Fattouh, 2013). In recent years, this lack of faith in global supply adequacy has spread from non-OPEC countries. The high oil prices in 2001–2008 and 2011–2014 saw a weak response from non-OPEC suppliers outside Russia. Several oil companies in non-OPEC countries have been pushed by the rise in oil cost and limited access to reserves to explore new investments (Vivoda, 2009). Yet many analysts focus on above-ground factors as the supply constraint, such as adequate and timely investments in extraction rather than depleting natural resources (Baumeister and Kilian, 2016).

The FF supply also relies on a number of players within the market. Some of these players do not merely accept market conditions but rather tend to influence or shape those conditions (Verbruggen and Van de Graaf, 2013). Supply factors can also be categorised into short- and long-run. Krichene (2002) noted that the oil supply has low,
albeit significant in the short-run, oil prices (elasticity: 0.08 in 1918–1999). However, since 1973, long-run supply price elasticity of oil has been significant and positive (0.1 in 1973–1999). Thus, the short-run price effect was found to be insignificant, and existing production capacity dictated the supply of oil and other FF. Kilian (2010) noted a distinction between the oil trade and oil supply shocks which have far-reaching effects. The author suggested that each shock, and the nature of influences on the supply on oil pricing in general, has implications for economies that differ based on the real oil price. Plante (2014) analysed the optimal monetary policy and found that the relative oil price is based on exogenous oil supply shocks. Cashin et al. (2014) also emphasised that oil supply shocks result in oil price swings, enabling oil-exporting countries to make additional profit from this situation. In contrast, the author found that oil-importing countries may stand to lose, mainly due to declines in GDP.

Experts predict that the global supply has been thoroughly examined and believe a peak in production will soon be achieved so that there is restricted ability to make trade-offs between the few sources of energy, leaving oil the only unique source. According to Hubbert (1971), oil fields will mature and as such, the cost to recover oil from them will greatly increase. Oil fields will be rendered un-exploitable from an economic standpoint when this recovery cost moves beyond 50% of a field’s capability. Helm (2011) also argued that the maturity of oilers will have no new discoveries and thus maintain production from existing oil fields. The discovery of new fields has largely fallen, resulting in higher oil prices (Baumeister and Kilian, 2016). In addition, resource size is not as important to the oil industry’s future; rather, investment conditions, developmental costs and the overall price related to energy and climate policies will be the drivers of market pricing (Huntington et al., 2014).
Productivity-driven supply shocks are one of the key drivers of oil pricing (Plante, 2014). A positive supply-driven oil price shock is the result of high external demand in oil-dependent economies. From a longer-term perspective, such shocks surpass the effect of rising oil prices. Kolodziej and Kaufmann (2014) explained the positive relationship between supply shocks and oil prices by way of an example. The authors examined the unimportance of supply shocks that are not robust to alternative specifications and that are consistent with many empirical findings about the world oil market. Pirog (2005) summarised the mutual impact of supply on oil prices, concluding that the supply tends to reflect fluctuations in prices. As a result, this relationship leads to cyclic price volatility.

2.3.2.2 Oil production driven by discovery of new reserves and oil storage

The production of FF has been constantly rising over the last several decades and is set to follow the same trend for several more years to come. The vast majority of oil producers operate at maximum capacity utilisation, indicating the importance of storage and other inventories to store FF. Hinton (2001) expanded on the historical trends in oil production in the US and stated that the key to expanding supply is more down to discovering new oil field reserves as opposed to developing more efficient extraction technologies. In 2010, the US used enhanced oil recovery technology to increase production. However, it is worth noting that some advance methods never boosted production in Pennsylvania and New York and elsewhere in the country, with the price of oil rising fivefold over its 1891 price. Both Pennsylvania and New York produced less than 4 MMbbl of oil, a mere 12% the amount produced in 1891 (120 years ago) (Hamilton, 2012). The decline in US oil production can be attributed to the fact that new fields were discovered and began to be worked for extraction as other mature fields
dried up. The fluctuation in production within individual states appears to be strongly linked to discoveries of new fields and their eventual depletion than to the sorts of price incentives or mechanical advancements upon which economists typically focus.

After 2010, the US ramped up oil production and reached a level 60% higher than in 1970. The underlying dynamics, however, were very similar to those in that past, in that growth came primarily from the discovery of new fields (Hamilton, 2012). Regarding other members of OPEC countries, a number of factors contributed to the decline in production. Falling production in OPEC countries, however, reflect dramatic geopolitical events and other political decisions such as the two Gulf wars. These events impacted production and caused overall production rates to stagnate (Kilian, 2008). Still, although production has grown in other countries, global oil production from all sources has essentially remained almost constant in the 2005–2010 period (BP, 2016a). Hamilton (2012) suggested that the price and production of oil follows patterns that can be identified through the industry performance, technological progress and exploitation of new geographical areas.

Because the vast majority of oil producers operate at maximum capacity utilisation, storage and other methods to store FF are increasingly important. Storage of the oil will allow market participants to speculate on oil prices (shielding against price swings as result). The author noted that immediately after the Libyan political crisis (2011), the shortfall in storage infrastructure resulted in increased oil prices in the rage of $3–$13 (Kilian and Lee, 2014). Countries such as the US hold large inventories that serve as a strategic oil reserve. Between 2005–2012, this strategic oil reserve inventory contained 695.9 billion barrels of oil (Andrews and Pirog, 2012). Likewise, in the same period, the
NG inventory in the US expanded from 117.7 to 129.6 billion cubic metres, and the number of sites (places for storing this FF) grew from 394 to 414 (Confort and Mothe, 2014). Essentially, such efforts allowed the US to decouple its NG prices from those of European markets (Erdős, 2012). Such additional storage capacity can be created via the capital investment route. Mitchell et al. (2012) noted that the capital investment by 50 leading FF companies reached approximately $500 billion per year.

### 2.3.2.3 Oil price research and development

As the struggle continues to find viable replacements for oil in the energy industry, supplies of oil will continue to show steady declines even though demand remains constant or even grows. These factors will only lead to increased prices and unpredictable market dynamics. One benefit that could arise from this future is that this situation will lead to an increase in research and development for alternative sources. Past discovery of reserves and greater extraction from existing reserves has been driven by oil prices, similar to the development of shale oil and unconventional gas. Present research and development programmes in renewables reflect this too, with the added incentives of a carbon price and subsidies (Helm, 2008). Vast amounts of government investments in research and development, and financial motivations to find substitute forms of energy to reduce world dependency on oil, are not new to political plans of action. Comparable investment pledges and incentives were made in the previous century with few tangible results. Furthermore, these policies are much impacted by economic developments and oil price fluctuations (Allsopp and Fattouh, 2013).

The most significant technological improvements in oil production have been the implementation of horizontal drilling and fluid injections into drilling sites to create
small fractures \citep{Hamilton2012}. More advancements like these are vital for discovering new resources that can be used for energy production. Existing oil fields are also being researched to find better and more efficient methods of recovery. These improvements have led oil reserve numbers to improve, but this does not mean that the world is on the cusp of a new era of oil abundance. As prices for oil rise, advanced technologies to expand oil supplies will become more viable.

The preference for NG technology that enables economical extraction has diversified availability of this resource, leading to a reduction in price. This has in turn increased demand for NG, making it possible for this fuel to compete with other FFs in the market. The possibility of converting NG into a liquefied form has made it easy to store, reducing the inability to balance between rising energy demand and creation of necessary infrastructure. Some transformations that have been realised in the extraction of NG include hydraulic fracturing, whereby a liquid under a specified pressure is used to split a rock, thereby creating pathways through which NG will flow easily \citep{DOE2015}. Also, computer modelling of capacities relating to an oil platform has made these extraction activities safer and more secure. These dramatic developments have unleashed new shale establishments that are extremely rich in NG. These methods of access to huge deposits of NG even from great depths of sedimentary rocks of shale types has made it economical to extract large amounts of this NG, thereby boosting its supply.

Considering the fact that in the US, a bigger portion of NG is consumed in creating electricity, the price of NG has dropped considerably in light of these supply increase attributable to new extraction methods. Countries such as Canada and Australia have
continued to embrace these developments with time, and the ramifications associated with an increase in the supply of NG in preference to other FF’s has been experiences across the globe. The trend of reduction in NG imports by the US began to be noted right from 2007, and by the year 2015, net NG imports had gone down by about 935 billion cubic feet (EIA, 2016b). Currently, the US no longer imports but rather has invested in increasing its production to meet rising demand, and this has seen prices of NG becoming relatively lower. Due to the current huge amount of NG available in the US, the country has become an exporter of coal, with statistics showing that it now accounts for about 7% of total export to other countries (EIA, 2015). This has increased the availability of coal in other parts of the world, especially in eastern and southern regions. By 2011, the price of coal in Europe had dropped by about 20%, forcing the EU to encourage its members to increase their use of coal considerably (Auverlot et al., 2014). Figure 2.3 provides an outline for the influence of supply on the FF industry.

![Figure 2.3: Summary of possible assumption process of resources supply.](image)

### 2.3.3 Temporary price fluctuations

Although oil prices fluctuate on a daily basis, small variations are expected. Long-term volatility can be more related to new data as opposed to fundamentals of the industry. The long-term price fluctuations tend to cause more issue for both producers and consumers and will be reflections of market fundamentals. In addition, they will show
upsets in supply and demand due to variations in the supply chain network (Allsopp and Fattouh, 2011). When oil fields show excess supply, market prices for oil generally fall. But when demand overtakes average supply, prices experience a sharp increase. High prices for oil encourage substitution at the margin by increasing the oil price relative to other energy sources. However, the market enters a phase of indeterminacy of beliefs, where market producers did not know where to anchor the anticipated oil cost that would balance supply and demand in short- or long-runs. In effect, prices in short- and long-runs became jointly determined (Fattouh and Scaramozzino, 2011).

The price floor for oil depends on two market conditions. The lower limit is set by the cost of production of the low-cost supplier, and the upper limit is set by potential entry of substitutes and new producers (Allsopp and Fattouh, 2013). At the point when the market is characterised by excess demand, potential alternatives and adjustments in demand cannot place an upper boundary on the short-term price. With an absence of spare capacity, most of the adjustments are likely to manifest as sharp increases in oil prices. Therefore, when KSA is producing at or close to its maximum capacity, it may have the ability to influence the oil market. However, when the market is characterised by excess capacity, the price of oil tends to move towards the lower boundary. In such a market, the ability to collude with other producers weakens and as result, prices can drop below the collusive outcome (Fattouh and Sen, 2015).

Towards the late 1980s, the oil market saw a shift in the pricing system for the first time in nearly four decades. Increasing the financialisation of FF’s combined with volatility in oil prices has caused doubts regarding the relationship between the oil price and subsequent industry fundamentals (Huntington et al., 2014). As the market tightened
and underinvestment of funds led to price fluctuations, consumers focused on the financial players to increase their involvement. This was attributed to market conditions and a history of scant connection to commodities within the sector. Despite increased research on the role of financial players, solid conclusions have yet to be reached (Fattouh, 2010). Furthermore, economists have also exemplified the role of financialisation of oil by speculating pricing from subsequent funding behaviours (Fattouh et al., 2012).

2.3.4 Participant trends

2.3.4.1 Exhibiting player behaviour

Conflicting theories exist regarding how to interpret the varying behaviours of OPEC and its dominant player, KSA (Fattouh, 2007). Some research has implied that financial requirements lead decisions, while others believe that the transfer of property rights caused production cuts in recent periods. Governmental bodies are considered to enjoy more discounted rates than even the oil companies themselves. Regardless of the role bureaucracy posited in studies or interpretations, no definitive evidence exists suggesting one specific point of view is most accurate. The standard OPEC model relies on unconfirmed assumptions that they are only concerned with increasing production and market share and as such, will be able to raise their investments in capacity (Fattouh and Mahadeva, 2013). However, by expanding production, the supply strongly exceeds demand and can subsequently lower prices. Unfortunately, this hurts the revenue of oil companies and investors who do not like shrinking profits. This may encourage them to be less than open about any issues with long-term supportability in regards to global demand.
KSA is can be considered the main price-setter in the global oil market through their membership in OPEC; it is therefore necessary to analyse KSA’s role in NG pricing. Influences on NG pricing were raised as far back as in 1984, when Rahmani and Rahmani (1984) argued that in spite of widespread opinions of that time, OPEC has little influence on setting prices for NG. On the contrary, some studies noted a dependence of NG prices on OPEC’s decisions led by KSA. During oil production dips, NG suppliers did not know how to react adequately, and the mere threat of oil reductions may lead NG prices to rise. For example, in 2001, when OPEC had intentions to reduce its oil output by 1 MMbbl/d. After this event, the price of NG rose in the US, demonstrating average growth of $1.71/gallon (Bonsor and Grabianowski, 2005). On the other hand, coal prices have been decreasing since early 2011, partly because of the slowdown in emerging markets and displacement by declined oil prices, which significantly influenced the coal sector, even controlling the price of coal (Husain et al., 2015).

2.3.4.2 Cycle of player behaviour

Global supply and demand for oil and energy can be impacted by many factors. This lends insight into the extent of analysis involved in forecasting and assessing upcoming market conditions. Assessments of future conditions incorporate more complex models and potential scenarios, and they each involve estimations about the different contributing factors. Experts will draw together their projections for the oil market and set parameters reflecting their beliefs regarding what pricing will look like. These assessments formulate their business plans and directly impact the behaviour they follow. The issue of whether or not these scenarios are accurate or reflect any of the basic market fundamentals has caused much controversy.
**Hamilton (2014)** stated that if China faces a financial crisis, or if peace prevails in the Middle East and North Africa, a sharp fall in oil prices would be expected. In any case, regardless of the possibility that such situations were to happen, the emerging economies would surely subsequently resume their development, in which case any gains in production from countries facing disturbances would only buy a few more years. In case the oil industry does experience another price cycle arising from such developments any downturn in oil prices would be short-lived. Figure 2.4 provides a general outline of FF producer trends.

![Figure 2.4: Summary of possible assumption process of resources player behaviour.](image)

### 2.3.5 Recessions and oil pricing

The last 50 years have provided multiple events that have seriously upset the production of crude oil. These events have caused sudden increases in oil prices, despite having little to no disruption to actual supplies. In each event, the production shortfall is expressed as a percentage of total global supply prior to the shock. Following each of these events, world supply fell between 7–9% (**Hamilton, 2009**). Patterns suggest that emerging economies are increasing their usage and thus demand for oil and are causing this back and forth cycle in price (**Baumeister and Kilian, 2016**). Of the last 12 major instances of sharply increased oil prices, 11 were immediately followed by economic downturns in the US (**Hamilton, 2011**).
The connection between oil prices and global economic growth has long been reviewed, and some studies found direct or at least indirect positive correlations. Finn (2000) established that there is a large effect from oil price shocks on real GDP. Other researchers revealed that when oil prices increase, it is not immediately evident in a nation’s real GDP, but it has a profound impact nonetheless (Kilian, 2010; Hamilton, 2012). Therefore, significant reactions to increases in oil prices cannot be directly associated with the impact of lower energy consumption on productivity. Another proposition is that the demand for motor vehicles has an impact as well (McManus et al., 2005). Data show that the population is spending less on motor vehicles, which could lead to wasted capital and labour, which could in turn then result in Keynesian tensions in wage and price changes (Hamilton, 2011).

Furthermore, the tourism industry is also concerned about the possibility of rising oil prices. Chatziantoniou et al. (2013) observed that aggregate oil demand shocks have a significantly positive impact on tourism industry income and the economy. It is important to consider oil pricing and its connection to both economic growth and recessions when nations are working to transition to a sustainable energy system. This is partly because emissions from energy consumption are directly related to economic and population growth. Another reason is the possible connection between economic growth and innovation, policy practices and finally the investment climate.

2.3.6 Differences in declining oil price trends

There have been many cases of incorrect predictions regarding the price of FFs. At the very least, prior conventional wisdom regarding these trends has been premature. While many economists have genuinely attempted to predict price behaviours, oil has always
been difficult to predict and thus projections have been well off target. When high oil prices hit the market in the 1970s, conventional wisdom was completely taken off guard by the following recession (Allsopp, 2011). Many areas began working on viable substitutions using NG in place of oil in the heating arena as well as power generation. Following that era, oil prices dropped dramatically and remained relatively low for some 20 years. This new trend again made economists believe the future price developments would follow a continuing trend. In 1999, economists’ prediction illustrated a development in price drops that would eventually lead to oil dropping as low as $5/bbl (Allsopp and Fattouh, 2013). Instead, the market experienced its longest sustained increase in price.

Husain et al. (2015) indicated that energy policies seem to be impacted implicitly by the assumptions economists make about what future oil prices will look like. After the major shock of oil prices in the 1970s, OPEC experienced success but still feared the end of oil supplies and thus created the conventional wisdom that the future would continue to see a rise in prices. The next 20 years of low oil prices also brought lowered concerns regarding the security of the energy industry, and the population came to believe that supplies were plentiful. McKillop (2005) projected that in 2010, the world would see demand growth between 89–99 MMbbl/d with prices above $55/bbl. Nearly a decade later, when actual numbers were assessed, global output was only 88 MMbbl/d and the average price was nearly $80/bbl (BP, 2014). The world has been overly optimistic during the last twenty years of low oil prices, encouraged by a belief that technology was going to revolutionise deep-water drilling and significantly augment future supplies.
After 2000, economists began to modify the foundations of their conventional wisdom, partly due to neglect of energy industry security in previous decades and the fact that exploration and production by oil companies had failed to come through with lowered oil prices (Allsopp and Fattouh, 2013). Although the price of oil recently falling towards $40/bbl, oil reached peaks of $100 at the end of 2007 and $147/bbl in summer 2008, and suddenly the security of the energy industry became a top priority again.

Jesse and Van der Linde (2008) stated that oil prices in the long-term are expected to be high for two reasons. First, there is no credible cushion of spare capacity in core OPEC countries. Although additional capacity has improved since 2004, OPEC is still fragile, uncertain and not perceived as adequate. As a consequence, when unexpected events occur, there only can be a response in volume, which has to be compensated with an equivalent upward pressure in the oil price. Second, demand and supply tension is aggravated by the problem of underinvestment in the upstream sector, especially in OPEC countries and Russia, where access to global oil companies is becoming limited. Having no alternative but to invest in difficult and remote areas led the global oil companies to be responsible for the rising costs of the marginal oil barrel and creating further pressure on oil prices as well.

This led Europe to gradually increase its NG dependence on Russia for oil supplies. This was causing NG to become not only physically but also politically restrained, and Europe was driven to seek alternative-energy sources such as nuclear power, renewable energy and renewed generation of coal (Dickel et al., 2014). The world was experiencing an economic crisis that had already impacted the market and knowledge of oil trends by reducing future demand predictions. Since then, NG prices have decreased
and it seems that the connection with oil has also loosened. Europe was also able to reduce its dependency on oil from Russia as the US ramped up production of shale gas (Helm, 2011).

An opposite review has been offered by Helm (2011), who believes that greater impact will result from electric transportation methods in addition to the transition from oil over to NG and coal. He stated that electricity could be produced by abundant NG, coal and shale gas, thereby pushing aside any serious notion of peak gas. Over the coming decades, lower NG prices and nearby major markets probably will cause NG to take or maintain market share from coal and renewables in the electricity generating sector as well as from oil in the transport sector (Ridley, 2011). The implication is not just that peak oil claims should be largely dismissed. Rather, it is also wrong to assert that there is not enough oil or even FFs in general. On the contrary, the world is awash with FFs — supplies are plentiful, not scant (Helm, 2011).

Even though conventional wisdoms and forecasts have more often than not been proven incorrect, the scenarios for prices of oil and other FFs are still considered indicative of the state of the industry and global supply. Typically, oil prices are forecasted high and considered to increase further if policies on CCs are not strengthened and updated. History has shown that prices are notoriously difficult to predict for oil (Benes et al., 2015), NG (Logan et al., 2015) and coal (Mohr and Evans, 2009). Little evidence is available to show how long-term forecasting models for their pricing are developed. The expected paths for each form of energy reflect IEA (2011) judgement of the costs needed to motivate sufficient investment in supply to meet forecasted demand over the outlook period. In addition to downgrades to global growth projections, recent surges in
unconventional oil have been attributed to the significant decrease in oil prices in late 2014 (IEA, 2013, 2014, 2015).

2.3.6.1 Projections for fossil fuel

The EIA (2014, 2015) projections are typically associated with CC policies and subsequent influence on the price of carbon. In general, they utilise three basic scenarios. The Current Policies Scenario (CPS) adopt the notion that nothing other than current climate policy programs are implemented and CO$_2$ prices start low and slowly rise. The New Policies Scenario operates under the assumption that investment judgements within the power industry are made with an unspoken shadow price for CO$_2$ and that China will offer a flat price for carbon that will be applied to all industries from 2020. The third is the 450 Scenario, which assumes that CO$_2$ prices are instituted across all OECD nations with a merger taking place from 2025 and the price will reach $140/tonne by 2040 (IEA, 2015).

The IEA (2014) projected that pattern of increasing prices in the oil industry after the financial crisis is indicative of rising production costs for oil from newly discovered sources, which is needed in order to meet higher demand in the face of current fields drying up. The need to increase prices is driven by the growing imbalance of demand over supply. In fact, the IEA has forecasted that oil prices will reach $155/bbl by 2040 in CPS, yet the 450 Scenario projects only $100/bbl because it posits that oil demand will subside with a decrease in need to develop higher-costing fields (Teske et al., 2016). In January 2016, the oil price was at a historic low of only $30/bbl, with NG prices also showing significant fluctuation. Moreover, the global coal price dropped significantly to a low of $50/tonne.
The price for NG has been projected to follow a pattern reflecting the ratio of NG prices to the average oil price underlying historic norms (IEA, 2014). A moderately low portion of coal usage is traded on the global market, with global prices impacting various local prices, whereas other national domestic prices are more closely associated with those countries’ in-house production levels. The most relevant factor impacting the future of coal prices is the competition between coal and NG within the power industry. The cost to produce coal are not anticipated to increase nearly as quickly as NG and oil costs are rising, and projections regarding future coal demand are anticipating a decline in 2030. Thus, coal prices are not anticipated to rise as much as those of oil or NG in terms of overall percentage (IEA, 2014).

2.3.7 Elevated prices and the new sustainable energy system

It is quite challenging to anticipate what the future will bring in terms of pricing for FFs. Indeed, controversy surrounds how to interpret data and reach a conclusion about what will happen if FF prices were to enter an extended period of elevation or even level off at a high plateau. Historical responses by the economy to increases in oil prices suggest that if the world were to enter another period of high oil prices and the future decades look like the last 5 years, we are in for a rough time (Hamilton, 2012). A continuously elevated price for oil or habitual increases in price connected to supply disturbances would adversely affect overall economic growth. Nonetheless, if the global economy maintains the same sluggish pace of reducing oil dependency in the transportation industry as it did in the power industry after the crisis in the 1970s, then the outlook for overall economic growth in the future will also be one of a slow pace with increased insecurity in the energy sector. Moreover, if this scenario becomes reality, then the political priorities will shift globally much as they did following the financial and
economic crisis. Economic growth and unemployment will be major topics on the global political agenda and governments will quickly play less attention to climate policies. Such a situation could also negatively impact the transition to a sustainable energy economy.

Conversely, if energy prices remain high into the future, then it could also be expected that energy consumption and thus related emissions will be reduced as the growth of the economy slows. This trend would likely lead to an increase in the efficiency of energy production and usage, and alternative-energy sources would be significantly boosted in not only research and development but also implementation (Martínez and Silveira, 2013). Throughout history, strong relationships have persisted between the efficiency and price of fuel, despite available substitutions. It is likely that out of all industries to experience success, the transportation sector will receive the most benefits from high efficiency. Rout et al. (2008) identified robust upsurges in efficiency correlated with high oil prices and related climate policies and/or increased prices for coal, which would imply that an increase in oil prices may be the frontrunner to reverting back to dirty fuels.

Not enough historical data exist on climate policies or previous policy-related transitions in the energy industry to truly establish a baseline for future projections. However, the world has seen some notable national policies geared towards transitions in the oil sector, with the 1970s-era crisis serving as a catalyst for change. These policies were designed to address the security of the energy industry. For example, Africa developed policies to transition towards renewable power (IRENA, 2013) and China actively invested and implemented various renewable-energy forms (IRENA, 2013).
Such political changes suggest that it is quite possible to reach a political solution to force energy transitions in various industries if adequate administrative support is provided. However, impediments remain on such transitions, and the world must make note of such limitations when working towards a total transition by any economic system. The previous policy change examples benefitted from presence of a driving force to increase energy security and push for affordable and readily available energy.

Increased worries over CC only served to create new issues. Elevated oil prices led to strained supplies to reach exhaustion. This offers further evidence that the need to transition to a sustainable energy source is economically crucial. Van de Graaf and Colgan (2016) stated that a trend of high oil prices will lead to a tighter consumer market and high price unpredictability will be exploited by private organisations and other groups with a vested interest in oil profits. This makes a rather strong case for governmental interference by investing and driving the transition from FF to sustainable and renewable-energy sources such as nuclear energy. The logic stands that if FF prices are going to increase regardless, then reinvesting those funds into a transition will not be unwise and could likely even wind up creating savings for both consumers and investors. In 2011, Intergovernmental Panel on Climate Change (IPCC) maintains that by relying more heavily on renewable-energy sources, FF prices will decrease in the future. Conversely, Helm (2011) argues that these assumptions were drawn by biased supporters of extreme climate actions in connection with optimistic assumptions about cost levels and trends for particular preferred technologies. Additionally, the supposition of increased FF prices opened the door to assert a reduced cost for climate
neutrality or de-carbonisation. This helped to gain political acceptance for the 2008 EU CC goals for 2020.

After the recession and economic slowdown, emissions first dipped but then spiked to new heights in line with some economic high-emission situations. Coal usage increased in the power sector due to its cheaper price, which also increased emissions because it is a dirty fuel source (Anderson, 2005). Sustainable energy transitions may not benefit from security in the energy sector, with growing the economy a priority rather than managing CC impactors. Even though coal presents a reduction in energy security concerns as well as reduced international security concerns, its impact on the environment is highest out of all FFs. NG as an energy source presents security concerns in relation to an overdependence on exports from particular nations (such as in Europe) and on pipelines where cross-transportation countries could disturb the supply chain (such as in Ukraine) (Allsopp and Fattouh, 2011). Moreover, extending supply dependence could hinder security concerns, as happened with unconventional gas production increases in the US and the potential for supply from other nations (Rogers, 2011).

The most likely option is for the economy to transition to a less-costly energy source, which would have a significant effect on elevated oil and NG prices. However, a severe consequence of this action is a greater shift to coal if subsequent climate control policies are absent (Mantzos and Capros, 2006). In the last 10 years, roughly 50% of increase in the world’s energy demand was satisfied by coal consumption. This rate is growing alarmingly faster than the use of renewables (BP, 2016b). Aside from coal, there are various other alternative-energy sources that could power the transportation industry
that would cause higher CO$_2$ emissions (Haug, 2011). Thus, higher oil prices may strain the economy, but would also serve to attract more investment to cleaner energy and ultimately, discovery of a sustainable economic solution. This would also depend on enactment of a comprehensive climate policy able to force this transition regardless of oil price trends.

### 2.3.8 Tax issues relevant to the fossil fuel industry

A carbon tax (CT) is a fee assessed for the use of FFs in order to reduce carbon emissions by encouraging non-use or efficient use of energy sources that contribute to CC. Numerous countries have developed their own versions of CTs to support the management of these fees, but the application of fees remains hampered by the global nature of all emissions, particularly GHG emissions, which cannot be seen as exclusively occurring in a single location (Bagnoli et al., 2008). In 1990, Finland became the first country to introduce a CO$_2$ tax, a measure aimed at addressing global warming and CC issues (Vourc'h and Jimenez, 2000). Since then, a number of developed and high-income countries have introduced such taxes. The proportion of tax is directly related to the ‘carbon content’ and the quantity of the FF used by a business/organisation. As a result, governments are encouraging the use cleaner sources of energy such as NG. Consequently, the NG industry is expected to see an increased level of demand, but it also has some carbon content.

CTs can be divided into two main groups: production-based taxes and consumption-based taxes (Zhang and Baranzini, 2004). Production-based CTs operate much like export taxes. If such a tax is implemented in oil-exporting countries (such as KSA), these countries would earn substantial profit, because the revenues generated from such
an output tax adds proportionally to the state’s production capacity. In contrast, a national consumption-based tax acts like taxes imposed on imported goods and services. In this case, FF exporting countries would face substantial losses, because the revenues generated from this type of tax is proportional to the taxed commodity’s consumption.

The potential losses that various income groups could face if the US imposed a tax of $100/tonne of carbon vary widely. For example, the tax burden would amount to 10% of revenue for the lowest income group, and only a meagre 1.5% for the highest income group (Zhang and Baranzini, 2004). Bruvoll and Larsen (2004) analysed the Norwegian CTs and found out that such measures increased prices for FF. The highest tax rate for gasoline was around $51/tonne of CO₂, and the CT on gasoline accounted for 13% of the its price in 1999. The CT regime in California imposes one of the highest gasoline taxes in the country. The national average tax on gasoline is around $0.46/gallon compared to California’s at 58.5cents/gallon. CTs accounted for nearly 20% of the overall price for gasoline (Lin and Prince, 2009). From the above discussion, it is understood that oil imports from producing countries such as KSA would be reduced. In such an event, KSA may decrease oil prices to compete in the global oil market, thus triggering increasing consumption.

Implementation of the CT in British Columbia (BC) enabled economic and environmental production, where the charges were based per tonne, starting at $10 and gradually raise to $30/tonne (Vettese, 2016). The CT has been remarkably effective, reducing BC’s carbon emissions by 16% in 6 years. This percentage is well above the KP goal of a 6% reduction in 20 years. In addition, Chan et al. (2012) studied the effects of CT policies on the Canadian oil sand industry. The authors’ emphasised that without
such policies, annual Canadian bitumen production would rise fourfold during 2010–2050. Essentially, such taxes seem to benefit oil-importing countries (by way of transferring profit from KSA to FF importing countries); therefore, FF-producing countries’ monopoly over the oil supply given them the ability to raise prices could diminish over time (Dong and Whalley, 2012; Wei et al., 2012).

The global climate action mechanism (such KP) would not deliver a uniform effect for producing countries, although the price for FFs will decrease. Countries such as KSA (which can produce oil at low a cost of approximately $2/bbl) will have more chances to survive in the FF market. In contrast, countries that have an higher output cost, like Nigeria ($9/bbl), would suffer and potentially will be marginalised in the global oil market (Barnett, et al., 2004).

There is a widespread opinion that CTs mainly have negative effects on producing countries in terms of oil pricing, and researchers have suggested that carbon policies and taxes are more a menace than an opportunity (Liski and Tahvonen, 2004). Because the payoff for importing countries can exceed the payoff realised in the absence of pollution, pollution problems accompanied by carbon taxation can result in net benefits for the Kyoto countries at the expense of FF-producing countries.

A number of possibilities exist for managing the forced reduction and increased efficiency of FFs as an energy source, from carbon taxing through end-user taxation and fees for carbon footprints (Stelzer, 2011). One working paper attempted to offset the negative perceptions of carbon taxation by proposing that CT proceeds would result in reinvestment into fields that allow for improvements to energy use and reducing carbon
emissions overall (Sewalk and Newman, 2013). The two opinions on CTs have valid arguments in regards to the implementation and continued growth of these taxes, specifically in terms of the availability of other energy sources or alternative equipment. Examples include the inability of households to change the types of heating in their home without incurring large costs or issues surrounding access to electric or alternative-energy vehicles. Many organisations around the world would suffer losses by implementing overhauls to meet the requirements of either increased efficiency or transition to an alternative-energy source, with the largest losses occurring in the transportation industry. Figure 2.5 summarise the tax issues related to FF industry and the historical aspects of the FF in KSA is presented next.

![Figure 2.5: Summary of possible assumption process of resources taxes.](image)

### 2.4 History of fossil fuels in Saudi Arabia

The exact dates for FF exploration, mainly oil, cannot be accurately determined, however, speculators pin it as 15 January 1902. The Saudi government merged the Arabian Peninsula into a unitary system to allow researchers to discover oil deposits. The search for FF, mainly oil, in Arabia was influenced by three major global events (Vassiliev, 2013). First, there had been a sharp increase in global demand for oil as a result of the First World War. Second, there had been discoveries and rumours of oil seepage in various regions of the Middle East. Finally, at the time, there had been a
global economic collapse, which consequently fuelled the need for oil as a revenue generator.

In 1933, the KSA signed a contract with Standard Oil Company of California (SOCAL), which awarded the company a 60-year oil concession. This contract granted them the authority to commence exploration in the Eastern region (Grutz, 1999). The company became associated with another subordinate organisation, the California Arabian Standard Oil Company (CASOC) two months later, whose aim was to acknowledge the oil treaty. SOCAL also merged interests with Texas Oil Company when they both established CALTEX in 1936 in order to exploit the latter’s great network in Asia and Africa. CASOC’s geologists analysed the allocation region allowed in the contract and acknowledged Dammam No7 as a promising place. On 3 March 1938, drillers finally struck oil, which would turn out to be the first as well as greatest supply of oil in the entire world. CASOC made amendments to the oil concession agreement in cooperation with Texas Oil Company, which extended the period to six years. Thereafter, KSA began to export oil to the global markets in 1938. In 1944, CASOC Oil Company changed its name again to Arabian American Oil Company (Aramco).

By 1948, the company was owned by four American companies. Texas Oil Company owned a 30% stake in the company, Standard Oil of California held 30% and Standard Oil of New Jersey possessed another 30% while Socomy Vacuum owned 10% of the shares (Alfarsy, 2009). In 1950, after the true economic implication of oil discovery became apparent to the government, an agreement was reached which meant that the company would split its profits with the government of KSA. By 1968, the government of KSA commenced negotiations that would see the country hold some stake in
Aramco’s stock. By 1973, the KSA owned 25% of the company. This ratio increased to 60% in 1974. Eventually, the KSA took full ownership of Aramco from 1980. In the next year, the Kingdom’s oil revenues peaked at about $118.3 million (Nasser, 1990).

2.5 Importance of the fossil fuel sector in Saudi Arabia

Empirical data uphold the significant role that FFs have played in the economic growth and development of KSA. High revenues earned by the government from oil transactions help finance development projects and infrastructural growth, which require large capital endowments to implement. The dependence of the state’s economic growth on the FF industry is thus rather high (Yizraeli, 2000). For example, in 1973, oil-GDP accounted for an overwhelming 60% of KSA’s Real GDP. However, the impact of dynamic shifts in the global energy market and worldwide energy consumption trends has impacted with the country’s economic position. Emergent oil producers have taken portions of the country’s share in the overall market space. Despite this observation, the country’s FF policy is still to be respected since it exhibits the consistency of providing oil requirements to the West at more economically favourable prices and at the same time easing pressure during periods of oil shortages.

![Figure 2.6: Share of oil to total government revenue and GDP.](image)
Figure 2.6 illustrates the share of oil-GDP in total GDP and share of oil revenue in total government revenue. The orange line indicates that the ratio of oil-GDP gradually decreased over the last three decades. The highest recorded values were recorded between 1971 and 1973. The 1970s period marked the country’s greatest dependence on oil. This observation was largely due to the high capital accumulation efforts conducted by policy makers in an effort to urbanise the state. The close of the 20th century was marked by the lowest figure recorded in 1985, when the oil-GDP ratio stood at approximately 46%. The 21st century has been marked by a decreasing dependence on oil as the main variable in the determination of the total GDP. Policy makers had set out comprehensive strategies with the aim of achieving economic diversification; hence, the downward trend over recent decades.

Falling oil prices have further pressured the government to revise the country’s macro-economic structure. In light of falling international oil prices that saw oil prices drop by about half in 2015, the government set out an ambitious agenda, dubbed Vision 2030, which aims to restructure the whole revenue system (Saudi Vision 2030, 2016). Saudi Arabia’s reliance on FF revenue as a key economic driver provides policy makers with sufficient opportunities and incentive to tackle ambitious development projects. However, recent developments in the global FF sector have called for revitalised control over the financial and economic future of the country.

2.6 World oil prices and Saudi’s production

Without doubt, KSA is an important player in the international FF markets as a result of its relatively large production capacity, enormous reserves of oil and prime position amongst global oil leaders in OPEC (Yizraeli, 2000). According to more recent
statistics, 2014 and 2015 saw an increase in total production by OPEC, with KSA included, by approximately 1.57 MMbbl, whereas a consequent increase of 1.06 MMbbl occurred for OPEC without KSA. On the other hand, KSA managed to increase production by approximately 0.5 MMbbl whereas non-OPEC states managed to produce 1.263 MMbbl (Figure 2.7).

KSA is therefore an influential factor in OPEC’s total oil production over time. The trending market conditions point towards a balanced oil industry after a global drop in price by about 70% between 2014 and early 2016. The aforementioned trend indicates a global increase in total supply of oil inventories. Key stakeholders attribute this to waning demand as all oil producers, in effort to cushion themselves from devastating changes in prices in the future, have kept excess stocks. In fact, the situation is so severe that specialists predict that total storage capacity for oil is almost depleted (Gloystein, 2016).

The key reason for this observed trend lies in the fact that major oil producers have recently acted speculatively against the markets. With the knowledge that the present value of oil sales at a later date will be much higher, there is increased incentive for all
producers to maintain optimal inventories so as to maximise future returns (Gloystein, 2016). The impact of this excess oil is that key consumers of oil products will lower their demand for these imports, which will cause a price fix. The maintenance of such vast spare inventories has required KSA to consequently forego oil production to the tune of approximately 2.3 MMbbl/d since 1997. In addition, the cost of maintaining these oil facilities at a state of preparedness for market changes calls for a yearly expenditure of approximately $100 million (Yizraeli, 2000).

The ease with which oil can be substituted by alternative-energy sources has also accelerated the recent observed oil market trend. The discovery of modern technologies for converting natural gas-to-liquid gasoline as well the global consensus on the need to harness green energy means that projections about future demand are more complicated for producers. However, a promise exists despite existing trends in the form of urbanisation and economic development, especially in third-world states (Yizraeli, 2000). Their increased demand for energy due to industrialisation should offset the rising surplus and mitigate some of the pressure on producers.

OPEC was unable to come to an agreement over the curbing of production in a meeting held in Vienna in 2014. This sent the price of a barrel of oil tumbling after almost half a decade of stability. The key reason for this observation in the oil prices lies in the economic interaction of demand and supply variables in the market. KSA’s capacity, which is the largest amongst OPEC producers, is therefore greatly affected by such dynamic changes in the industry. Four determining factors can explain this situation:

1. Demand is significantly lower owing to increased efficiency, growth in use of alternative fuels and general weak global economic activity;
2. Political turmoil in FF producer countries, has done little to reduce their total production. This has a great effect because the market is very sensitive to geopolitical risks;

3. The US has become the largest FF producer in the world, mainly in oil. However, given the fact that the country now actually exports petroleum products, it now imports much lower quantities. This creates a gap in demand for international FFs, thereby raising levels of supply; and

4. Actions by KSA and other Gulf allies have been geared towards avenues that do not attempt to restore the price. In practice, KSA can weather lower oil prices with little impact owing to its massive $900 billion reserves (Rathesh et al., 2015).

Other political factors also influence the decision by KSA officials to not alter the current market trends. For example, KSA can curb production sharply in order to control surplus capacity in the market, but this would only benefit countries that are historically allied to the nation, such as Russia. The complexity of this modern scenario contrasts earlier findings by Barsky and Kilian (2004), who pointed out that ‘it is commonly believed that there is a close link from political events in the Middle East to changes in the price of oil’. This observation was further developed by Guo and Kliesen (2005), who stated that a vast majority of the largest daily oil future price changes in our data are associated with exogenous events such as wars or events in the Middle East. These viewpoints have been echoed throughout history and have significant bearing on recent trends, which are an amalgam of exogenous cases culminating to oil price in a global dilemma. The nature of KSA’s management and policy aspects are discussed next.
2.6.1 Saudi Arabia’s structure, management and policy in the fossil fuels industry

The Saudi structure, management and policy in the FF industry have been the focus of Saudi Aramco, which is an industry leader. A strengths, weaknesses, opportunities and threats analysis by Kobayashi (2007) indicated a number of important areas in Saudi Aramco’s management and policy. Strengths identified included the size, access, technologies and government relationships, specifically the ability of Saudi Aramco to remain an industry leader as a result of advancements in technologies and access to reduced cost production and capacity. Some of the opportunities identified included investment capital, demand for oil and membership in the World Trade Organization (WTO).

However, weaknesses and threats that are influencing Saudi Aramco and threaten its global leadership in the industry were found to include dependence on oil sales and small downstream capacity, along with increased domestic demand for product and carbon emission-reduction policies that are decreasing demand for oil. Further research from Al-Darwish et al. (2015) found that the companies’ policies exhibit a failure to address growth in other OPEC countries in production capacity, and the decisions of KSA indicate assumptions are made that exports will remain unchanged in upcoming years.

Current predictions posit that supply will outpace demand in upcoming years, with increased competition that Saudi policies fail to address (Al-Darwish et al., 2015). Key fiscal policies identified include developmental, stabilisation and intergenerational goals designed to support continued economic growth, manage oil price changes or shocks.
and identify how future generations will manage the economy as a result of oil being a non-renewable resource (Fattouh and Sen, 2015; Hill et al., 2015). Increased domestic demand, supported by policies for decreased for domestic supply costs to users and a growing economy, contributes to a reduction in production available for export. Other challenges hindering development of stronger policies regarding use and production include the available spare capacity, which is a key aspect of the KSA’s FF industry.

KSA’s policies have advantages in the area of stability, which is a focus and benefit to the country and industry, which may continue based on the availability of growth within the country and the current focus on maintaining stability. Due to limited risks, policies that seem to drive the pricing strategies of the FF industry in KSA appear to be related to the limited risks associated with lower prices (Fattouh and Sen, 2015). KSA’s ability to survive lower oil prices is considered more than probable and unlikely to influence either supply or production available from KSA (Alsweilem, 2015; Hill et al., 2015). However, these policies increase future fiscal risks and decrease interest in areas such as global CC.

KSA’s policies focus on increased production and maintaining leadership within the oil industry. Additionally, in order to continue to contribute to global CC initiatives and preserve the role of oil in energy sectors, KSA has placed a strong focus on developing ways to reduce emissions from oil use. KSA’s future is dependent on developing stronger policies aiming to reform the energy sector and increase diversity of industries directly influencing the country’s GDP (Alsweilem, 2015; Hill et al., 2015). Markets and competition for oil production are rapidly changing, increasing the need for policies that have a stronger focus on areas that can directly contribute to GDP and jobs in KSA.
In the case where oil production may not decline in the future, it is still likely that the need for additional income will not lessen in upcoming years.

### 2.6.2 Mechanism and strategies controlling Saudi oil production and prices

Researchers such as Fattouh and Sen (2015) have indicated that KSA has a crucial role in the oil industry, acting as a dominant supplier with spare capacity. KSA’s pricing strategies have not coincided with the OPEC pricing market, although its pricing strategies have been previously noted as contributing to the balance that OPEC must maintain as part of its role as an oil industry leader (Alkhathlan et al., 2014). KSA’s strategic goals are focused around the production and distribution of oil globally, and such aims are included in nearly every public strategy (Saudi Vision 2030, 2016).

Price shocks in the oil industry can be a direct result of OPEC oil production behaviour, including long-term variances that are difficult to reverse or end. Barros et al. (2011) found that OPEC has 43% influence on the global oil distribution, of which KSA is a strong contributor. Time-series analysis found that this global influence in the oil market has existed over the long-term. Further, KSA has the potential to double exports; it maintains control of distribution through a combination of methods, but overuse by the domestic population reduces this export potential (Al-Kibsi et al., 2015). KSA has strategies aimed at global market leadership in oil production and distribution, which may also have a direct influence on the long-term oil industry.

KSA can respond to price changes in the market by decreasing prices to remain competitive and to remain a leading provider; however, this can also influence the income generation power of its primary industry (Kilian, 2014). Speculation, flow
supply shocks and flow demand shocks, which are directly related to areas in which oil’s ability to reach or be available to meet demand, are directly impacted by outside events and contribute to changes in pricing strategies by oil providers. Furthermore, price shocks contribute to growing interest in other energy sources in order to prevent or counter increased prices or inability to obtain necessary supplies (Hamilton and Wu, 2014; Kilian, 2014).

Indirect effects are also considered by Kilian (2014), who found that the market value of goods and services as well as economic conditions in KSA are directly dependent on oil and the pricing strategies implemented in order to manage both supply and demand shocks in the industry. In the past, OPEC had worked to control pricing, or promulgated strategies to improve upon the pricing in the oil industry for the countries in the organisation; however, over time, this has become less common. KSA has a direct role in OPEC, being a leading supply of oil, both globally and in OPEC, which grants it a direct role in improving the stability of the oil industry for both OPEC and global organisations. Essentially, there is a need to study KSA’s management structure, in the FF industry. This can be done through an in-depth qualitative interview-type analysis in order to gain deeper insights into FF production and pricing over time. The KSA economy is considered in the following section.

2.7 Performance of Saudi Arabia’s economy and oil market

KSA’s policies have achieved some degree of success in increasing the overall degree of domestic economic diversification. However, the lowest indicated level of oil to total GDP has always been just shy of 50%, even during the existing poor spell. In the past, the dependence on FF was so great that volatility of oil prices greatly affected the
country. Figure 2.8 reveals that during the 1969–1973 era, the country’s economy grew at an accelerated rate. This growth can be attributed to the existing low level of economic development at the time. The average annual growth rate during that time frame was approximately 18%, which could be termed a period of high economic growth.

![Figure 2.8: Percentage growth of GDP.](image)

The patterns of real per capita growth highlighted above further indicate that no dramatic changes occurred since the astonishing 174% change in 1974 (Figure 2.9). This relative stability can largely be ascribed to the dramatic change in GDP composition. In recent years, trends have harmonised and acted in a dynamic manner. However, with speculative ambitions by the existing regime to shift away from oil
production as its main sector, it would probably be expected that a minor boom or regression will appear in the near future. This expectation could be easily mitigated owing to the robustness of the economy’s official reserves.

Figure 2.10 decomposes the KSA annual growth rate in GDP for both oil and non-oil sectors. The oil sector’s influence shows heightened volatility owing to the many factors that influence it. This trend, although insufficient on its own, suggests an interaction amongst capital variables. For example, the 1970s trend, in the exclusion of global political factors, suggests growth in both variables of GDP. The high growth in the 1970s could thus be attributed to transitional growth in the non-oil sector. With the proposed economic restructuring in the near future, it is speculative to assume that the role of the non-oil sector in determining GDP growth shall be far superior to oil’s role. This is in light of existing global trends in the oil market, which is set to experience great turmoil as a result of shifting demand cycles. The changing worldviews on FF emissions have led to consideration of ‘green’ options regarding fuels.

![Data source: KSA Monetary Authority (SAMA, 2016).](image)

Figure 2.10: Decomposition of KSA GDP growth.
2.8 Saudi use of petroleum and the need for green energy

One of the largest problems that KSA will face in the future is a growing domestic need for oil, which is predicted to grow due to continued population growth (Akhonbay, 2012; Taher and Al-Hajjar, 2014). KSA’s oil usage is expected to increase as much as 24% of government revenues and 11.3% of GDP by 2030, which will have other impacts in addition to the decrease of oil available for exports and revenue. Some of the costs that will be directly influenced are utilities and CO₂ emissions costs, which have been estimated as reaching $1.3 trillion in 2010 and are expected to rise a combined total of 5.6 trillion by 2030 (Taher and Al-Hajjar, 2014). Reducing CO₂ emissions is critical to KSA’s ability to be successful in the future, both by increasing profits through exports of oil and increasing environmental quality within the country. However, KSA had developed the Renewable Energy Programme (REP), aimed at increasing the generation of renewable energy, specifically solar power generation, to 54,000 MW by 2032 (Nachmany et al., 2015).

Energy policies introduced during the last decade include the National Energy Efficiency Programme objectives, focusing on improving upon energy efficiency as well as sustainability due to the high percentage of GDP dependent on oil production. Amongst the achievements made in 2010, including recognising the need for policies to address sustainability and energy efficiency, the challenges would be related to the economic disadvantages that can occur during such a process (Alyousef and Varnham, 2010). In the following years, the main focus has moved away from researching policies developed by KSA to areas such as security of global oil production and oil industry. Research indicates that risks exist when considering policies developed for
sustainability, due to the need to be successful and secure in providing global supplies of oil to industries (Levi, 2013).

The domestic demand for oil in KSA is expected to triple as a result of the unchecked demand growth in the country. In response to this problem, KSA developed Tarsheed, which is a public awareness program designed to reduce demand by providing education in regards to efficiency and rational use of the fuel source (Akhonbay, 2012). This program aim to increase the amount of product available for export versus domestic use and increase profits as well as reduce dependency on FFs. KSA has involved universities and professionals in programmes designed to improve both popular education in fuel efficiency and management and in developing renewable energy sources (Akhonbay, 2012). However, KSA is responsible for some of the worst pollution in developing countries, both land and air pollution, largely due to desalination processes that are being developed (Taher and Al-Hajjar, 2014).

Although these goals match the goals of climate control and change, they are specifically developed to address the pricing and management of exported FFs in order to maximise profits. The plans developed may not make adequate consideration for changes in the economy, costs of extracting fuel as levels grow lower or the continued inefficient use of FFs in KSA. The attempt to develop policies to support the goals and initiatives in both research and design as well as education programs established in the country have not solely addressed environmental issues and have typically returned to the primary objectives of profit maximisation in oil production. However, for increased environmental safety, legislation included in the national environmental legislation has been developed to reduce causes of pollution.
2.9 **Summary**

FF prices have played and will continue to play a significant role in modern world. Humanity has been and will be in the near future still heavily depended on these FFs. Due to the economic and technical developments there is an increasing interest in FFs consumption by emerging nations. Fluctuations in pricing and output (demand and supply) of FF has been observed over time and these have been mainly due to shocks in the industry caused by extreme events. Likewise, the FF industry faces rising constraints in accessing hydrocarbon reserves as the continual exploration for new sources conflicts with rising efforts to preserve ecosystems and protect biodiversity. Further, CT could alter the economies of the entire FF industry and could also significantly affect the survivability and profitability of FF companies.

Furthermore, rapidly decreasing in process for these FFs is not in the best interest either, for example, the demand will grow, when prices become lower, and consequently, the consumption will be increasing and cycle continues. That is, when oil companies notice an increase in consumption, they will start increasing their output. Many environmentalists and economists support high-carbon prices because these will allow shifting the economy to low consumption of FFs. Nevertheless, achieving this switch will become possible with a better understanding of how changes in policies and energy system influence the energy services’ price instead of that for energy.

The continued and persistent ‘greening’ of the world has changed the dynamics of FF industry worldwide but more so in the KSA where they rely on FF sales. Therefore, problems facing of FF pricing now requires more detailed investigation and analysis,
both in terms of management of KSA, its effect on policy and pricing as well as to gain insights into undiscovered aspects like interdependence between FF prices themselves. Energy efficiency will drive down the cost of energy from alternative sources, making such services more appealing than traditional ones, which will help the economies of many countries become low-carbon.

The FF industry, determined, like all industries, to raise its market profits and share, significantly would contribute to GHG emissions, which drive CC. By virtue of its long-capital investment horizon and carbon intensive products, the FF industry is uniquely exposed to economic and competitive risks. Since FF companies are significantly impacted by CC and significantly can contribute to CC, stockholders’ perceptions can have an enormous effect on the value of the FF market. Considering its importance, the CC is discussed in the following chapter.
Chapter 3

Climate Change
3.1 Introduction

The environmental issue of CC has become a great concern for world leaders. Climatologists, economists and environmentalists debate as to whether CC exists and the feasibility of potential solutions. A predominant global consensus has emerged that CC is a reality and that human industrial activities significantly contribute to the problem (IPCC, 2007a). The primary GHG is CO₂, which is created when FFs are burned in energy production within the electrical and transport industries, as well as within the residential sectors (Köhler et al., 2010). In addition to CO₂, other impactful GHGs, such as CH₄ and N₂O, are products of waste and industrial and agricultural processes. Hydrofluorocarbons (HFCs) are fluorinated forms of GHG, or F-gases, which are found in smaller quantities in the environment; however, the HFCs are more potent than CO₂ (Figure 3.1).

The atmospheric concentration of Kyoto GHGs is estimated to be approximately 449 parts per million (ppm) of CO₂. The total atmospheric concentration of GHGs, both Kyoto and Montreal, is estimated to be approximately 472 ppm. The annual increase in CO₂ concentrations in the atmosphere is 3 ppm and that the rate continues to increase (EEA, 2015). Despite historical variations in the Earth’s climate, climatic shifts have intensified in the past few decades, causing concern and increased uncertainty in regard to current environmental sustainability policies and expectations of the future impact of anthropogenic, or human, industrial activities.
Climatologists and environmentalists have proposed that significant increases in CO₂ have the potential to transform global geographic demographics. In turn, such a geographic transformation could also have unsettling implications for society; particularly in regards to modern ways of life. The societal environmental sustainability issues that drive CC debates have increased the urgency for accurate research and strategies for GHG emission reductions. Hepburn (2015, p. 317) observed that CO₂ remains in the atmosphere for hundreds of years and that approaches to the GHG problem must become more aggressive for a number of reasons:

- The extensive atmospheric time lag between the current human industrial activities that contribute to CC and the approximately three decades that climatologists predict it will take for the CO₂ molecules to penetrate the Earth’s upper atmosphere and stimulate the trapping of heat effect. Thus, the projected CC towards 2040 to 2050 will require significant GHG reductions in the current generation and for a duration of 10 consecutive years; and

- GHG emissions incur long-term high capital infrastructure costs. The construction of factories, power stations and other types of buildings generate
GHG emissions at the same rate a time span that may extend from 40 to 50 years, based upon the assumption that new energy-efficient technologies have not evolved. Furthermore, the lifetime emissions that result from the construction of capital assets are not immediately irreversible.

The negative impact of CC upon energy industries is complicated by the ongoing release of CO₂ into the atmosphere. Lal (2004) stated that between 1850 and 1998, the FF emissions were approximately $270 \pm 30$ gigatons (Gt), which is double the amount of emissions in the terrestrial ecosystems of $136 \pm 55$ Gt. Since the industrial revolution, FF emissions have been estimated to reach levels of 403 Gt of carbon dioxide (GtCO₂), or 110 Gt of carbon (GtC), of which, approximately 660 GtCO₂, 180 GtC has been released into the Earth’s atmosphere; vegetation has absorbed approximately 403 GtCO₂, or 110 GtC; and the oceans have absorbed the remaining harmful emissions (Sathaye et al., 2006). Olah (2005) contends that CC is significantly impacted by hydrocarbon industry by-products. Furthermore, the World Energy Outlook (2012) and Inkpen and Moffett (2011) agree that projected FF demands towards 2030 are likely to increase by approximately 60% or more, in contrast to estimations at the onset the 21st century.

Increasing GHG emissions have long since been attributed to economic growth; however, the potential for attaining GHG emission stability has been deemed by some as high and consistent with continual economic growth (Ostrom, 2010; Wang et al., 2016). Others have expressed scepticism over this potential and have asserted the accuracy of CC projections for the next 150 years that support CC cannot be confirmed. CC projections have been criticised as being higher or lower than actual outcomes due
to the inefficiency of CC models used to formulate the projections. Still others argue that CC is actually a natural environmental phenomenon not driven by human industrial activities, and that this theory should remain as the predominating assumption until evidence-based research models indicate otherwise (Lomborg, 2001a; Whitmarsh, 2011; Leiserowitz et al., 2013). Sullivan (2013) presented a more neutral argument, namely that the impact of global warming on the global environment and global economy would be negligible, small or insignificant.

3.2 Correlation between greenhouse gas and temperature

The GHG effect has been categorised as a natural process in which the Earth’s mean surface temperature would be approximately 33°C lower than the traditional 18°C. Dawson and Spannagle (2008, p. 196) found that in the absence of the GHG effect, Earth’s surface temperature would be approximately −15°C; which would be unsuitable for human habitation. The climatic estimations of Fourier (1766–1830), Tyndall (1820–1893) and Arrhenius (1859–1927) have since evolved into an enhanced comprehension of the absorption behaviours of GHG’s and correlations between GHG concentrations and temperature (Gregory et al., 2004; Meinshausen, 2006).

The significance of climatic science research has been its contribution to understanding the weather, which is a highly complex phenomenon that defies mono-causal theory applications and even more significantly, mono-causal interventions (Gramelsberger and Feichter, 2011). The understanding that has been gained in regard to this complexity may be applied to long-term observation series and the increased implementation of numeric models researching global warming. The numerical models provide digital simulations of the Earth’s atmosphere that are used in research to expand...
knowledge. In addition, the numerical models assist scientists in the separation of internal and forced variabilities and the execution of feedback interactions. Thus, the conclusion that the temperature effect of CO$_2$ increases logarithmically with atmospheric concentrations has been well established (Smil, 2003, p. 23). Global climatic policies focus upon reductions in the Earth’s average temperature and future increases due to the effect of GHG emissions. Table 3.1 provides a summary of CO$_2$ projections based upon a range of research studies on projected temperatures.

Table 3.1: Illustration of different global temperature forecasts to 2100.

<table>
<thead>
<tr>
<th>Time</th>
<th>CO$_2$ level (ppm)</th>
<th>Temperature (°C)</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td>400–450</td>
<td>0.8–3.1</td>
<td>1.3–3.7</td>
<td>0.9–2.3</td>
<td>1.4–4.5</td>
<td></td>
</tr>
<tr>
<td>2040</td>
<td>500–550</td>
<td>1.3–3.8</td>
<td>2.0–5.3</td>
<td>1.7–3.2</td>
<td>2.3–5.4</td>
<td></td>
</tr>
<tr>
<td>2080</td>
<td>650–750</td>
<td>1.5–5.5</td>
<td>2.9–7.7</td>
<td>2.0–3.7</td>
<td>1.0–9.3</td>
<td></td>
</tr>
<tr>
<td>2100</td>
<td>750–1000</td>
<td>2.2–8.3</td>
<td>3.4–9.9</td>
<td>3.2–5.0</td>
<td>0.7–10</td>
<td></td>
</tr>
</tbody>
</table>

Source:
A: IPCC.
B: Met Office Hadley Center (MOHC).
C: Representative Concentration Pathways (RCP).

The climatic system’s response to increased GHG concentrations is typically addressed in terms of climate sensitivity, defined by Gramelsberger and Feichter (2011, p. 17) as warming that results from doubling of CO$_2$ concentrations. Recent research studies on climatic sensitivity have pursued approaches to constrain the degree of uncertainty through investigations and subsequent projections of future global warming based upon projected global GHG emissions. This research is critically important in two aspects: (1) the conclusions reached have been found to be largely consistent with the claims of the IPCC with the exception of climatic sensitivity exclusions; and (2) the studies provide an analysis of risk that is more explicit. Some of the research support that the probability of climatic sensitivity less than 1°C is 0% to 2% and that the probability of climatic sensitivity greater than 5°C is 2% to 20% (Meinshausen, 2006).
The climatic sensitivity mitigation pathways that significantly reduce CO₂ emissions will be characterised by temporary atmospheric concentration overshoots. IPCC (2014b) argues that limitations to global warming with probabilities of less than 2°C in contrast to preindustrial levels could only be accomplished through substantial reductions in anthropogenic GHG emissions by mid-century and by significantly impactful energy systems and land-use changes. Climatic predictions for temperature increases for the duration of the 20th century contain necessary uncertainty due to the quantification deficiencies of the climate system’s sensitivity to fluctuations in atmospheric GHG concentrations and rates of heat uptake in the oceans as well as the complexity of anthropogenic and natural climate predictions (Stott and Kettleborough, 2002).

The quantification of uncertainty in regional CC predictions is more complex than in regard to global predictions due to the compounding effect of regional uncertainty (Dessai et al., 2005). Therefore, research methodologies that assign probabilities to CC on the regional level should encompass the implementation of a model evaluation phase. However, all current GHG emissions and other agents that produce climate forcing will have a direct impact upon the magnitude and rate of CC for the next 3 to 4 decades (IPCC, 2014b).

3.3 Impactful climate system changes: Earth’s atmosphere, oceans and ice caps

In the past 28 years, the IPCC has investigated the correlations between CC that is a by-product of human activities, FFs consumption and global warming. The IPCC (1990) submitted that global surface temperature increases, variations in precipitation and
fluctuations in oceanic and arctic temperatures support that CC is an authentic environmental threat. The IPCC (2013) climate assessment found that a high percentage of the modelling that has been conducted with computer technology since the 1950s also supports an unequivocal and unprecedented instance of global warming that continued to trend into the new millennia. Further, the effect of global warming due to increases in atmospheric GHG’s has been observed on land surfaces, the oceans and ice caps (IPCC, 2014b).

Trenberth (2011) confirmed a direct correlation between global warming and precipitation, which included critical amounts of water evaporation and drying of the Earth’s surface. The moist regions of the Earth are becoming more saturated with water; while the dryer regions are becoming more dehydrated (Allan and Soden, 2008). The air’s capacity to hold water increases by approximately 7% per 1°C of global warming; this, in turn, increases the concentrations of water vapour in the atmosphere. The global temperature acceleration has also been reflected in the rates at which the Earth’s ice is melting. Ice caps and mountain glaciers as an indicative markers for climatic sensitivity have demonstrated that historical temperature records based upon ice cores and tree rings, as well as instrumental and historical data, support the intensity of recent global warming (Trenberth, 2011).

Allan and Soden (2008) demonstrated the complexity of the processes of CC predictions and adaptations that impact the global water cycle. The societal effects of global warming will be realised predominantly in global water cycles, which will be driven by negating regional climatic shifts that are characterised in Table 3.2.
### Table 3.2: Regional effects of global warming.

<table>
<thead>
<tr>
<th>Event</th>
<th>Environmental Impact</th>
<th>Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall</td>
<td>Excessive humidity; soil erosion and nutrient losses and flood.</td>
<td>The daily frequency of rainfall has increased in almost world land by 65% of areas exhibit positive trends for annual maximum rainfall between 1951–1999 and the world averaged 20th and early 21st century frequency of daily rising in annual maximum rainfall intensity was estimated between 5.9–7.7% per °C of globally averaged temperature near-surface atmospheric (Westra et al., 2014).</td>
</tr>
<tr>
<td>Seal level</td>
<td>Saltwater intrusion; threats to barrier islands; low-lying deltas; and subsidence.</td>
<td>The global average sea level rose by 0.17 m in the last century and specifically, the seal level raise recorded the fastest rate of 3.1 millimetre (mm) annually between 1993 and 2003 (IPCC, 2013).</td>
</tr>
<tr>
<td>Ice caps</td>
<td>Sea-level rise; decline in water resources; increase in flash floods; and accelerated warming from albedo.</td>
<td>The contributions of ice sheets to sea-level rise between 0.4 ± 0.4 mm and 1.1 ± 0.4 mm per year between 1993–2003 and 2003–2008 time periods respectively (Van den Broeke et al., 2011).</td>
</tr>
<tr>
<td>Cyclones</td>
<td>Destructive winds; heavy rainfall, increased high tide and storm surge intensities.</td>
<td>Since 1949, the annual accumulated cyclones in Western-North-Pacific and the North-Atlantic has increased by approximately 60%, and average cyclones peak wind speed summed over eastern/Western-North-Pacific and the North-Atlantic has increased by 50% (Emanuel, 2005).</td>
</tr>
<tr>
<td>Heat waves</td>
<td>Excessive water evaporation; land-surface drying, increase energy demand.</td>
<td>Heat waves used to occur every 20 years and now come in 10 years by raising three standard deviations (+3σ) that are around 10% of the global land area compared to 0.1–0.2% above the historic average for the period 1951–1980 (Hansen et al., 2012).</td>
</tr>
</tbody>
</table>

The frequency of modest rainfall events, or 10%–20% bin, are anti-correlated with the extreme rainfall events, or 95%–99% bin frequencies in observation satellite data and that the opposite effect occurs in simulation models (Allan and Soden, 2008). Cyclones require warm temperatures across the sea surface, high scale values and low vertical wind shear in relationship to troposphere lower-layer vorticity. Henderson-Sellers et al. (1998) found that thermodynamic schemes for the prediction of tropical cyclone maximum potential intensity are projected to increase between 10% and 20% for climates with doubled CO₂; in addition, momentum restrictions, ocean spray and potential changes in surface to a 300 hectopascal lapse rates contribute to the reduction of temperature increases. Zacharias et al. (2015) found that a probability that CC will increase instances of heat waves as well as the heat-wave intensity and duration; these
in turn will increase projected future rates of heat-related mortality. Future heat-health associations are projected to fluctuate due to societal adaptations to higher temperatures by means of incremental physiological acclimatisation. However, heat waves negatively impact human health through the exacerbation of associated conditions such as heat cramps, heat exhaustion, fainting spells, heat strokes and increases in mortality. Thus, risk assessments of increasing temperatures and human health are a critical component of future planning in order to reduce heat-related health outcomes due to CC (Zacharias et al., 2015).

3.4 Global impact of climate change on society

The effect of CC on the Earth’s surface, atmosphere and temperature threatens the fundamental components of human life. The potential impacts of CC upon society range from deficiencies in water and food supplies to the overall declines in human health and well-being (Table 3.3). Therefore, the implications of CC for society and human adaptations to CC have evolved as an integral part of global political and socioeconomic discourses. Adger et al. (2009) described human adaptation as a natural or human system adjustment in response to projected or actual climatic stimuli and the effects of the stimuli as an approach to moderation of harm or exploitation of potential benefits. The accrual of societal health risks due to (1) depletion of land cover and biodiversity, (2) disruption of fundamental environmental cycles, (3) FF inputs to global food systems; (4) increasing global concentrations of bioactive nitrogen compounds; and (5) animal husbandry and crop production activities have all been found to significantly contribute to increases in GHG emissions (McMichael et al., 2007).
Adger et al. (2009) proposed that societal resilience to negative climatic experiences may be realised through coastal defence mechanisms and innovation analyses that promote analytical functionality accomplished by ethics, past and future knowledge, culture and an assessment of risk. The global status of rational energy consumption and food production that has been defined as congruent with environmental sustainability would serve to underpin the health, well-being and longevity for global human populations as well as the global environment (McMichael et al., 2007).

The impact of slow-onset events and extreme climatic variability due to GHG emissions will require diversity in regard to governmental responses able to minimise the damage to global critical infrastructures; particularly in developing nations (Warner and Zakieldeen, 2012). Mitigation for climate finance that will provide assistance to developing nations has been confined to ‘considerations [of] low-carbon developments, adaptation and mitigation; the economic costs of each component; and the platforms for the financial mechanisms’ (Craeynest, 2010). Building code enforcement and retrofitting of hospitals, schools and other primary infrastructures may be incorporated into global risk-planning strategies to increase resilience to environmental and economic shocks. However, Warner and Zakieldeen (2012) highlighted that the economic costs of effective global administration, relief and rehabilitation plans are high and that smaller communities may go without assistance from global humanitarian agencies.

Further, the emission debts from excessive resource consumption are significantly higher for developed nations, which disproportionately contribute to the future threats arising from CC. Craeynest (2010) proposed that wealthy nations be required to repay emissions debt by more aggressive emissions reduction plans, donations of
technological and financial provisions to developing nations and compensation for communities that cannot mitigate environmental damage due to the severity of the impacts.

Table 3.3: Effects of CC on people around the world.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Environmental Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food</td>
<td>Reduced yields; planting and harvesting changes; increased irrigation; decreased arability; more Insect and plant pests; and risks to fisheries.</td>
</tr>
<tr>
<td>Water</td>
<td>Decline in drinking water; water infrastructure vulnerability; decline in irrigation supplies; higher shipping costs; disruptions to power supply; and ocean acidification.</td>
</tr>
<tr>
<td>Health and human toll</td>
<td>Extreme heat; poor air quality; natural disasters; allergens and other nuisances; and spreading diseases.</td>
</tr>
<tr>
<td>Land use</td>
<td>Forced migrations and extinctions; desynchronisation of life-cycle events; increase in agricultural pests; changing woodlands; increase in allergens; and noxious plants.</td>
</tr>
<tr>
<td>Economic loss</td>
<td>Damage to property and infrastructure; mass migration and security threats; lost productivity; increased poverty in developing nations; and coping costs of carbon emissions.</td>
</tr>
</tbody>
</table>

Global water and energy systems are connected in that energy is used to process, distribute and use water; power plants also require water for cooling. Energy and water are both instrumental in agricultural crop production, which extends to the generation of energy through crops as biofuels (WBCSD, 2009). The global water-supply’s vulnerability to CC has been linked to excessive runoff and passage of water through Earth’s network of rivers. Therefore, the sustainability of the global water supply and irrigable lands is often researched in terms of the topology of global river systems and magnitude of human water use.

In turn, increases in temperature due to GHG emissions are expected to increase the demand for energy, which will deepen global energy issues of overconsumption. More robust projections of future global water-supply vulnerability due to CC will require research into the interactions between CC and water engineering, variability; human
systems and groundwater and land-surface hydrology along with societal adaptation to future water scarcity (Vörösmarty et al., 2000). Sustainable solutions to CC issues will require a holistic approach to evaluating CC, energy and water together, because solutions are interconnected (WBCSD, 2009). Figure 3.2 provides an overview of the CC process. Changes in KSA’s climate are considered in the following section.

Figure 3.2: Summary of climate change phenomenal.

### 3.5 Climate change and Saudi Arabia

Like the challenges faced by the other nations, KSA too faces similar challenges from climate. Changes have emerged in both precipitation and temperature over time in KSA (Almazroui et al., 2012; Donat et al., 2014). Some risks to KSA specifically are clean potable water, which is being directly influenced by CC and has a negative influence on
KSA in both the use of FFs to process and supply water and on future access to water (DeNicola et al., 2015). The KSA has a low marginal abatement cost of reducing environmental impacts like pollution (Vandyck et al., 2016). Essentially, given KSA’s low cost of energy for producing goods for domestic consumption as well as for exports, it uses FFs widely (Sorrell, 2015).

The KSA faced a decreasing level of precipitation (at the rate of 6.2 mm/decade) during 1978–2009. As a result, significant portions of the country suffer from extreme heat and lack of water (Almazroui et al., 2012). The CC trends for KSA include general warming, decreased precipitation and a loss of as much as 4674 hectares of beach by 2100. Due to water scarcity in KSA, as much of what is available is non-renewable, a decreased focus on agriculture has occurred in the country but improvements in irrigation and construction of dams has increased. Farmers experience risks in developing irrigation and managing water supplies or sources, where continued heat increases or dry spells have a direct influence on their ability to maintain production (Darfaoui and Al-Assiri, 2010). In fact, an average temperature rise of 0.71ºC per decade was noted during 1978–2009 (Almazroui et al., 2012). The average of temperature rise is predicted to be in the range of 2.2–2.7ºC by 2041 as compared to the present situation (Darfaoui and Al-Assiri, 2010).

However, in recent times, KSA has experienced extreme climate events such as flooding as result of ‘heavy’ rain within a short period of time. For example, the western parts of the country experienced a significant downpour that resulted in widespread flooding in 2009. KSA’s civil defence forces reported the above event to be the most destructive floods in the past 27 years. More than 100 people died and nearly 350
people unaccounted for were deemed missing as a result of the flooding (Al-Saud, 2010). The financial losses were estimated at $240 million. A similar scenario played out again in 2011. Like the previous incident, several people were reported dead and the financial losses were comparable (Ismail-Zadeh et al., 2014).

Pugliese and Ray (2009) indicated that fewer than half of people in KSA were aware of CC or its causes as of 2008; fewer than the results from respondents throughout Arab nations. Education regarding CC has been seen as an important aspect of managing CC by organisations, including the IPCC, globally. Aljohani (2010) found that primary concerns in a population sample were employment, financial and health concerns, all seen as much greater problems than CC. This sample population indicated that the strongest knowledge and concern for the environment was found amongst persons with a high education level. Concern for employment and financial needs of respondents could have a direct influence on individuals’ willingness to consider alternative fuels or support industries that could reduce access to employment opportunities.

KSA was ranked amongst the top 50 CO2 emitters as of 2008, with one of the largest carbon footprints in the world and some of the fewest environmental policies in effect (Raouf, 2008). Awareness is a key element of achieving goals regarding carbon emissions due to the number of people in KSA who use cars, heating and FF energy sources. Furthermore, only 36% of respondents felt that the government needed to do more about CC (Darfaoui and Al-Assiri, 2010). Some resources that can improve the population’s knowledge of CC have been created by KSA, including assignment of a team to the project and creation of resources for individuals; however, this is not enough to indicate that this area is a priority. It is possible that both economic conditions and
employment security are areas requiring improvement in order to create larger contributions by individuals within the country; however, policies working towards encouraging reduction in individual carbon use would be a first step. Economics and CTs are important areas that contribute to the value of the CC initiatives that a country focuses on, specifically in motivating change at the individual level.

3.6 Long-term predictions of climate change: Evaluation over time and discounting

The long-term effects of GHG emissions on the Earth’s atmosphere have evolved into an authentic global concern about their catastrophic implications. The impact of global warming encompasses devastation to both the environment and human health and well-being. The causal contributions of modern biological trends in GHG emissions are complex due to non-climatic factors that dominate short-term, local biological variations (Parmesan and Yohe, 2003). Therefore, global movements towards environmental sustainability will require reduced emissions strategies that will have long-term, as well as immediate, positive mediating effects for all economies. Freshwater withdrawals will have increased by approximately 18% in developed nations and by approximately 50% in developing nations by 2025 (WBCSD, 2009). The long-term ecological impact of CC encompasses alterations to tropical marine, dry land and polar terrestrial environments that have been assessed with a significant degree of uncertainty. An adaptation to the projected, long-term impact of global warming equates to behavioural change and innovative methods of energy production, allocation and distribution.
Considerations of renewable energies as a solution to increasing GHG emissions are outcomes of the need to sate the need for continuous economic and social development and improve social welfare. IPCC (2011) confirmed that the provision of energy products and services has increased GHG emissions historically from 1850. The global demand for energy is projected to increase by approximately 50% towards 2030, along with significant increases in global demand for water (WBCSD, 2009). Thus, efforts to reduce the ecological footprint of industry and global energy consumption have become drivers of research into energy alternatives, namely renewable forms of energy. The primary sources of renewable energy for CC mitigation consist of bioenergy, geothermal energy, solar energy, wind and ocean energies and hydropower. Renewable energies have the capacity to generate mechanical energy, thermal energy and electricity as well as produce multipurpose fuels that may be used in urban and rural communities and central energy networks. Other options for the reduction of GHG emissions while simultaneously meeting global energy demands include renewable energy, FF switching, nuclear or carbon capture and storage (CCS) and increased overall energy efficiency and conservation best practices (IPCC, 2011).

A meta-analysis of CC’s environmental footprint utilised a methodology of investigation of functional multi-species phenology and concluded that biological trends reflect both neutral, positive and negative effects of global warming. These consisted of agricultural activities, leaf unfolding and colouring and fruit ripening as well as the sensitivity of these changes to annual temperature variations and responses. Long-term CC projections match modern biological trends; the effects of CC have already begun to affect living systems (Parmesan and Yohe, 2003). Muñoz et al. (2010) also found that the biological and physical systems exhibit the effects of global GHG emissions through
terrestrial ecosystems that display continuous outcomes of CC. Thus, the economic loss and strain upon food security is exacerbated by crop failure and deficiencies in irrigable water systems. Muñoz et al. (2010) also found that the generation of CO$_2$ by deforestation and large-scaled agricultural activities are compounded by other anthropogenic developments and correlated with the terrestrial organisms’ respiratory processes.

CO$_2$ will remain in the Earth’s atmosphere for centuries, which underlines the long-term effect of GHG emissions. Economists have established that the economic impact of CC is also a legitimate concern. Losses in ecosystem services will equate to trillions by 2050, with cumulative losses arising from avoidance of these issues. In this light, the primary drivers of the environmental threats from increasing GHG emissions have been attributed to global economic growth. However, some researchers see the remedy for these projected economic losses as continued economic growth. The environmental impact of GHG emissions occur particularly through increases in the intensity of adverse climate conditions such as tropical storms, droughts and flooding. The IPCC (2007a, 2011, 2014a) concluded that human industrial activities are an impactful contributor to increasing GHG emissions.

### 3.7 Global climate change initiatives and policies

CC initiatives are developed around energy use and development due to population and industry growth, as well as the amount of pollution or potential energy resources that can cause CC versus other potential harming factors or activities. The KP, originally adopted in Japan in 1997, came into effect in February 2005, with developments in the protocol over the last years. Mechanisms instituted by the KP are international
emissions trading, clean development mechanism and joint implementation (UNFCCC, 2015). These three areas contribute to the measurement, sharing and control of the emissions controls designed to reduce the effects of CC and contribute to global improvements of air quality.

Policies designed to manage CC also focus on non-renewable energy sources, favouring renewable sources; however, fuel consumption emissions could be further assisted by initiatives focusing on ‘technologies for gas conversion and fixation to value-added products’ (Saneepur et al., 2014). Global CC policies have resulted in disagreement and disappointment in their management, due to the results of countries being unable to maintain the requirements for reducing emissions; or suffering an inability to focus on areas that were attainable and are instead still working towards the reduction of identified emissions goals. Achieving global CC goals requires a number of different areas to be considered (Spence, 2011).

A number of international organisations are involved in CC policies and have conditions or requirements that are influenced by growing concern about global CC. The WTO’s contributions to CC policies include the Marrakesh Agreement, which focuses on the sustainability of economic conditions, specifically in linking economics and CC as practical areas of governmental long-term strategic goals to protect the future. The WTO’s influence is related to both economic conditions in a variety of different programs available globally, trade agreements and management of programs such as the Committee on Technical Barriers to Trade and Committee on Trade and the Environment (WTO, 2008). Another international entity working towards improvements in CC, with larger support and country involvement, is the UN.
3.7.1 United Nations’ framework convention on climate change and related treaties

In 1979, the World Climate Conference was the first international meeting devoted to CC. The UNFCCC works to improve global conditions regarding the environment by enabling and promoting countries to come to terms and agreements in managing current and future issues that are both being caused by and will be caused by human interactions with the environment, specifically areas of carbon footprint and global warming (UNFCCC, 2016). Since the first meeting, a number of other panels, reports, agreements and actions have been managed by the group and the countries working with the organisation. The framework established the basic framework and principles for international CC actions. Currently, the framework remains the only international climate policy with broad legitimacy partly due its global membership (IPCC, 2014a).

The main goal of the framework is stabilisation of GHG concentrations in the atmosphere at a level that would prevent anthropogenic emissions from dangerously interfering with the global climate system. In general, the framework prescribed a timeframe that is sufficient

- To allow ecosystems to adapt naturally to CC;
- To ensure that food production is not threatened; and
- To enable economic development to proceed in a sustainable manner.

The framework promoted the idea that developed nations will take the lead in cutting FF emissions with the developing nations following suit by accepting financial and technical support from developed nations. Although, no legally-binding emissions
targets were agreed for any countries in the UNFCCC framework, it was agreed that governments were obliged to

- Collect and share data and information on GHG emissions, national policies and best implemented practices;
- Launch national strategies to address GHG emissions and adapt to expected impacts, developing financial and technological support to developing countries; and
- Cooperate in preparation for mitigation measures and adaptation to the influence of climatic fluctuations (NRG4SD, 2011).

Amongst these global initiatives and policies are the KP and Paris Agreement, both of which evaluate how the distribution and use of FFs are managed in terms of success in meeting global needs for emission reductions. However, this also invites other concerns, specifically those about the relationship between green initiatives and economics. Countries with high production and international distribution of FFs, such as KSA, may have financial drawbacks resulting from such policies and a greener the world that manages carbon emissions.

### 3.7.1.1 Report of The United Nations framework convention on climate change

The UNFCCC is the original UN climate treaty, which was established in 1992. The framework sets out the basic framework and principles for international CC actions. Currently, the framework remains the only international climate policy with broad legitimacy, partly due its global membership (IPCC, 2014a). There are 197-member nations (196 states and one regional economic integration organisation). In the UNFCCC (1992) report, all parties acknowledged that changes in the Earth’s climate
and resultant adverse effects are common concerns of humankind. This report states the principles, objectives, obligations and responsibilities of nations. The report also defines the financial mechanisms and recognised bodies responsible for implementation and preparation of decisions and other related issues.

The UNFCCC’s objective is to achieve stabilisation of GHG condensation in the atmosphere at a standard that would prevent dangerous anthropogenic interference with the climate system. Atmospheric concentration levels would be achieved within appropriate period to allow the ecosystem to acclimate naturally to CC and to allow economic development to continue in a sustainable manner (UNFCCC, 2015).

This report provides guidance for implementation and achievement of UNFCCC aims and delineates requirements to protect the climate system for the advantage of present and future humankind based on equity as well as common but differentiated obligations and respective capabilities. Additionally, it prescribes an equitable and balanced financial mechanism for providing funding for the implementation of this convention including for technology transfers. For example, the transportation sector is most influenced by oil prices and poses a leading problem in managing CO₂ emissions globally. As a result of the transportation market being the most volatile actor in relationship between oil production and prices, the challenges in reducing emissions may be reliant on discovering methods to reduce emissions from oil. This report established bodies for scientific and technological advice and implementation and describes specific national priorities and objectives (UNFCCC, 1992).
3.7.1.2 Kyoto Protocol and Conference of the Parties’ key decision

The 1997 KP occurred after the Conference of the Parties (COP) and resulted in increased awareness and focus on improving the conditions perceived to be causing CC. During the first COP meeting in 1994, 13 decisions were made, including one regarding a method of reporting and developing information using scientific inquiry. Since this time, more than 100 decisions have been made, leading to programs, support for cities and local governments and the Cartagena and Nagoya Protocol.

In the first commitment period, 37 industrialised countries and the European Community were obliged to decrease their levels of GHG emissions to an average of 5% in comparison to 1990 levels. In 2012, the new amendments to the KP were adopted. From such time, the second commitment period began wherein all Parties were obliged to decrease GHG emission levels by at least 18% in comparison to 1990 levels by the year 2020 (UNFCCC, 2015).

The Protocol placed a heavier burden on developed nations under the principle of ‘common but differentiated responsibilities’, because the developed countries are principally responsible for the current high levels of GHG emissions in the atmosphere (UNFCCC, 2005). Such a burden proved challenging and left several stressing points unresolved. Sanctions on countries that failed to meet their target obligations are an important issue that was left unresolved (Anderson, 1998). Huang et al. (2008) highlighted the failure of 38 industrialised countries in meeting their goal within the specified time period and therefore emphasised that it is not enough to merely rely on efforts by scores of Annex I Parties of the Protocol to achieve the reductions in GHG emissions. Dagoumas et al. (2006) ascertained that implementation of the KP through
only domestic efforts led to significant costs for developed countries. The next stop was Copenhagen in the progression of developing a global climate policy.

3.7.1.3 Copenhagen Accord

The KP expired in 2012 and to keep the process on target, a new protocol was urgently required. The purpose of conferences was to form a comprehensive and legally-binding global treaty to replace the KP. COP representatives met in Copenhagen and agreed to recommend the continuation of the KP in 2009. The Copenhagen Accord is not legally obligating and does not commit nations to remain bound by the KP. The Accord outlined five essentials for success in reducing GHG emissions:

1. Donate to the poorest and most vulnerable countries to manage emission issues;
2. Major industrial nations must propose substantial GHG emission reductions;
3. Limit the growth of emerging economies’ GHG emissions;
4. Developing countries to engage in mitigation and adaptation activities such as finance through both short- and long-term funds; and
5. Development of a more equitable governance structure for the deployment and management of financial resources.

At Copenhagen, it was generally accepted that global temperatures should not exceed 2°C. The results of the Copenhagen Accord were not a negotiation over aims or activities, but a series of unilateral press releases that were announced by each country with further intentions and action plans to mitigate CC (Hunter, 2010). Here, for the first time, both developed and developing countries made emission-reduction pledges—reductions of 12%–18% below 1990 levels for Annex I countries and 11%–14% below baseline for the seven major non-Annex I countries (den Elzen et al., 2011).
The Copenhagen Accord stresses that for 2010–2012, the developed countries should collectively commit a sum approaching $30 billion, and by 2020 collectively provide $100 billion per year. In 2010, environment ministers from China, Brazil, South Africa and India discussed their ongoing commitments to the UNFCCC process and Copenhagen Accord. These nations agreed to submit voluntary reduction actions they would undertake. They also called for the $10 billion funding from developed countries to be released to developing nations quickly. Also, about 55 nations, including US, EU, China and India, had submitted their targets for GHG emissions reduction. As anticipated, the EU put forward a 20% cut from 1990 levels, and the US submitted a 17% cut from 2005 levels (Houser, 2010). Reducing GHG required the cooperation of global bodies, such as the IPCC.

3.7.1.4 Intergovernmental panel on climate change

The IPCC provides scientific assessment of the current condition of CC, including research and socioeconomic impacts of the CC and related conditions. The panel’s main role is to provide and continually update scientific evidence on CC. It is also tasked with elaborating on the possible environmental and socioeconomic effects that could potentially result from CC. The peculiarity of the IPCC is that it does not conduct any study nor does it monitor climate-related data or parameters. Rather, the panel reviews and assesses the most recent scientific, technical and socioeconomic information worldwide that is relevant to understanding climatic fluctuations. The IPCC receives strong support from a great number of scientists from nearly all countries. Edenhofer and Seyboth (2013) claimed that since 1988, the Panel has become a key framework for the exchange of scientific dialogue on climatic fluctuations within the scientific community and that it seems to hold some influence over politicians worldwide.
The IPCC’s work is shared between three Working Groups (WG) and each WG’s activities are administrated and coordinated by a technical support unit that provides technical, scientific and organisational support to their respective WG. IPCC’s WG-I assesses available scientific evidence and data on climate systems and CC; WG-II assesses socioeconomic and environmental impacts; and WG-III formulates the UN’s response strategies. A number of assessments and special reports have been published by these groups, which include environmental changes that may have a direct influence on people’s lives in the future.

However, in 2005, IPCC published the IPCC Special Report on CCS, which raised the issue amongst the expert community dealing with global climate policy. The scientific community now generally sees CCS as a key option for decreasing CO₂ emissions globally. In long-term scenarios, CCS plays a major role where significant reductions in GHG are achieved (Clarke et al., 2009). Moreover, decreased atmospheric CO₂ are envisaged when applied to large services/business that uses FFs. This report can be considered the most important report for FF-producing and importing countries by outlining a scenario where FFs still have a role to play. The ability to reduce warming is reliant on the global community’s ability to control GHG emissions, which would directly lead to slowing or reductions in the amount of global warming and melting of polar ice caps (IPCC, 2014a). As highlighted and subsequently discussed, integrating climate science and policy is critical.

### 3.7.2 Interaction of climate science and actual policy focus areas

The influence of CC on government policies around the world is felt most strongly in areas such as GDP and the challenges of balancing national economic needs against
future environment needs and global organisations’ international policies. Numerous countries are struggling to meet current requirements, particularly controlling emissions. The EU is challenged by non-complying member states whose emissions ceilings are too high to meet the expected mandatory emissions ceilings by 2025, and in some cases by 2030 (Maione et al., 2016a). Problems are related to costs in some areas; one example is the United Kingdom (UK), where cost estimates of implementation have been over-estimated and savings through energy efficiency are unable to meet the overall costs. Utility costs were found to have increased by 37% for electricity while NG increased by 5% (Ang et al., 2016). These were both found to be different than the predictions in reports identifying how prices would change as a result of policies, but in the most extreme cases, increases were likely difficult to manage by organisations expecting to see cost reductions as a result of efficiency.

Flaherty et al. (2016) used the Sachs model to demonstrate the relationship between green bonds as a source for investment and meeting emission control requirements. That work focused on mitigation strategies for emission trading schemes and CT policies, which are found to be increasing public debt and may still negatively influence the efficiency of energy use. Green bonds, according to Flaherty et al. (2016), can contribute to economic benefits of emissions control.

FF exporting countries are working to diversify their economies by developing other types of businesses, as per regulations in CC and sustainability, which are currently active in trade agreements or based on international organisations’ regulations. Some of these challenges are faced by carbon-based economies, where the changes that must occur are contrary to the needs of the country or conditions for economic growth.
However, other claims that the disadvantages to carbon-based economies, such as OPEC countries, are numerous unless a system for managing CC and costs associated with controlling these factors is considered in regard to these countries as well as the larger economies that support the methods of management of GHG emission controls (Abbas, 2011).

3.8  Risk and uncertainty surrounding the costs and benefits of climate change policies

A considerable degree of uncertainty in regard to the future impact of GHG emissions is inherent given the reliability of the modern computer models and simulations from which many projections have been derived. The costs and benefits of CC are relative to the assumptions made for a particular sector. Bosello et al. (2011) associated the costs of CC with the requirements of coastal protection; and associated the benefits of CC with the savings that result from an avoidance of residual and non-residual damages. IPCC (2011) associated the costs of CC with the economic expense of transition from traditional to renewable energies. The economic costs of global CC policy administration are high; and it has been projected that humanitarian-based economic assistance will be largely inaccessible to small communities in developing nations (Warner and Zakieldeen, 2012).

CC policies have evolved at a slow pace through global conferences such as the UN Conference on the Environment and Development, held in Rio de Janeiro in 1992, the 1997 KP, the 2002 World Summit on Sustainable Development and the Lima conferences from 2010. Craeynest (2010) supported that global administrators must (1) increase attention paid to potential damage and losses due to CC; (2) identify and
acknowledge that the potential financial recovery efforts require a different approach; (3) pursue country-specific data in regard to damage and loss; and (4) prioritise efforts for damage and loss mitigation for the most vulnerable in society. Critical global water management strategies must be initiated at the watershed level and should be characterised by economically efficient trajectories of allocation and distribution (WBCSD, 2009).

Global society may become empowered in regard to the future effects of CC by a more robust consideration of behaviours that negatively impact the environment and creation of supportive environments for societal decision-making (Adger et al., 2009). The global ecological footprint from CO₂ emissions has become significantly higher due to per capita CO₂ emissions from highly industrialised nations such as the US, China and the EU. Furthermore, best practices for CC mitigation should consist of innovative solutions from private businesses and governments that are integrated with the promotion of community engagement (WBCSD, 2009).

3.9 Effects of the carbon-mitigation policies on the fossil fuel industry

Climate policies have a direct influence on the losses suffered by the EU due to rising FF prices, specifically in a 2.2% drop in GDP without a climate policy where 1% of GDP is applied to climate policy costs and 1.5% GDP to oil price rises. The influence on trade resulting from rising FF prices was found to be 5.7% by 2030, which is expected to only decrease EU exports by 1% with higher reductions in the US and China (Maisonnave et al., 2012). Some of expectations regarding future consumption of FFs are a direct result of voluntary use of green energy programs such as those
providing electricity, which have found varying interest and willingness in populations around the globe (Oliver et al., 2011; Zhang and Wu, 2012; Zorić and Hrovatin, 2012).

The cost of FFs versus green technologies are of considerable importance to many economies, resulting from both the costs to implement these technologies and costs of using FFs under current policies regulating emissions. CO₂ emission policies have recently become more lax in order to enable countries to achieve future goals at a pace reasonable to their ability to be successful. Bauer et al. (2015) indicated that CC policies are formed based on both idealised and non-idealised stabilisation ideas, which result in either the inability to meet requirements that reflect global needs, or the inability to meet policy requirements. These types of actions result in both short-term target misses and carbon leakage from too-rapid movements (Saeed and Tularam, 2017). Similarly, Suranovic (2013) compared CC reductions to cigarette addiction, as in terms of an inability to take concrete and meaningful action when only limited damage occurs in the present. This problem is highlighted by demonstrating the difficulty of understanding how the depletion of FFs and CC have been reported as occurring at different rates or levels based on different researchers over the past decades (Höök and Tang, 2013).

Bigerna et al. (2016) analysed the EU’s CC policy, in a study focused on the instruments primarily being used for the Renewable Energy Directive (2009/28/EC) and promotion of renewable energy, which seeks to attain 20% renewable energy consumption by 2020. This plan focused on adoption of renewable energy, such as biofuels and goals for heating and cooling in the country. Targets within the framework were estimated to cost as much as €90 billion each year, but no lower than €73 billion. The simulation model used in Bigerna et al. (2016) was developed to use the data
gathered from official EU documents and found that the challenges caused by the EU’s goals are imposing difficulties on all states. The costs arising from EU members failing to contribute and from failure to achieve these goals can increase the costs to member states working towards or succeeding in the goals. These additional costs can greatly influence the true costs of EU implementation of CC policies.

Countries around the world must change the sources of energy that power both industries and citizens. These changes require development of a number of projects, including those focused on implementing renewable-energy sources, national policies for industry management of emissions and green initiatives, such as rewards, when goals are achieved. Challenges facing all countries range from the costs of implementation through to the challenges posed by requiring industries to undertake changes without risking increased unemployment rates due to business performances being undermined by the new policies and regulations. An industry amongst those most influenced by CC policies is the manufacturing industry. Ang et al. (2016) reported that UK businesses will see their costs increase by 0.4% by 2020 following the implementation of CC policies. In contrast, Tvinnereim and Ivarsflaten (2016) indicated that CC policies could potentially stimulate new employment opportunities and that many Norwegian organisations were in support of the changes, with the exception of the oil and NG sector.

Researchers are also focused on the methods through which organisations can implement CO₂ emission reductions in their operations through actions specifically designed to adapt to changing regulations. Betancourt-Torcat et al. (2012) developed a complete plan for reducing CO₂ emissions for Canada Oil Sands, offering reduction of
38%, which would comply with federal government requirements and meet targets; however, the design did not include costs other than to suggest that these would not increase energy costs. Costs are the largest area of confusion for organisations and consumers, whose choices for energy continue to increase but the clarity regarding which options are best are not described beyond the costs they see upon purchase or intent to purchase.

### 3.10 Climate change viewed by economists

Economics play a significant role in analyses of and studies on CC from the early 1990s, at the very start of UN process. There have been three critical reviews about the effect of CC on the world economy. First, Lomborg (2001b) suggested that a better use of resources and money would be to decrease poverty and rapidly develop third-world nations. The economist claimed that the cost of reducing global GHG emissions is high, and persons living in developing nations suffer most from the effects of CC.

Second, Stern (2006) discussed the effects of CC and global warming on the world economy. That review opined that CC threatens to become the greatest human failure ever seen and suggested environmental taxes as well as other policies to minimise economic and social disruptions. Stern emphasised the economic impact of CC as well as the budgets and benefits of taking action to resolve CC from a global perspective. Definitely, CC has global roots and effects, and global cooperative action is important in addressing the issue effectively, quickly, efficiently and equitably. The review examined the evidence on the economic influences on CC and discussed the budgets for decreasing GHG in the atmosphere. Stern also measured the complex policy challenges involved in dealing with the global shift to a low-carbon economy.
The Stern suggested that all nations need to donate 1% of their GDP to stop GHG from increasing into the Earth's atmosphere to risky levels. Failure to take such action could lead to spending much more, which Stern estimates to start from 5% and exceed 20% of global GDP. This view has been criticised by a number of economists for being excessively optimistic about the budget needed to adopt low-carbon energy sources. Moreover, critics stated that the figures for GHG emissions used by the IPCC (2007b) are too low and the costs of reducing these numbers should be much higher (Maslin, 2014). In 2008, Stern revised his projected costs up to 2% of GDP because global warming is progressing faster than anticipated.

Third, Garnaut (2008) started to point out that human activity has led to increases in GHG emissions, creating a high possibility that dangerous CCs will occur in the next 50–100 years. The review indicated that developing countries are becoming major contributors to global GHG emissions increases, and without mitigation, these sources will account for around 90% of emissions rises in the near future. The review concluded that the chaos and collapse that will follow extreme CC would destabilise nearly every aspect of modern life. Garnaut expressed optimism that the Copenhagen (2009) meeting would be a vital step in achieving global aims on reduction emissions. The review stresses that trade in emission rights would be much better as a trade in offset credits, which must be restricted, and a CT is preferable to a heavily agreed ETS.

Additionally, economists have evaluated the relationship between CC and the costs to organisations in terms of energy management and efficiency (Lin et al., 2011; Bigerna et al., 2016). Managing costs to transfer from FFs energy sources to renewable or alternative-energy sources can be costly for organisations. Some research indicates that
the risks from failing to move to new energy sources will be costly over time, with researchers indicating that the costs may be unmanageable for all organisations and influence organisations’ efficiency or effectiveness of in meeting goals (Aloui et al., 2014; Zhang et al., 2014). Organisations must assess their contributions to the global issues resulting in CC, and these are often estimated or managed based on results found in reports developed by non-profit organisations at both local and global levels.

Accordingly, economists and politicians have taken the danger of CC extremely seriously since the late 1990s, which has led to validation of CC and the threat of global warming. Economists marked and discussed a turning point in nations’ opinions that CC is in fact a real risk. If economists are anxious about the cost of CC, the risk must be real (Maslin, 2014). The growing recognition of the need for governments and industries to act immediately to significantly decrease global GHG emissions led to many books, research and policies to address this concern.

### 3.11 Institutional reports on climate change

The potential impact of CC mitigation policies on global economic conditions and the management of FFs have been studied by a number of scholars, with their findings published as reports found in journals and academia. The current changes in policies provide opportunities for organisations and countries to create industries, income, or efficiency that will drive future economies (Klasinc, 2015; Maione et al., 2016b). Numerous non-profits organisations have emerged to seek out research and projects using both private and public funding and resources to examine on current conditions associated with both economic and environmental policies and the future in these two areas.
The global responses from business to CC is assessed by the Carbon Trust company, who reported in 2006 that work is being undertaken to accelerate the move towards a low-carbon economy. The Carbon Trust studied the growth of CC mitigation strategies utilised by global firms. The object was to recognise successful business climate strategies and policies that show awareness to market components related to CC. The research found that multinational corporations’ actions in dropping GHG emissions are more aimed at achieving sustained competitive benefits and compliance with government regulations for environment (NAO, 2007). Buurgaard et al. (2006) provided a framework for commercial banks to decrease CO\textsubscript{2} emissions produced by their clients’ investments. They concluded that commercial banks now are progressing with their aims to lower CO\textsubscript{2} emissions and have developed useful and comprehensive CC policies.

Coalition for Environmentally Responsible Economies (2003) examined how the corporate emitters of GHG are incorporating CC into their governance practices and business strategies. Their report indicated that effective business responses to CC should be built on a well-functioning foundation of governance practices and environmental management systems. However, only a number of companies have adopted inclusive plans to treat the problem as an environmental threat and financial issue. The report identified several steps firms can take to decrease financial losses and GHG emissions. RepuTex (2007) examined the relative influence of carbon risk on companies’ values in the context of macro and micro economic analyses on Australia. The report indicated that corporations do not adequately act to mitigate carbon capitalise or liabilities on potential incomes and that the relationship between share-price performance and carbon value is starting to strengthen.
Moreover, McGeachie et al. (2005) reported on a survey of securities analysts, finding that most analysts surveyed confirmed that information on the environment cannot be quantified and only in some cases can specific environmental criteria be quantified. A precise discounting or valuation of environmental problems could be difficult to calculate because of constantly changing rules. Environmental effects often undergo a qualitative analysis, which is harder to include in assessment processes. In addition, qualitative analysis is useful and necessary in the stock selection process. Environmental effects can be considered using quantitative analysis, but only after deciding how environmental criteria might affect stocks.

Considering the amount of research that has focused on environmental information and performance as well as share-price responses, there seems to be limited research that has analysed the direct relationship between stock prices and environmental information in the context of the FF sector. Innovest Strategic Value Advisors (2006) explored FF firms and found that financial analysts for the FF industry feel that environmental problems tend to be irrelevant over short-period investment horizons. From their point of view, limited substantial differences exist between FFs firms regarding environmental information and performance, and consequently, there is a reason to conduct in-depth comparisons and analyses.

The European Microfinance Platform published report to teach microfinance companies how to measure their carbon footprint using a new index (e-MFP, 2014). The report discussed the US demonstrating CC influences, beginning with using numbers from the 1960s to indicate areas of analysts that included temperature. This report is designed to increase the number of organisations and individuals working to achieve a reduction in
carbon footprint, in order to preserve areas that are current being hurt by CC, including western areas suffering from wildfires and southern states facing flooding and challenging climate changes (Melillo et al., 2014).

Shared information between organisations has resulted in a number of resources being similar or containing similar information. For example, country-, region- and city-specific information is shared amongst agencies on global and local levels. These reports are primarily designed to provide guidance and support as countries and regions work towards developing policies and regulations to mitigate environmental changes. CC reports evaluate the information gathered over time, including from weather, rainfall, emissions, use of energy sources and other data that can be directly linked to or result from CC. Many of these areas are indicative of a country’s ability or need to meet the requirements of policies and agreements being or having been developed in order to meet GHG and carbon emissions reduction needs. Global changes resulting from CC are expected to influence each country, even in the case where the changes appear to be primarily influencing climate patterns in single countries.

3.12 The green economy and climate change policy

Use of FFs based on their subsequent content of carbon, or CTs on emissions, has historically been a commonly used tool for economists to develop climate policies. Over time, atmospheric harm from CO₂ emissions slowly increases, as must the subsequent tax increase. The theoretical argument by Sinn (2012) spawned quite a controversy by illustrating that rather than reducing emissions, any tax or policy that tries to dampen FF demand will in fact increase emission releases while simultaneously having no change on cumulative emissions. Essentially, the contention is that as producers become
conscious that future demand for energy will dwindle, they will begin boosting output of FFs, which includes emissions, before new climate policies can negatively impact their investments.

Further, Sinn (2012) proposed that the reaction of producers in supply production may be the reason for reduced fuel prices between 1980–2000, corresponding to the ‘green’ undertaking as well as energy policies that restricted demand. Sinn also stated that there is still no pragmatic indication that this theory is responsible for dropping prices. The concept is more a speculation based on theory that directly applied Hotelling’s rule. Although the theoretical results have strength as an idea, they are weak when used as a policy guide. Even with practical policy guidance, historical trends are used as explanations. Specifically, adjustments to the concept or model that add realism can certainly offset motivations for producers to increase production of FF. For example, studies have illustrated that if a greener backstop technology is comparatively inexpensive, then sponsoring the backstop will lead to less CC (van der Ploeg and Withagen, 2012). Considering that new FF production necessitates a significant venture in expenditures for exploration and development, FF companies will begin limiting these costs in light of reduced prices, which is actually the reverse effect of Sinn theory (Cairns, 2014).

Aside from the theoretical application, Sinn (2012) is also beneficial in identifying market prices and production strategies for oil refineries in addition to their supply behaviours. Wei et al. (2012) reviewed methods that fuel-producing economies employ to offset climate policies. They found that though fuel consumption taxes lower climate damage, OPEC could respond by funding oil and raising domestic use, as they are quite
conscious of the stakes. Countries that export energy have already applied for compensation based on research that highlights situations in which they will experience losses from carbon-reducing policies. The markets for unconventional and synthetic oils will be disproportionally impacted. The possibility that consumption of FFs will be restricted creates a powerful incentive for FF producers to sell more before the limitations come into effect. This reason might be behind KSA’s reaction to plummeting oil prices. The result is a further fall in FF prices and stronger incentives for consumers to buy FF.

A number of researchers developed an innovative tool to measure green measures based on the concept of environmental performance in microfinance and to expand upon the use of these concepts into other areas which were measurable and thereby identified key performance indicators. Use of their tool allows for evaluation of environmental performance, comparisons between competitors, strategy evaluations, examination of performance over time and reporting of performance in a way that they can communicate value to stakeholders (Allet and e-MFP, 2014).

Venkatesh (2014) evaluated the environmental performance of 30 European cities in terms of adequacy, appropriateness, acknowledgement of interlinkages and awareness of conflicts and synergies with non-environmental goals. Results indicated that a number of conditions occur that have a direct influence on cities’ ability to implement policies that are effective, including costs of alternatives and stability of the city’s economic conditions. Venkatesh concluded that the 30 European cities do have a foundation for building sustainability, a driving strategy and encouraging growth in green measures, but only as a one of the strategic tools guiding growth and change.
The ecological footprint of a country is used to provide guidance in managing the country’s emissions and other CC factors. Chen et al. (2011) developed the energy analysis model to study the sustainability growth of Taiwan; energy from both renewable and non-renewable resources was considered. This methodology evaluated and utilised green economy indicators such as the pressure-state-response, environmental performance index and the green statistics pocketbook (Chen et al., 2011). Each of these variances are developed by separate entities and strongly rely on information provided from within their country or international organisations, which indicate some or most of the factors used to determine the final scores.

Global value chains are the focus of a number of different organisations and economies working to meeting CC policy requirements, either at the global or state level. Research amongst industries was studied by Klasnic (2015), using value added created by exports to determine if a relationship existed between domestic value added and investments in the green economy. The results indicated that investments attracted more ‘foreign direct investment’ and had higher levels of ‘knowledge-based economy’. The data envelopment analysis model is used for energy and environmental modelling, specifically as a non-parametric method, whereas the green GDP index evaluates energy consumption, environmental pollution and GDP of the area, which enables a model to consider the impact of growth on an area and management of green initiatives (Lin et al., 2011). Assessing the economy for a specific area can be used to identify pollution and consumption issues occurring in that specific location. Green score measurements exist for identifying how well nations are able to utilise green policies and manage environmental policies.
3.13 Fossil fuel prices shocks and greening polices

Price shocks occur as a result of sudden increases in prices that are unexpected or result from unexpected circumstances. Therefore, FF price shocks can occur from the greenish of the world by increasing CC policies. Bennett (2012) reported the argument from the Energy Secretary that CC policies may have a direct ability to reduce the negative aspects of price shocks in FF prices, as of 2050, in the UK. However, green energy price shocks also occur, as reported by Brooks (2016) and as have occurred in Canada, specifically Ontario, resulting from costs of electricity, specifically wind generators and global adjustment taxes. Downturns in some areas can indicate risks of price shocks in other areas, which must be measured and evaluated as having interactions amongst types of energy resources, whether green or FFs.

Many consumers are subject to a large range in prices over time but causation or causality concerning global CC policies, initiatives, or environmental changes, such as seasonal temperature changes, have not been well-researched. Mann (2012) indicated that price spikes in FF have negative influences on consumers, which could be reduced by integrating energy efficiency through low-carbon forms of electricity. While alternative-energy sources can cost consumers in terms of equipment or integration, this is also true of organisations and energy resources such as electricity. Considering the report by Brooks (2016), price shocks may not be exclusive to this market, indicating the need for further research and evaluation of different types of shocks, their causes and their relationship with CC.
One problem with price shocks occurs as a result of increased costs to consumers when access to alternatives is either too expensive or impossible for consumers to manage. For example, household heating can be costly in terms of exchanging one type of fuel for another. In some cases, a house heated by NG or coal may be able to use small electric heaters; however, the initial cost of purchasing these heaters may not be affordable. Additionally, price shocks in green energy can discourage consumers from making large investments to switch, particularly in the case of commodity price shocks that are harmful to household incomes (Vielle and Viguier, 2007).

Price shocks challenge the economy and are perceived as having the ability to hold a nation captive economically (Mann, 2012). While Vielle and Viguier (2007) predicted that the price shocks in oil would result in stronger consumer willingness to move to alternatives, Bauer et al. (2016) suggested that the lack of coal use would cause reduction in coal costs. Reduced costs are one of the areas that increase interest in moving to other fuel sources. Costs of implementation may be offset if costs of the alternative fuel source are low enough to invite consumers to switch. Some countries may see less evidence of this, having had consumers widely discard some fuel sources, such as coal, in favour of sources such as NG.

Coal-fired electricity plants are being discontinued, or are scheduled to be discontinued, by numerous countries, including Canada (Brooks, 2016). The role that the government has in climate policies and oil price shocks occurs as a result of policies that reduce the need for oil as well as policies that increase CC requirements around the country. Solaymani et al. (2015) demonstrated that climate policies and oil price shocks could directly influence the economic conditions in Malaysia resulting from use of other
energy sources. This is a leading cause of interest in CC policies, such as in the UK, in reducing dependency and economic influences of price shocks in FFs (Bennett, 2012; Mann, 2012).

China is an example of a coal-focused country that has economic growth and productivity in the early 2000s and massively increased coal use throughout the country; however, in 2012, China made movements to decrease emissions and energy-intensive activities (Garnaut, 2014). While CC is a global concern, high-growth countries, or countries expected to have large growth over time, contribute to energy usage at faster rates than slower-growing countries; particularly in terms of increased emissions and decreased ability to control energy use. Introduction of alternatives is a critical measure where growth is largest.

### 3.14 Review of methodology used in studies

Researchers have applied a range of methods, measurements, processes and variables in the environmental, FF and CC areas. This section of the review presents and summarises the empirical methodologies and variables used and classifies the most suitable methods for the present research to achieve its aims and objectives. This review states the variables that have been empirically examined to expose those that are hypothesised as determinants of CC, financial performance and price relevance. This finding will lead to an evaluation of the relationship between changes in FF prices that correspond to changes in CC policies.

Approaches vary in their weaknesses, strengths and ability to measure qualitative and quantitative evidence. This section shows the need for existing approaches to be
evaluated and adapted, and reorganised to better gather and examine data. Qualitative and quantitative methods ranging from methods that are largely qualitative and interpretive to methods that are largely quantitative and integrated are noted in the literature. This review assists in identifying an effective methodology and direction for the present study.

3.14.1 Fossil fuel prices modelling and analysis

Modern civilisation is built on FF, which appear to be crucial to our continued economic growth and lifestyle. This dependency has persisted in contemporary economies, most of which depend on FF energy, and has spurred research on FF use and its advantages to various economies or sectors. These studies utilise varied statistical modelling techniques to highlight the fluctuations and relationships in the energy industry. Ediger and Akar (2007) used the autoregressive integrated moving average (ARIMA) and seasonal ARIMA methods to investigate future primary energy demand. They stated that the results of ARIMA forecasting appear to be reliable and that FF will continue to play a major role as a future source of energy. Additionally, within the FF industry, oil—the leading fuel—will be replaced by NG, making energy systems more dependent on NG than on other fuels. Tularam and Saeed (2016), who used the ARIMA, exponential smoothing and Holt-Winters models to determine that, of the three models, ARIMA provided the best overall results when applied to forecasting in the oil market. Model robustness is key to policymakers’ ability to make critical decisions in managing emission controls and pricing strategies in oil markets.

Streeter and Tomek (1992) presented an integrated method for volatility designed to simulate the effect of Autoregressive Conditional Heteroskedasticity (ARCH). Their
model included seasonal trend and lagged dependent variables, which revealed seasonal volatility trends. Futures returns and non-normality in stocks could refer to the presence of heteroskedasticity. Susmel and Thompson (1997) applied switching to an ARCH model to examine the effect of regulatory change and storage capacity on the volatility of NG futures. Their modified model outperformed the standard generalised ARCH (GARCH) model by explicitly accounting for changes in NG markets. The main criticism of the model is that GARCH is unable to fully account for any observed excess kurtosis. However, modifying this model could solve the problem.

Michieka (2013) highlighted the relationship between (1) real GDP, the urban population, electricity production and coal consumption, and (2) forecasted coal production for China’s coal-producing regions using ARIMA and GARCH. The empirical results from that study revealed that growth in real GDP, the urban population, electricity production and exports are areas that bear the greatest responsibility for the consumption of coal along with the amount consumed in the future. Moreover, the projected path that coal production is set to take is analysed in each coal-producing country. A GARCH model or process is used in financial time series measurements to determine or understand the precise relationships among the areas of management risk, portfolio selection and asset pricing. Sariannidis et al. (2009) used a GARCH model to investigate the effects of capital, energy market returns and the $/¥ exchange rate on sugar futures and found that higher oil and ethanol prices positively affected the sugar market, whereas $/¥ negatively influenced the sugar market.
Day and Lewis (1993) used the GARCH and exponential GARCH (EGARCH) methods to model oil volatility during 1986–1991. They found that both methods implied volatility and both models’ conditional volatilities contributed information on their incremental instability. Fabini (2012) estimated the conditional variance and covariance of the returns using the GARCH, EGARCH and threshold GARCH (TGARCH) models. The models implied a robust persistence in the volatility method of NG returns. This volatility was found to be more responsive to unexpected negative returns than positive ones. Hasan et al. (2013) estimated TGARCH and fractionally integrated GARCH by showing that coal fluctuation returns exhibit a strong mean reversion, whereas oil and NG volatility returns endured shocks for comparatively longer periods. Their results also confirmed that fluctuations in oil and NG increase after positive price shocks.

Giovannini et al. (2006) examined stock price returns and their financial risk factors for integrated oil corporations using the multivariate GARCH and Vector Autoregressive (VAR) methods. They found that market index variables spread within oil prices are endogenous for oil corporations. The oil price shock that occurred within the industry (1970–2015) showed that drastic changes in global oil prices resulted in increased GDP for related countries in the long run using VAR model analysis (Algahtani, 2016). A VAR model that evaluates the relationship between global oil prices and the manufacturing sector in KSA found no such relationship (Mahboub and Ahmad, 2016). KSA has not been the subject of as much research as other countries have, and the limited access to research on this country directly influences the ability of policies and CC to be effective given the large quantities of FFs made available by KSA.
Indications from a VAR examination of the relationship between prices and output in the Turkish market showed that oil price increases were not a significant influence on the manufacturing sector (Alper and Torul, 2009). Ji et al. (2014) showed that both global economic activity and oil prices have positive and significant long-term effects on regional NG import prices, whereas global oil price volatility has a negative impact on regional NG import prices. Additionally, Lee and Chang (2005) applied a Granger Causality Analyses (GCA) to report a unidirectional causality relationship between oil and NG consumption and GDP and between GDP and coal consumption in Taiwan.

Nazlioglu et al. (2015) examined the existence of volatility between oil prices and financial stress by applying Granger causality methods using a VAR system. The result of their study showed the direct effect of oil shocks and financial stress on the economy, as well as the indirect effect on the economy through the energy and financial markets. Masih et al. (2010) adopted a VAR model and found that NG prices became the main driver of methanol prices in the US, EU and Far East. Chae et al. (2012) examined the Granger causality between liquefied natural gas (LNG) fuel and electricity prices. Their research determined that a unidirectional causal relationship between LNG fuel and electricity prices existed in both the short and the long run. Maxwell and Zhu (2011) examined the dynamics of NG prices and LNG transportation cost innovations on US LNG imports using Impulse Response Analyses (IRA), Variance Decomposition Analyses (VDA) and GCA. The findings from Maxwell and Zhu included the inability of the US to maintain production of dry gas at sufficient rates to prevent the need to import NG from other countries.
Henry (1983) analysed the deregulation of NG prices and its effect on the US by using a Leontief price model. He stated that the NG price for 1,000 cubic feet increased to $6, resulting in a 5.5% reduction in companies’ profits; an increase up to $8 results in an 11.4% reduction in profits. Linn and Zhu (2004) examined NG volatility and showed that price volatility is considerably greater around the time of the release of the NG storage report. Haushalter (2001) studied the risk management activities of oil and NG producers and stated that managers’ hedge to decrease the likelihood of financial distress, indicating that business hedging could increase shareholder value.

A number of models were employed by Ghorbel and Boujelbene (2013) to test volatility, such as its persistence in oil returns and stock markets of the US, the Gulf Corporation Council (GCC), Brazil, Russia, India and China. Their results demonstrated a high degree of fluctuation persistence in oil returns and stock markets. However, this finding does not agree with the results of Gorton and Rouwenhorst (2006), who stated that commodities returns are less volatile than stock market returns because the pairwise correlations between returns on contracts for various commodities such as oil have traditionally been relatively low.

**3.14.2 Quantitative approaches to climate change**

Scientific researchers on CC have proposed a diversity of methodologies to employ to assist in explaining and measuring the effects of CC. The type of models and variables selected for use depends on the area of impact. A number of models have been used to create climate scenarios for impact assessment by identifying potential ‘worst’ and ‘best’ case impact scenarios or ‘high’ or ‘low’ projections of CC impacts. Dynamic downscaling and nested modelling methods are applied to simulate CC.
Variables such as CO₂, temperature and precipitation are highly interactive, indicating that a change in one variable influences the other variables. Therefore, mixing variables from different models in a single scenario may result in invalid outcomes. Inconsistent variables can provide a spurious estimation of future impacts.

ARIMA was implemented by Prananda et al. (2015) to determine the relationship between industrial and transportation sector growth and CO₂ emissions. Their result indicated the need for more policies to reduce CO₂ emissions, conversion of FF into renewable energy and implementation of a transportation policy to reduce the number of vehicles that use FF. Hassani et al. (2015) selected ARIMA as one of 12 parametric and non-parametric univariate and multivariate models to use to examine global temperature anomalies and CO₂ to determine a robust and successful future research model. They found that global temperatures could be predicted by CO₂ levels regarding both increases and decreases in these temperatures. Kaushik and Singh (2008) described the ARIMA approach for predicting temperature and precipitation on monthly scales. The results showed that the seasonal ARIMA model provides reliable and satisfactory predictions for temperature and precipitation parameters.

The study by Shirvani et al. (2015) was driven by two main concerns: 1) prediction of anomalies in the Persian Gulf Sea surface temperature using the ARIMA model and 2) detection of the CC signatures in the considered sea surface temperature data. They showed that Persian Gulf temperatures have warmed by approximately 0.57°C during 1950–2010, which is noted as a significant upward trend. Sea surface temperature also experienced significant steady warming during the last six decades.
Yusofa et al. (2013) showed that daily rainfall series are affected by the nonlinear characteristics of the variance frequently referred to as variance volatility or clustering, in which small changes frequently follow small changes and large changes frequently follow large changes. In this study, hybrid ARIMA-GARCH models were developed to take into account both the serial dependence and the volatility in the daily rainfall series. Taylor and Buizza (2004) compared both point and density forecasts from the GARCH model by addressing seasonality issues for winter and summer. They concluded that strong potential exists for using ensemble predictions in temperature density forecasting.

Research such as that conducted by Gaoyang (2010) studied the dynamics of CO$_2$ emission price allowance spots in the EU ETS using the GARCH, EGARCH, TGARCH and the power ARCH (PARCH) models. The empirical analysis comprised both fit-performance and parameters-stability-performance evaluations for the alternative models and found that TGARCH best fits performance. Hyndman and Wand (1997) found that the autocorrelation in Australian daily maximum temperatures (time series) varies throughout the year regarding AR-GARCH modelling, possibly indicating the need for inclusion of time-varying parameters. The main aim of the research of Javari (2017) was to detect linear and nonlinear variability modelling when analysing the variability patterns of rainfall series using the ARCH family (GARCH, EGARCH and TGRACH models). The result showed that GARCH (1,1) provides a quantitative analytical method to distinguish between a particular random and non-random model for rainfall variability.
Sun and Wang (1996) used a VAR model with different orders to study the lead and lag relationship of the changes in global CO₂ emission and temperature. They found that the increases in global CO₂ emissions cause climate warming and that global temperature changes lag behind changes in global CO₂ emissions. Kaufmann and Stern (1997) used a VAR(4) model to examine the causal link between the Northern and Southern Hemisphere temperatures (1865–1994) using the GCA. They stated that temperature anomalies for the Northern and Southern Hemispheres are trend-stationary. The researchers used the standard F-test and found that Southern Hemisphere temperatures ‘Granger cause’ Northern Hemisphere temperatures.

A study on the cause and effect relationship of the Northern Hemisphere air surface temperature and the solar cycle length by Reichel et al. (2001) showed that a cause and effect ordering exists between the two variables. Using the GCA and data on the 20th century, the researchers demonstrated that solar forcing (which they parametrised by the solar cycle length) causes temperature variations in the Northern Hemisphere.

Elsner (2006) tested two hypotheses on hurricanes using the GCA. The first hypothesis stated that changes in radiative forcing resulting from increased GHG build-up in the atmosphere increase global temperatures and cause sea surface temperatures to increase, at least from August to October. The second hypothesis asserted that natural changes in the ocean’s deep-water circulation drive hurricane season sea surface temperatures, resulting in changes to both hurricane activity and global temperatures. The test for causality showed that the global temperature is useful in predicting the sea surface temperature, but not the other way around. Thus, the global temperature Granger causes
the sea surface temperature, providing additional evidence that supports the first hypothesis.

3.14.3 Fossil fuel markets and climate change variables in scientific research

Much study interest has focused on the relationship between FF price/production and CC variables, and on the casual impact of the climate on security returns. Nick and Thoenes (2014) used a VAR framework to analyse the determinants of the NG price. Their results showed that the NG price is affected by temperature, supply and storage shortfalls in the short term, whereas long-term development is closely tied to oil and coal prices. Wang and McPhail (2014) evaluated the impact of energy price shocks on US agricultural productivity growth and commodity prices by developing a structural VAR model. Their results indicated that an energy price shock has a negative impact on productivity growth in the short run, according to IRA.

Orlov (2015) analysed the optimal point for NG prices in Russia and stated that the increase in NG led to an increase in domestic NG prices that drove a reduction in CO₂ emissions. In turn, Busch and Gimon (2014) emphasised that further decreasing NG prices resulted in substitution by coal and that the climate will deteriorate because of GHG emissions.

Höök and Tang (2013) indicated that the current set of CO₂ emission scenarios used by the IPCC and other groups is perforated by optimistic expectations of future FF production that were found to be improbable or unrealistic. In fact, these scenarios may even mislead politicians into making decisions that mitigate one problem but worsen another. It is important to understand that the fossil energy problem and the
anthropogenic CC problem are tightly connected and need to be treated as two interwoven challenges that necessitate a holistic solution (Höök and Tang, 2013).

Peak oil and its relationship with CC policies were investigated by Verbruggen and Al Marchohi (2010), whose results showed that higher oil prices lead to energy efficiency and the use of renewable sources of energy, which consequently diminish the effects on the climate.

Vielle and Viguier (2007) indicted that one might be tempted to consider high oil prices as good news for the environment, specifically to achieve the objective of reducing GHG emissions. They stated that CC organisations lead us to think that oil prices must remain high to address CC and to mitigate GHG emissions. Vielle and Viguier presented four major objections to this argument. First, the influence of high oil prices on GHG emissions may be far lower than expected because of fuel substitution effects (oil and gas to coal). Second, GHG emissions reductions obtained from higher oil prices may be inequitably distributed across sectors and regions. Third, the international welfare cost of GHG emissions reductions may be very high compared with the cost of the same reduction obtained from an efficient climate policy (i.e., a CT or ETS). Fourth, welfare costs may be unequally distributed across regions and a high burden may be placed on oil-dependent developing nations.

Salahuddin and Gow (2014) examined the relationship between economic growth, energy consumption and CO₂ emissions by calculating and analysing the trends in the inequality of CO₂ emissions in GCC countries. They found a significant association between 1) economic growth and energy consumption; and 2) energy consumption and
CO\textsubscript{2} emissions in both the short and long run. No significant connection was found between economic growth and CO\textsubscript{2} emissions. However, energy consumption and CO\textsubscript{2} emissions Granger cause each other, whereas a unidirectional causal relationship was found between economic growth and energy consumption.

Research specifically targeting the relationship among economics, global temperatures and CO\textsubscript{2} included indications that GDP directly influences a country’s willingness or ability to engage in energy savings or emissions reduction methods that address either CC or steadily declining FF resources (Wagner et al., 2016). However, research also indicated that new FF sources could further complicate the issues of global temperature and the goals assigned by international CC initiatives (McGlade and Ekins, 2015). Reserve estimates are challenged in terms of predicting the ability of either currently known FF supplies to support an unknown future population or alternative energy sources to be implemented at a sufficient scale to reduce the need for FFs before depletion. Additionally, the relationship between FFs and temperature is the direct result of CO\textsubscript{2} emissions, and not all of the CO\textsubscript{2} entering the atmosphere is the result of FF emissions.

Zhang et al. (2014) examined the promotional effect of rising oil prices on companies’ behaviour towards CO\textsubscript{2} reductions. They found that the promotional impact of rising oil prices on companies’ carbon reduction behaviour was uncertain and suggested establishing CC regulations and laws that fully consider different initial conditions in each industry for a better environment and economics. In addition, Kim (2014) studied the consequence of oil endowment on technology innovation designs in the transportation sector. The author found that nations with larger oil endowments have
less innovation in alternative technologies. Conversely, higher gasoline prices positively impact energy efficiency and alternative technologies, a finding that highlights the importance of and challenges to designing CC policy agreements.

### 3.15 Summary and literature gaps

The growing recognition of the need for vital reduction in global GHG emissions has led to a range of government, world organisation and industry policies and government regulations, along with an array of publications on FF, CC and these regulatory methods. A number of reports and scientific papers have examined the potential impacts of CC and mitigation policies, with some emphasis on the significant risk implications for many areas of the economy. Much academic attention has emphasised that the need to better understand FFs and their relationship to economic and climate conditions has become more critical and necessary for both the development of effective policies and to prevent irreversible CC. A number of studies have investigated the FF industry and CC; however, the roles of KSA’s FF or the effect of global CC policies on the country have been less examined.

The IPCC evaluated the available technical, scientific and socioeconomic publications on CC. The IPCC’s key reports, published in 1990, 1996, 2007 and 2014, have had a crucial influence on the outcome of the KP and the other UN conference on CC. A landmark internationally known publication by economists that has had profound effects on the CC debate is the Garnaut CC Review (2008), which discuss the effects of CC on national economies. Although some reports have been criticised for underestimating the prices of a low CO₂ adapting economy, thereby sending seismic waves around the world.
CC policies are researched in areas where consumption is larger than expected or occurs at larger rates than should occur based on policies and international standards. In other research, concerns are focused around areas of sustainability and risks of developing policies that could negatively influence the global economy. KSA, as indicated by Hossein et al. (2012), could be negatively influenced by strong energy consumption policies and standards if a relationship links consumption of oil with economic growth. The WTO established specific policies in regard to numerous areas of energy consumption, renewable energy and a global-scale focus on reducing consumption of FF and slowing of CC (Cottier, 2014). These laws or policies are designed to protect and encourage the changes necessary for countries to remain compliant and focused on reaching energy goals. However, CC policies are not as widely researched in terms of their effectiveness or support for reducing CO₂ by restriction the use of FF by researcher. A research gap exists in how policies and these structures are supporting countries in a way that increases success and contributes to improvements in the environment.

Since 2000, research regarding relationships between fuel, energy sources and CC policies has focused on areas such as competitiveness, relationships between developing economies and CC policies, impacts on the transportation industry and other areas that do not directly evaluate the relationship between FF prices and CC (Yudken and Bassi, 2009; Wold et al., 2013; Kevin and Wesley, 2015). Public awareness of CC and the necessary measures to reduce the changes is an important aspect of achieving goals in reduction and efficiency; however, public knowledge regarding CC causation, actions of the government and the need for CC policies seems to be limited.
Nevertheless, based on the literature search, all research studies assume that the greening and CC could change FF investors’ mood and behaviour. Moreover, none of researches assumed or proved that CC policies are influencing demand or production in FF sectors of the economy. Additionally, no study assumed that capital markets include FF sectors or that investors react rationally to changes in the CC or greening of the world. Nor have any researches investigated these issues in the context of the KSA FF industry, or performed a virtual empirical analysis between the FF industry and the effect of CC on the KSA and other FF-producing countries as a whole. One of the concerns about CC effects relates to the extremes in variables such as green stock, CO₂, temperatures and precipitation. FF are the sources of GHG emissions and considered the main driving forces behind CC. Likewise, FF companies are affecting the environment significantly by catastrophic accidents such as oil spills; in addition, they use chemical-intensive and waste-generating processes. From a green viewpoint, environmental investments and global efforts to decrease firms’ negative environmental effects boost their competitive advantages and as result, improve financial returns to stockholders from ‘greening of the world’. The rising attention from financial markets has led to increased research into these issues. Environmental information may lead capital markets to revise their expectations regarding the performance of FF companies and revenues.

However, no empirical studies have inspected, on an industry level, the long-term connection between CO₂ emissions, related environmental policies and their effects on the market value of FF. Furthermore, no empirical value relevance researches examined the FF sector, the main product of which is hydrocarbon, or the oil, NG and coal industry, which is holds significant climate influence. Only some qualitative,
forecasting and scenario-building studies focused on the value relevance of CC in the world’s leading FF industry (Wellington and Sauer, 2005).

Therefore, the literature suggests and the study questions of this thesis follow from the interaction between FF industry and CC. Given the dominance of the financial system existing today and the urgency required in dealing with CC, investigating how FF markets react to CC information is definitely a relevant and required area of study. Such research is also valuable given that the FF industry is crucial to the KSA and other producing countries’ economies and also responsibility for a substantial portion of CO\textsubscript{2} emissions. Currently, no comprehensive analysis has examined the extent to which capital markets incorporate CC-related information into the stock valuation process in the context of the FF industry. Moreover, no empirical research or case studies have examined investors’ reactions to CC following the KP policies. In addition, the abovementioned studies have several drawbacks, such as (1) methods applied may not be appropriate for the data types; (2) data analysis and results that are derived from insufficient data; (3) insufficient number of variables; and (4) lack of use data on of climate-related variables in their analyses. Thus, the present study attempts to fill this gap.

Challenges in meeting of the requirements of established regulations in global CC initiatives include KSA-specific challenges and the supply of, access to, demand for, and ability to meet demand for FF production globally. A large portion of KSA’s GDP and economic well-being is dependent on the FF industry. In addition, global measurements of CO\textsubscript{2} provide sufficient information regarding the true amounts influencing CC. Even though temperature and precipitation are more accurately
recorded and tested, methods of establishing how CO₂, temperature or precipitation are influencing global economic trends in regards to the production of FFs do not currently evaluate these areas in using time-series models.

Specifically, the production of FF may become less pronounced in future global economic conditions; however, to-date, no study has sought to understand how these conditions will influence producing countries (like KSA), or if these CC policies are yielding the results expected to meet the stated goals. This research is designed to fill the gap identified by the lack of time-series model usage in pricing and CC policies, where the goal is to identify how these policies influence the pricing of FFs and determine if progress in alleviating CC has occurred in relationship to pricing.

Empirical studies on this topic use advanced methodologies such as autoregressive models. However, no study has applied VAR or CCA in the development and selection of variables. Moreover, no other studies have applied more than two models to perform a more robust and informative analysis, and, no research has focused on the causal direction between FF, CC and green share prices, using GCA that rely on temporal predictability as evidence of Granger causality. In addition, the gaps in the literature in relation to the general understanding of the relationship between FF prices and CC are highlighted in the following cases:

- It is unclear how an organisation can resist and react to oil shocks, various political and economic crises and CC policies that may potentially have a negative influence on the economy in which it operates. It is also not known whether the management of KSA has the capability to resolve issues of such magnitude. This ambiguity need to be resolved. Hence, it is essential to analyse
and explore the mechanisms of KSA’s response to the abovementioned problems;

- KSA has its own viewpoints on the future of FF industry, which seem to contradict those of FF importing and exporting nations. The intentions of developed countries to turn towards renewable source of energy may result in changing policies regarding different sources of energy. Thus, FF production and prices in KSA and other producing countries may significantly vary. Hence, this situation warrants a detailed study on the KSA’s FF production and pricing in relation to further projections as well as other producing countries. A majority of the studies in the literature do not seem to exclusively cover the issues of FF pricing in KSA and other exporting countries. It is a well-known fact that FF prices are subsidised in KSA, whereas other FF producing countries impose heavy taxes on FF, which seem to ‘get passed’ on to economy as a whole. Nonetheless, there seems to be a wide gap in the technical and scientific literature on this topic given that KSA is a significant producer of hydrocarbon products. Having established that the global price of FF can have significant long-run repercussions on national economies, it is important to conduct further studies on this issue; and

- By expanding the issue of CC and its influence on FF prices, exporting countries or companies have the liberty to implement both climate policies and FF prices independently, so the effect of the same need to be understood in view of global CC and economic development. Currently, there are rather few studies that have investigated or touched upon the above topic in any great detail. Hence, it is necessary to explore this further qualitatively and quantitatively.
Chapter 4

Data and Methodology
4.1 Introduction

This chapter will introduce the various techniques that will be used in the conducted study in order to achieve its aims and objectives. This study’s main objective is to investigate FF prices and the impact of the total effect of CC and GHG emissions on the market value of FF. The purpose is to determine the dynamic nature of relationships among FF production, pricing and CC not only in term of CC policy and management structures, but also how the ‘greening of our society’ has influenced or is influencing the present/future production and pricing of FF. A combination of approaches has been developed and established to reject or confirm the existence of these relations. This study is deductive and quantitative, while also inductive and qualitative in analysing the FF and CC. Chapter 4 connects these research concepts and data to measurement procedures that produce precise qualitative and quantitative information. This chapter clarifies how data were gathered and analysed to achieve the research objectives. The selection of the study approaches most appropriate to the research objectives are guided by published research on methodology discussed in previous chapters.

This chapter presents how the proposed study is going to obtain the ‘best’ data or information regarding the impact of the CC on KSA’s FF prices, and will present the qualitative research methodology that that will be crucial in achieving the aims and objectives of this thesis. More specifically, qualitative methods will be used to investigate the management structure and policies that have influenced FF prices and CC over time. In this manner, the researcher will provide significant insights into KSA’s FF industry.
The present research uses a quantitative analysis aspect to address the second major aim, which is to investigate in depth the dynamic relationships among pricing and climate-related variables. This is done within univariate and multivariate frameworks that will allow individual variable volatility-based modelling, forecasting and accounting for contemporaneous and/or deterministic variables in the regressive modelling process.

A time-series univariate analysis will be employed in this study in terms of ARIMA and autoregressive conditional heteroscedastic family to understand serial correlation and volatility. Chapter 4 will also provide a review of the multivariate framework, which will help examine the relationship between FF and CC. The multivariate analysis will include vector autoregression that will identify other dynamics such as Granger causal effects, how shocks may affect the system using an IRA, and how each of the dependent variables are influenced by serially related and/or deterministic and exogeneous variables by conducting VDA. CCA, a multivariate method for describing and confirming the relationship between variables simultaneously and able to produce both spatial and structural meanings, contributes to layer-type FF and CC variables by providing information based on indirect selection. Both the univariate and multivariate analyses are well-established methods and deemed appropriate for such analysis – a study of the lagged dynamics and interdependence as well as longer-term relationships between CC and production and pricing of the FF.
4.2 Data

4.2.1 Qualitative data analysis

To build sophisticated and reliable arguments, quality and reliable data are needed. The first part of this major study will involve a qualitative analysis that includes individual interviews. The focus groups are drawn from various professional backgrounds in the FF industry. Participants will be interviewed and they will be representatives who are have different functions, have access for data and possess theories or research regarding the FF market. More particularly, the discussion guide is a series of questions used by the focus group to ensure that important objects of interest are discussed in interviews. This is of particular importance because it increases consistency across focus groups and provides increased confidence that the questions obtain the specific information needed. The interview script incorporated various categories of questions, including opening, introductory, key and ending questions, which will involve discussion of FF and CC. In-depth detailed information on the data collected, method and analysis is provided in Chapter 5.

4.2.2 Quantitative data analysis

The analysis in the quantitative section will mainly use the established time-series methodology. The research focuses on the FF industry due to its established influence on CC in both physical and economic terms. This industry is deemed important because changes in global temperatures are expected to cause various other environmental and financial changes; in addition, CC strikes at the industry’s fundamental products. GHG emissions can only be minimised by decreasing the use of FFs. This research focuses on the CMP that can significantly impact the market and earnings value of FF-producing...
countries. This research selected the FF industry for a number of reasons. First, the FF industry is a vital component of the Saudi economy. Second, the KSA economy depends more on FFs for its wealth generation and power supply than most economies. Third, the FF industry significantly affects CC, and thus, the industry plays a significant role worldwide in reducing GHG. Four, FF countries are more likely to be affected in a material way by CC, making this industry a key subject for integrating environmental investigations into shareholder’s financial assessments.

For more informative results, data examined at different levels, including a total of 2,008 weeks, 462 months and 38 years (1 January 1978 to 30 June 2016), were used to examine the interaction between the market value of FF and CC-related variables. The variables for the analysis consist of two sets: (1) \( Y_i \) – FF variables; and (2) \( X_i \) – CC variables. \( Y_i \) and \( X_i \) represents independent and dependent variables, respectively. The variables which were subject to the analysis can be obtained from various sources; the details of variables and sources are shown in Table 4.1 and Table 4.2.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Abbreviation</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global oil price ($/bbl)</td>
<td>( Y_1 )</td>
<td>Bloomberg; Energy Intelligence Group (EIG); Organisation of Arab Petroleum Exporting Countries (OAPEC); and World Bank (WB).</td>
</tr>
<tr>
<td>Saudi oil price ($/bbl)</td>
<td>( Y_2 )</td>
<td>Ministry of Petroleum and Mineral Resources of Saudi; Ministry of Petroleum and Mineral Resources of Saudi Arabia; OAPEC; and Saudi Arabian Monetary Agency.</td>
</tr>
<tr>
<td>Global NG price ($/mmBtu)</td>
<td>( Y_3 )</td>
<td>The Wall Street Journal (WSJ); Thomson Reuters Datastream; WB; and World Gas Intelligence.</td>
</tr>
<tr>
<td>Global coal price ($/mt)</td>
<td>( Y_4 )</td>
<td>Bloomberg; Coal Week; Coal Week International; HIS McCloskey Coal Report; International Coal Report; and WB.</td>
</tr>
</tbody>
</table>

The FF market data examined in the study are end-of-financial-trading-day, weekly, monthly and yearly share prices traded on different FF markets (Figure 4.1). \( Y_1 \) is the
average spot price of a major trading classification of oil that serves as a major benchmark price for global oil purchases, equally weighed (Brent 38°API, Fateh 32°API, WTI 40°API). The Saudi oil price, $Y_2$, refers to the average spot price between Arabian Light 34°API and Arab heavy 27°API. The global NG price, $Y_3$, is the average spot price for Europe, Japan (LNG), UK and US. Average spot coal prices for Australia (Thermal GAR, f.o.b. piers), Colombia (Thermal GAR, f.o.b. piers) and South Africa (Thermal NAR, f.o.b. piers) are used to calculate $Y_4$. The set $Y_i$ variable transformed to form of returns ($R_{Y_i}$) on the price indexes as calculated by the following formula:

$$R_{Y_i, t} = \frac{\text{PRICE}_{Y_i, t} - \text{PRICE}_{Y_i, t-1}}{\text{PRICE}_{Y_i, t-1}}, \text{ where } i = 1, 2, 3, 4$$

Figure 4.1: Time-series plots, FF variables (real prices and returns).
The authors constructed the green energy index ($X_1$) in this research. Designed as a liquid, transparent benchmark, it indicates the organizational performance of developers, installers, producers, and distributors of clean energy. To achieve a decision-making system based on classification techniques, we must select a particular company. To be included in the green energy index, the security must satisfy at least four of the following criteria:

1. The security must be listed in eligible global stock exchanges approved for this research.

2. The security issuer must be categorised as one of the following:
   - Renewable Fuels and Renewable Electricity Generation – covers geothermal, wind, biodiesels, biofuels, ethanol-enabling enzymes, and solar photovoltaics;
   - Energy Intelligence – includes automated meter reading, smart grids, superconductors, conservators, power controls, and energy management systems;
   - Advanced Materials – includes silicon-based materials and substitutes, nanotechnology, bioplastics and advanced membranes that enable clean
energy implementations and/or decrease the requirements for petroleum-based materials; and


3. The security issuer supports environmental companies and green energy projects that encourage transition to clean, low-carbon energy economies.

4. The security issuer introduces recycling programs and implements initiatives to decrease harmful carbon emissions, thereby mitigating the negative effects of primary business processes.

5. The security issuer can demonstrably capitalize upon the growth of the clean energy sector.

6. The security issuer presents environmental awards in recognition of world-class contributions and innovations that drive energy efficiency and long-term environmental sustainability.

7. The security issuer derives at least 20% of its current power requirements from renewable energies or aims to source 100% of its power from renewable energies in the near future.

Under these restrictions and after a careful study of the green companies’ stock market, a total of 70 firms were selected for this study. The selected firms are listed in Appendix I. The stock variable ($X_1$) enables us to track the renewable energy industry, and hence construct an energy index that reflects the most notable opportunities for clean energy. This index will provide a benchmark for future clean-energy sectors and a financial
performance measure for environmental sustainability projects. The variable \( X_1 \) transformed to green energy share prices return \((R_{X_1})\) by using the following formula:

\[
R_{X_1,t} = \frac{1}{70} \sum_{t=1}^{70} \left( \frac{\text{PRICE}_{X_1,t} - \text{PRICE}_{X_1,t-1}}{\text{PRICE}_{X_1,t-1}} \right) + \text{DIVIDEND}_{X_1,t}
\]

The variable \( X_2 \) was transformed to standardised discrete data or normalised data \((S_{X_2})\) by subtracting its mean from each observation in \( X_2 \) and dividing the difference by the standard deviation of the \( X_2 \) series. Similarly, other variables \((X_3, X_4, X_5 \text{ and } X_6)\) were normalised to achieve consistent variances among the data \((S_{X_3}, S_{X_4}, S_{X_5} \text{ and } S_{X_6})\) and ensure good statistical properties (Figure 4.2).

Figure 4.2: Time-series plots, CC variables (real data and transform).
Employing a combination of qualitative and quantitative data can enhance an evaluation by confirming that the limitations of one type of data are balanced by the strengths of another. However, neither qualitative nor quantitative data are seen as preliminary or superior but rather as complementary. This will ensure that understanding is improved by integrating different ways of knowing. These analysis technique offers ways in which insights into strategic planning could be gained that would in turn be useful for decision-makers needing flexible decisions for the benefit of the long-term goals. Qualitative and quantitative analyses can be viewed as tools that bring together intuition and logic and make use of information to develop understanding of the contexts and situation presented (Figure 4.3).

4.3 **Methodology**

A methodology is an overall research strategy that outlines the way in which study is to be undertaken, and amongst other things, recognises the tools and techniques for doing research. These methods, explained in the methodology, determine the means or modes of collecting the data or sometimes how a particular result is to be calculated. Methodology does not describe specific methods, even though much attention is given
to the kinds and nature of processes to be followed in a particular procedure or attain an objective. All research is based on some underlying philosophical hypotheses about what constitutes valid research and which research methods are appropriate for the development of knowledge in a given study.

Joint logical suppositions were appraised and brought forward for finalising the structure of the study. The meaningful literature that is connected to the research clearly implies FF market sway. The examination of acquired data, *i.e.* CC variables and FF returns, is performed to determine the relationship between them. The evaluation used is association study methodology; this was taken up to analyse the link connecting information and FF market value. The association technique is useful in the empirical explorations of the connection between CC and the FF industry plus market value. The study adopts a variety of time-series models and practices to look over and comprehend the value relevance relation between FF business and CC. A time series is calculated to establish the long-term relationship linking climate and the FF market. Time-series modelling and prediction has essential significance to several practical spheres. Several of the models that have been suggested over time for improvement of the precision and efficacy of time-series structuring and foretelling of values are discussed below.

### 4.3.1 Time-series models

A time series can be described as: a series of discrete statistical points that are grouped/listed in time order. The stepwise construction and final application of time-series models to any scenario is highly theoretical. Time-series models are founded on the behaviour of variables being tested, such as here, the nature of CC and FF variables. Time-series models highlight characteristics of case samples that come about due to
different non-specific structures. The design of a time series facilitates the capture of features that are often tied to changes observed in variance. The methods affiliated with time series are useful in the exploration of connections between endogenous and exogenous variables, e.g. connection amongst CC and FF variables. Exogenous variables are exclusive and not affected by others within the system in which they are contained. The endogenous variable is referred to as the dependent variable in linear regression because it is influenced by other variables.

To perform a time-series analysis, one shall have to first conduct data collection. Once that is done, the researcher will then compile the various variables and use the best-fitting time-series model to work the analysis. The methods shall quantitatively estimate the guiding influence of CC on FF. The CC variable acts as the explanatory aspect in the analysis whereas FF, *i.e.* pricing and production, comprise the dependent variable. Time-series models are categorised into two distinct groupings: univariate and multivariate models. A univariate time-series model consists of scalar data recorded as per equal time intervals. It takes account of past variances to perform predictions of upcoming variances, noting some vital features, *i.e.* surplus kurtosis, influence exhibited and unpredictability of constructed time series. The multivariate model contains a variety of data and focuses on matrix and vectors in its analysis.

Just about all administrative dealings and judgements are founded on prospective outcomes that have been predicted. A time-series analysis works as a guide for establishments in their everyday operations. When forecasting is completed and some influencing variables are noted, that information can be used to better the outcome of the company’s processes. Research on climate and FF market values purposes to
determine whether the CC variables openly or circuitously impact FF. Researchers desire to discover whether FF variables are independent and perhaps affected by other variables like KSA production prices or ranking. As is sometimes noticed in correlation, some relationships are established by the existence of a third variable. If it is established that CC does indeed influence FF variables, then plans can be made to work around the variable. If FF is independent of CC but under the influence of a third variable, KSA management may alter procedures.

4.3.1.1 ARIMA and ARCH/GARCH models

An autoregressive integrated moving average model [ARIMA \((r, d, m)\)] encompasses a sequence of series transformation to a nature of stationary covariance, followed by identification, diagnosis, approximation and forecast. The litter \(l\) in the model’s name indicates that chosen datasets go through variation and that once the modelling has been done, the output is subjected to an integration procedure to yield ultimate expectations and approximations. The ARIMA model produces a stationary function autoregressive moving average model [ARMA \((r, m)\)] upon differentiation with respect to period. This process begins with the simplest autoregressive model, AR \((r)\) with \(r\) denoting the number of lag steps measured. The equation for AR \((r)\) is

\[
y_t = \alpha_0 + \sum_{i=1}^{r} \phi_i y_{t-i} + \epsilon_t
\]

where \(\alpha_0\) and \(\phi_i\) are real constants, often estimated using an ordinary least-squares method and \(y_t\) is the return at a time \(t\). The residuals \(\epsilon_t\) are believed to be autonomous and identically disseminated with zero-mean and perpetual variance. An extension of the above is an ARMA model suggested by Whittle (1951), which also relies on lagged residuals of the time series. The equation for ARMA \((r, m)\) is
\[ y_t = \alpha_0 + \sum_{i=1}^{r} \phi_i y_{t-i} + \sum_{j=1}^{m} \theta_j \varepsilon_{t-j} + \varepsilon_t \] (4.2)

where \( j \) is a constant parameter. The assumption that variance is constant, however, is sometimes untrue; variance is not always homoscedastic. Benz and Trück (2009) discuss evidence supporting the opinion that this is not the case for emission allowance returns. The autoregressive conditional heteroskedastic [ARCH \((q)\)] formula that was proposed by Engle (1982) deals with this issue. In simple cases, it is assumed that the time series \( y_t \) is zero-mean and then models the residuals \( \varepsilon_t \) split up into two terms: (1) a stochastic part \((u_t)\) and (2) a time-dependent standard deviation term \((\sigma_t)\). The ARCH \((q)\) model considers from \( q \) lagged terms.

\[ y_t = \varepsilon_t, \text{ and } \varepsilon_t = u_t \sigma_t, \text{ with } \sigma_t^2 = a_0 + \sum_{k=1}^{q} a_k \varepsilon_{t-k}^2 \] (4.2)

where \( a_k \) represents the parameter of the model, \( u_t \) are iid. having null mean and a variance equalling one. The observed distribution of \( u_t \) is determined under the assumption that it has normal or standardised t. A generalised heteroskedastic model [GARCH \((q,p)\)] is obtained by using both past \( \varepsilon_t \) values and \( \sigma_t \) to model conditional variance. Suggested by Bollerslev (1986), this is defined as

\[ y_t = \varepsilon_t, \text{ and } \varepsilon_t = u_t \sigma_t, \text{ with } \sigma_t^2 = \alpha_0 + \sum_{j=1}^{q} \beta_j \sigma_{t-j}^2 + \sum_{i=1}^{p} \alpha_i \varepsilon_{t-i}^2 \] (4.3)

where \( \beta_j \) and \( \alpha_i \) are real constants. The parameters need to meet the condition \( \sum \alpha_i + \sum \beta_j < 1 \) so that variance stays finite, and \( \alpha_i, \beta_j \geq 0 \), and \( \alpha_0 > 0 \) to ensure positive and stationary variance.
4.3.1.2 TGARCH model

Another model is part of the disproportionate GARCH group, Threshold GARCH which introduced independently by Glosten et al. (1993) and Zakoian (1994). TGARCH model obtained by incorporating the lagged conditional standard deviations as a regressor (Miron and Tudor, 2010). The comprehensive requirements that constitute conditional variance are given by

\[
\sigma_t^2 = \alpha_0 + \sum_{j=1}^{q} \beta_j \sigma_{t-j}^2 + \sum_{i=1}^{p} \alpha_i \epsilon_{t-i}^2 + \sum_{k=1}^{r} \gamma_k \epsilon_{t-k} \Gamma_{t-k}^i, \text{ where } \Gamma_{t-i}^i = \begin{cases} 1 & \text{if } \epsilon_{t-i} < 0 \\ 0 & \text{otherwise} \end{cases}
\]  

(4.4)

Depending on whether \( \epsilon_{t-i} \) is below or above the threshold value of 0, \( \epsilon_{t-i}^2 \) can have different effects on \( \sigma_t^2 \) (the conditional variance). When \( \epsilon_{t-i}^+ \), the conditional impact of \( \epsilon_{t-i}^2 \) on \( \sigma_t^2 \) is \( \alpha_i \sigma_{t-i}^2 \); when \( \epsilon_{t-i}^- \), the impact is \( (\alpha_i + \gamma_i) \epsilon_{t-i}^2 \). If \( \gamma_i > 0 \), the bad outcome gains some degree of volatility; thus, there is leverage influence for the \( i \)th order, and if \( \gamma_i \neq 0 \), the impact is asymmetric.

4.3.1.3 EGARCH model

The Exponential GARCH model (EGARCH) had been described by Nelson (1991). This model allows the impact of positive and negative shocks to be asymmetric. This method ensures that the conditional variance remains positive and can be described as follows;

\[
\log \sigma_t^2 = \alpha_0 + \sum_{j=1}^{q} \beta_j \log(\sigma_{t-j}^2) + \sum_{i=1}^{p} \alpha_i \frac{\epsilon_{t-i}}{\sigma_{t-i}} + \sum_{k=1}^{r} \gamma_k \frac{\epsilon_{t-k}}{\sigma_{t-k}}
\]  

(4.5)
The logarithm of $\sigma_t^2$ indicates that the pull weight is exponential and not quadratic. There are no restrictions on the equation’s parameters, which are $\alpha, \beta$ and $\gamma$. The predictions of conditional variance are positive values since the model uses the variances log. It can test for the presence of leverage effects by using the hypothesis $\gamma_i < 0$; if $\gamma_i \neq 0$, this means that the obtained impact is asymmetric.

### 4.3.1.4 PARCH model

The power ARCH model (PARCH) is an extension of GARCH introduced by Ding et al. (1993); it is an asymmetric model. In the PARCH model, the control value $\delta$ of standard deviation is estimated leaving behind the norm being imposed. Optimal $\gamma$ statistics are incorporated to establish asymmetry up to the $r$th order. The PARCH model has the following representation:

$$
\sigma_t^\delta = \alpha_0 + \sum_{j=1}^{q} \beta_j \sigma_{t-j}^\delta + \sum_{i=1}^{p} \alpha_i (|\epsilon_{t-i}| - \gamma_i \epsilon_{t-i})^\delta
$$

(4.6)

where $\delta$ for the power term $> 0$, $|\gamma_i| = 1$ (for $i = 1, \ldots, r$), and $\gamma_i = 0$ (for all $i > r$ and $r \leq p$).

### 4.3.1.5 Empirical models

The development of this model to investigate a relationship between returns on investments in FF indices and CC variables involved designation of conditional variance model (ARIMA, ARCH/GARCH, TGARCH, EGARCH and PARCH). The following empirical models have been applied to test the value relevance of the CC in FF returns:
\[ R_{Y_{i,t}} = \beta_0 + \beta_1 R_{X_1,t} + \beta_2 S_{X_2,t} + \beta_3 S_{X_3,t} + \beta_4 S_{X_4,t} + \beta_5 S_{X_5,t} + \beta_6 S_{X_6,t} + e_{i,t} \]  \hspace{1cm} (4.7)

where \( R_{Y_{i,t}} \) is FF return set at time \( t \), \( Y_i \) where \( i = [1 \text{ (Global oil)}, 2 \text{ (Saudi oil)}, 3 \text{ (NG)}, 4 \text{ (Coal)}] \) price of return) and CC variables are: \( R_{X_1,t} = \) Green energy index return, \( S_{X_2,t} = \) Global CO\(_2\), \( S_{X_3,t} = \) Global temperature, \( S_{X_4,t} = \) Global precipitation, \( S_{X_5,t} = \) Saudi temperature, \( S_{X_6,t} = \) Saudi precipitation and \( e \) is an error term.

### 4.3.1.6 Vector autoregressive analysis

This study employs VAR approach to capture the evolution and interdependence between multiple time series. VAR imposes a minimum theoretical demand on the model’s structure and requires only the variables and largest number of lags to capture most of the variables’ inter-effects. The model was introduced by Sims (1980) in form of a non-structural econometric model context. The research methodology estimates a multivariate form of time-series VAR by using number of select variables within the VAR system. In a time-series analysis that is observed to be multivariate, variable \((y_t)\), which consists of \( n \)-variables, is characterised by a VAR model of an autoregressive order that is \( \leq p \)

\[ y_t = \xi_0 + \sum_{k=1}^{p} \xi_j y_{t-k} + \tau_t \]  \hspace{1cm} (4.8)

where \( y_t \) is an \((n \times 1)\) matrix, a column vector of daily, weekly or monthly time-series data, and \( \xi_0 \) and \( \xi_j \) are \((n \times 1)\) and \((n \times n)\) matrix coefficients, respectively. The variable \( p \) is the lag length and \( \tau_t \) is a column vector \((n \times 1)\) of serially uncorrelated error value terms. The \( j \)th term of \( \xi_j \) is used to estimate the immediate influence on the \( i \)th value of a variation in changes to the \( j \)th value in \( k \) periods. The \( i \)th component of \( t \) is the innovation of the \( i \)th value, which cannot be forecasted from past values of other
variables in the system. The multivariate statistic is denoted by VAR \((p)\) – a VAR process of order \(p\) as written in the below equation (Brüggemann et al., 2008):

\[
y_t = \varphi_0 + \varphi_1 x_{t-1} + \cdots + \varphi_p y_{t-p} + \tau_t \tag{4.9}
\]

where \(\varphi_0\) is a column vector \((n \times 1)\) of intercept parameters, \(\varphi_i\) is a coefficient matrix \((n \times n)\) for \((i = 1, 2, \ldots, p)\) and \(\tau_t\) is an unobservable vector error term \((n \times 1)\) with zero mean and time-invariant with \(\Sigma_{\tau}\) covariance matrix. There aspects involved in the VAR methodology are discussed next.

### 4.3.1.6.1 Impulse response analysis

An IRA can be described as the output obtained in signal evaluation. It is the observable general reaction to change in an external dynamic with respect to time. IRA is able to identify the dynamic associations exhibited over time and identifies period and effect/consequence of variables in one variable to another through tracking a shock to one endogenous variable on the others in structure VAR. The dynamic relationships between time series selected are identified by the impulse response function. In the case where the VAR \((p)\) model is stationary, it has a moving average (MA), which can be written as

\[
y_t = \omega + \sum_{i=1}^{\infty} \Phi_i \tau_{t-i} \tag{4.10}
\]

where \(\omega\) is the mean of the process, which is equal to \(\Theta_0(I_m - \Theta_1 - \cdots - \Theta_p)^{-1}\). The MA matrix \(\Phi_i\) consists of responses to predict errors of \(\tau_t\) that occurred \(i\) periods ago. If the contemporary residual relationship is high, it becomes difficult to interpret the responses.
Cholesky decomposition has been used in analysis of orthogonalised shocks as obtained by $\sum_\tau$. Since the outcome of the IRA may possibly rely on the ordering of the variables, generalised impulse responses was used (Pesaran and Shin, 1998). In the latter method, shocks are orthogonalised by looking at a shock in variable $k$ and integrating out the influences of other shocks by using the distribution of the errors; thus, correlation amongst $\tau_\ell$ components are considered. If $\tau_\ell$ has a multivariate normal distribution, it is illustrated as

$$
E [\tau_{kt} | \delta_k] = (\sigma_{1k}, \sigma_{2k}, \ldots, \sigma_{nk})^T \sigma_{kk}^{-1} \delta_k = \sum_\tau e_k \sigma_{kk}^{-1} \delta_k
$$

(4.11)

where $\sigma_{nk}$ represents the elements of $\sum_\tau$ and $e_\nu$ is a selection vector ($k \times 1$) with a 1 in position $k$ and 0 elsewhere. Therefore, the response vector to a shock variable $k$ that occurred $i$ periods ago is shown in the below equation:

$$
\frac{\Phi_i \sum_\tau e_k \delta_k}{\sigma_{kk}} = \frac{\Phi_i \sum_\tau e_\nu}{\sqrt{\sigma_{kk}}} \cdot \frac{\delta_\nu}{\sqrt{\sigma_{kk}}}
$$

(4.12)

where $\delta_k$ is then scaled to achieve a standard deviation of size 1 and setting $\delta_k = \sqrt{\sigma_{kk}}$ yields the following equation:

$$
\vartheta_k(i) = \frac{\Phi_i \sum_\tau e_{kk}}{\sqrt{\sigma_{kk}}}, \text{ for } i = 0, \ldots, h
$$

(4.13)

which provides a generalised impulse response of variables in $y_i$ to a shock variable $k$ that took place $i$ periods ago. The IRA can be uniquely estimated and take full account of historical correlation patterns observed amongst the different shocks. Unlike the orthogonalised impulse responses, these are invariant to the variable order in the VAR.
4.3.1.6.2 Variance decomposition analysis

VDA is an additional familiar tool applied in appraising multivariate time-series models. The VDA shows the amount of variance each variable contributes to other variables within the context of the VAR method. The VDA decomposes variation in an endogenous variable into the component shocks to the other endogenous variables in the VAR. The generalised impulse analysis aids the derivation of error VDA. Meanwhile, the error terms are associated with uncertainty; even a perfect model includes ambiguity about the realisation of \( y_t \). VDA is useful to decrease the uncertainty in one equation related to the variance of error terms in all equations. VDA is the proportion of the \( h \)-step prediction error variance of variable \( i \) that is accounted through the innovations of variable \( j \) in the VAR (Pesaran and Shin, 1998). Denoting the \( ij \)th part of the coefficient of the orthogonalised impulse response matrices, \( \Theta_K \) by \( \Gamma_{ij} \), the variance of forecast error is given as

\[
\sigma_i^2(h) = \sum_{k=0}^{h-1} (\Gamma_{1,k}^2 + \Gamma_{2,k}^2 + \cdots + \Gamma_{K,k}^2) = \sum_{j=0}^{T} (\Gamma_{ij,0}^2 + \Gamma_{ij,1}^2 + \cdots + \Gamma_{ij,h-1}^2) \quad (4.14)
\]

The second method to investigate VDA is interpreted as contributions of variable \( j \) to the \( h \)-step prediction error variance of variable \( t \). Therefore, dividing the above terms by \( \sigma_i^2(h) \) provides the contribution percentage of variable \( j \) to the \( h \) step prediction error variance of variable \( t \) (Lütkepohl, 2005):

\[
\omega_{ij}(h) = \frac{\Gamma_{ij,0}^2 + \Gamma_{ij,1}^2 + \cdots + \Gamma_{ij,h-1}^2}{\sigma_i^2(h)} \quad (4.15)
\]

However, to conduct analysis on the generalised prediction error variance, the form proposed by (Pesaran and Shin, 1998) has been used in this study as shown below:

\[
\Psi_{ij}(k) = \frac{\sigma_{ij}^{-1} \sum_{l=0}^{k} (e_l' \Phi \sum_{\tau} e_{\tau})^2}{\sum_{l=0}^{k} e_l' \Phi_{l} \sum_{\tau} \Phi_{l}\tau e_{\tau}} \quad (4.16)
\]
4.3.1.6.3 Granger causality analysis

This test works to determine causal attribute between variables. GCA enables examination of which variable is influencing which and thus to identify which variables have more or less effect. In simple mathematical terms, the GCA can be described as follows: ‘variable \( \bar{A} \) does not Granger-cause ‘variable \( \bar{B} \)’ if and only if forecasts of \( \bar{B} \) based on the universe (\( U \)) of forecasters is no better than the forecast of \( \bar{B} \) based on \( U-[\bar{A}] \); that is, the universe with \( \bar{A} \) omitted.

In determination of interdependencies, the bivariate Granger (1969, 1980) causality test was applied. A methodological framework supports use of GCA to determine if there is one or two-way Granger causality between variables. The definition of causality in Granger’s terms is framed by conditions of probability. VAR models have been used frequently to examine the Granger causality relations between two subsets of variables. As noted by Emirmahmutoglu and Kose (2011), in the VAR context, Granger causality is based on the null hypothesis framed as there being no restrictions on the coefficients of the lags of subsets of variables.

In a bivariate VAR of \( \Psi \) and \( \eta \) variables, \( \eta \) does not Granger-cause \( \Psi \) if the coefficient metrics are lower triangular for all \( j \)

\[
\Psi_{1t} = c_1 + a_1 \Psi_{1t-1} + \cdots + a_p \Psi_{1t-p} + b_1 \Psi_{2t-1} + \cdots + b_p \Psi_{2t-p} + \tau_{1t} \quad (4.17)
\]

If the null hypothesis is not rejected (\( H_0: b_1 = \cdots = b_p = 0 \)), \( \Psi_{2t} \) will not Granger-cause \( \Psi_{1t} \). Therefore, if \( \Psi_{1t} \) does Granger-cause \( \Psi_{2t} \), the in a similar manner, the following equation can be written:

\[
\Psi_{2t} = c_1 + a_1 \Psi_{1t-1} + \cdots + a_p \Psi_{1t-p} + b_1 \Psi_{2t-1} + \cdots + b_p \Psi_{2t-p} + \tau_{2t} \quad (4.18)
\]
If the null hypothesis is not rejected ($H_0: a_1 = \cdots = a_p = 0$), then $\Psi_{1t}$ does not Granger-cause $\Psi_{2t}$. More particularly, the VAR (2) case scenarios can be written as follows:

$$
\begin{bmatrix}
\Psi_{1t} \\
\Psi_{2t}
\end{bmatrix} = 
\begin{bmatrix}
C_1 \\
C_2
\end{bmatrix} + 
\begin{bmatrix}
\varphi_{11}(L) & 0 \\
\varphi_{21}(L) & \varphi_{22}(L)
\end{bmatrix} 
\begin{bmatrix}
\Psi_{1t-1} \\
\Psi_{2t-1}
\end{bmatrix} + 
\begin{bmatrix}
\varphi_{11}^2(L) & 0 \\
\varphi_{21}^2(L) & \varphi_{22}^2(L)
\end{bmatrix} 
\begin{bmatrix}
\Psi_{1t-1} \\
\Psi_{2t-1}
\end{bmatrix} + 
\begin{bmatrix}
\tau_{1t} \\
\tau_{2t}
\end{bmatrix} \tag{4.19}
$$

For the bivariate VAR, $\Psi_{2t}$ does not Granger-cause if $\Psi$ is lower triangular for all $j$.

This case yields the following:

$$
\Psi_{1t} = \Theta_{11}(L) \tau_{1t} + \Theta_{12}(L) \tau_{2t} \text{ and } \varphi_{22}(L) \Psi_{2t} = \tau_{2t} \tag{4.20}
$$

Thus, in case $\Psi_{1t}$ does not Granger-cause $\Psi_{2t}$, and then MA ($\infty$) representations can be written as follows:

$$
\begin{bmatrix}
\Psi_{1t} \\
\Psi_{2t}
\end{bmatrix} = 
\begin{bmatrix}
\mu_1 \\
\mu_2
\end{bmatrix} + 
\begin{bmatrix}
\Theta_{11}(L) & \Theta_{21}(L) \\
0 & \Theta_{22}(L)
\end{bmatrix} 
\begin{bmatrix}
\tau_{1t} \\
\tau_{2t}
\end{bmatrix} \tag{4.21}
$$

where $\Theta_{ij}(L) = \Theta_{ij}^0 + \Theta_{ij}^1 L + \Theta_{ij}^2 L + \cdots$, with $\Theta_{11}^0 = \Theta_{22}^0 = \Theta_{21}^0 = 0$.

### 4.3.1.7 Canonical correlation analysis

The correlation analysis research methodology is an assessment of bilateral variable relationships through the correlation coefficient between two variables. The multiple correlation approach consists of an assessment of the independent variable and two or more independent variable relationships. Canonical correlation analysis (CCA), introduced by Hotelling (1936) in 1935, posits that the number of weighted linear functions equals the number of the most minute variables (Gunderson and Muirhead, 1997). The relation function between the variables is called *canonical correlation*. The CCA is a multivariate assessment approach to variable trait relationships, which focuses upon correlations between linear variable combinations from variable sets $\alpha_i$ and $\beta_i$.

The aim of the canonical correlation analysis in research is to produce estimations of
canonical coefficients when the canonical correlation is at maximum. The linear combinations of such variables can be useful in research that encompasses prediction and juxtaposition. Thus, the canonical variates that depict the most optimal variable combinations and the variable canonical correlation expressions are of particular interest (Hair et al., 2014).

The variables of $\Phi_j$ and $\Psi_j$ can be defined as canonical variates based upon the following equations:

$$\Phi_j = \theta_{ji} \alpha_i \text{ and } \Psi_j = \phi_{ji} \beta_i$$

where $\alpha_i$ is the first set ($i$ is the subscript for FF variables – $R_Y$), $\beta_i$ is the second set ($i$ is the subscript for CC variables – $X_i$) and $\theta_{ji} (\theta_{j1}, \theta_{j2}, \theta_{j3}, \theta_{j4})$ and $\phi_{ji} (\phi_{j1}, \phi_{j2}, \phi_{j3}, \phi_{j4}, \phi_{j5}, \phi_{j6})$ are established as standard canonical coefficients commonly used to distinguish between redundant variables within the interpretation of canonical variables.

The correlation between $\Phi_j$ and $\Psi_j$ can be called canonical correlation ($C_j$). The squared canonical correlation, which is also referred to as eigenvalues and canonical roots, is equivalent to the variance of one canonical variate that can be accounted for by other canonical variates (Hair et al., 2014). To this end, the standardised coefficients exhibit similarities to standardised regression coefficients in regard to multiple regression, which is indicative of the relative significance to the independent variables in the dependent variable value calculation.

The maximisation method process contains the follows steps. The dimensions of datasets $\alpha_i$ and $\beta_i$ are $(n \times i)$, where $i \leq n$ when evaluated within the same dataset of $n$ subjects; under the assumption that $\alpha_i$ and $\beta_i$ are standardised to a zero mean and a
standard deviation of 1. Vector weights of $\theta_{(i\times1)}$ and $\phi_{(i\times1)}$ are defined for the linear combinations of $\alpha$ and $\beta$ datasets, respectively, where $\Phi_j$ and $\Psi_j$ are $(n \times 1)$ vectors. The coefficient vectors $\theta$ and $\phi$ are estimated by the maximising following equation:

$$
C = \frac{\text{cov}(\Phi, \Psi)}{\sqrt{\text{Var}(\Phi)(\text{Var}(\Psi))}}
$$

$$
= \frac{\theta^T \text{cov}(\alpha, \beta) \phi}{\sqrt{(\theta^T \text{cov}(\alpha) \theta)(\phi^T \text{cov}(\beta) \phi)}}
$$

$$
= \frac{\theta^T S_{\Phi\Psi} \phi}{\sqrt{(\theta^T S_{\Phi\Phi} \theta)(\phi^T S_{\Psi\Psi} \phi)}}
$$

(4.22)

where $S_{\Phi\Phi}$ and $S_{\Psi\Psi}$ are depicted as empirical variance-covariance matrices and $S_{\Phi\Psi}$ depicts the covariance matrix of $\Phi$ and $\Psi$. It should be noted that the scaling of $\theta$ and $\phi$ does not affect the correlation coefficient.

4.3.1.7.1 Hypothesis for the assessment of statistical significance of the CCA

This section presents the hypothesis for the assessment of the canonical correlation statistical assessment. The null and alternative hypotheses used in the assessment of canonical correlation statistical significance are as follows:

$$
H_0: C_j = 0 \text{ and } H_a: C_j \neq 0
$$

In order to test the above hypotheses, the most widely used test statistic is Wilks’ lambda, given by

$$
\Lambda_{\text{Wilks}} = \prod_{m=1}^{j} (1 - C_m^2)
$$

(4.23)

where $C_j^2$ is the squared canonical correlation or the eigenvalues ($\lambda_j$) of $S_{\Phi\Phi}^{-1}, S_{\Phi\Psi} S_{\Psi\Phi}^{-1}, S_{\Psi\Psi}$ for $m = 1 \text{ to } j$. 
Bartlett showed that based upon the null hypothesis of linearly unrelated $\alpha_i$ and $\beta_i$, a particular function of $\Lambda_{\text{Wilks}}$ would be distributed approximately as a chi-squared variate distribution (Levine, 1977). Thus, the statistical significance of $\Lambda_{\text{Wilks}}$ demands that the following statistic is calculated:

$$\xi^2 = - \left[ (n - 1) - \frac{v + \omega + 1}{2} \right] \ln(\Lambda_{\text{Wilks}})$$

(4.24)

which is approximately distributed as $\xi^2$ with $v\omega$ degrees of freedom (DF). Where $n$ is the number of cases, $v$ is the number of variables in one set and $\omega$ is the number of variables in the other set. This particular hypothesis can also be tested using a range of commonly multivariate test statistics that are classified as functions of the following eigenvalues:

- Pillai’s Trace, $\Lambda_{PT} = \sum_{m=1}^{j} \frac{\lambda_m}{1 - \lambda_m}$;
- Hotelling-Lawley Trace, $\Lambda_{HL} = \sum_{m=1}^{j} \lambda_m$; and
- Roy’s greatest root tests, $\Lambda_{Roy} = \max_m (\lambda_m)$.

A large canonical correlation does not indicate that a strong relationship exists between the trait sets, as a canonical correlation generates a maximisation of linear combination correlation in cases of two sets; however, it does not generate maximisation of the variances that occur from one variable set to another. Thus, it is recommended that the redundancy is calculated for each canonical correlation in order to measure the amount of variance from one variable set that may be justified by other variable sets. Redundancy measure can be formulated as
\[
R_{d_{\alpha_i, \beta_i}} = C_j^2 \frac{\sum_{j=1}^{r} (C_jL)^2}{r}
\]  

(4.25)

where \(C_jL\) is the loading on the \(j\)th canonical variate and \(r\) is the number of traits in the mentioned canonical variates.

Figure 4.4 summarises the type of data used and the methodology applied to achieve each of the aims and their related objectives.

4.3.2 Prediction and building conditional variance models

To build a model, the model factors were approximated from a data sample containing a significantly large number of observations. After getting the value of the parameters, a test to determine the predictive ability of our models is performed. There are many ways to determining the best fit model; in order to provide for both rigorous results and accuracy in modelling, the approaches selected for testing included the Akaike (AIC), Schwarz (SIC) and Hannan-Quinn (HQ) information criteria and these measures are Model-develop criteria (Table 4.3). Note that Model-develop criteria only compare
considered models and selects the model that best fits the given data. In this study, all three are used in order to optimise results and compare model fitness overall. However, risks are associated with samples sizes and parameters, due to the need for these to be a best fit in the model test.

The first step in the analysis is deciding on the number of lags or parameter that provide the best fit for the models, where consideration must be given for the criteria and evaluation of the models for robust predictions. Although a model can occasionally be suitable for different types of datasets, the accuracy of a model’s predictions requires that various models be evaluated to determine which one provides the best results with minimal errors for the variables presented. Different methods of computing, reducing and quantifying errors exist. Determining criteria to correct prediction errors is often a problem, given that no single criteria can identified a clear-cut indication of prediction performance. Thus, using more than one method is recommended when using these models, due to the importance of forecasting successfully without creating unnecessary errors due to modelling.

Therefore, six model-selection criteria (*i.e.* Model-accuracy criteria) were applied and the appropriate time series was selected to apply the models. From the wide range of applicable model-selection criteria that exists, the following criteria were deemed suitable: mean squared error (MSE), root-mean-square error (RMSE), mean absolute error (MAE), mean absolute percentage error (MAPE) and Theil’s U-statistic. Both of Theil’s U-statistics were applied and were defined as $U_1$ and $U_2$. Table 4.3 illustrates how model development and accuracy criteria were calculated.
Table 4.3: Model-develop and accuracy criteria.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model-develop</strong></td>
<td>AIC ( -\left( \frac{1}{y_i} \right) + 2 \frac{k}{y_i} )</td>
</tr>
<tr>
<td></td>
<td>SC ( -2 \left( \frac{1}{y_i} \right) + k \log(y_i) )</td>
</tr>
<tr>
<td></td>
<td>HQ ( -2 \left( \frac{1}{y_i} \right) + 2 k \log(\log(y_i)) )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model-accuracy</strong></td>
<td>MSE ( \frac{1}{n} \sum_{i=1}^{n} e_i^2 )</td>
</tr>
<tr>
<td></td>
<td>RMSE ( \sqrt{\frac{1}{n} \sum_{i=1}^{n} e_i^2} )</td>
</tr>
<tr>
<td></td>
<td>MAE ( \frac{1}{n} \sum_{i=1}^{n}</td>
</tr>
<tr>
<td></td>
<td>MAPE ( \frac{1}{n} \sum_{i=1}^{n} \left( \frac{</td>
</tr>
<tr>
<td></td>
<td>U1 ( \sqrt{\frac{1}{n} \left( \sum_{i=1}^{n} y_i^2 \right) + \sqrt{\frac{1}{n} \left( \sum_{i=1}^{n} \hat{y}_i^2 \right)}} )</td>
</tr>
<tr>
<td></td>
<td>U2 ( \sqrt{\frac{1}{n} \left( \sum_{i=1}^{n} \left( \hat{y}_i - y_i \right)^2 \right)} )</td>
</tr>
</tbody>
</table>

Note: \( e_i = y_i - \hat{y}_i \), where \( y_i \) is the actual value at time \( i \), \( \hat{y}_i \) is the forecast value at time \( i \). \( k \) is the number of parameters in the models. \( n \) is the number of observation used in the calculation.

### 4.3.3 Test for the time-series data

#### 4.3.3.1 Unit root

The econometric approach requires evaluation of the stationarity of every discrete time series because many of the macro-economic statistics are non-stationary, *i.e.* vary in terms of how they usually showcase a deterministic and sometimes stochastic drift. Most macro-economic variables are different stationary, \( I(1) \) variables. Therefore, the use of the first variances in econometric research is beneficial.

A variable is considered stationary if its mean and variance are time-invariant, and the autocovariance of the series by two-time periods relies simply on the interval. If a variable does not satisfy this statement, it is then said to be non-stationary. A variable of this kind has a time-dependent mean and/or variance. The need to keep variables...
stationary stems from the desire retains valid typical norms for asymptotic analysis in
the Granger test. Some alternative unit root tests used in time-series analysis include the
Augmented Dickey-Fuller (1979) (ADF), Philips-Perron (1988) (PP), Ng and Perron
(2001) (NP), GLS altered Dickey-Fuller (Elliott et al., 1996) (DF-GLS) and
Kwiatkowski et al. (1992) (KPSS). A point optimum unit root evaluation determines if
the sequence (at first or second level difference) is stationary.

An ADF test consents to sequential associations in the residual and also investigates for
unit roots. The chosen ADF test consisted of a time drift and slope in the level form and
only the intercept in the initial variation of every variable. One can adopt automatic lag-
length selection through the use of AIC and SIC and a supreme lag length of 9. The
Augmented Dickey-Fuller test was founded on this regression model:

\[ \Delta y_t = \varphi_0 + \varphi_1 t + \varphi_2 y_{t-1} + \sum_{i=1}^{L} \theta_i \Delta y_{t-i} + \psi_t \]  

(4.26)

where \( \psi_t \) is used to denote the error term for pure white noise that adjusts errors in
autocorrelation. It is independent and identically distributed. In the above equation,
\( \Delta y_{t-i} = y_t - y_{t-(i+1)} \), where the term \( \Delta y_{t-i} \) articulates the first degree of
differentiation with \( L \) lags. The terms \( \varphi_0, \varphi_1, \varphi_2 \) and \( \theta_i \) are under estimation in the
equation.

The regression test conducted under ADF is done in an effort to identify if there is a unit
root of \( y_t \). The variable denotes all variables in the expected logarithmic arrangement at
time \( t \). The test is done on the coefficient of \( y_{t-1} \) found in the regression. When it is
observed that the coefficient is less than zero \( (i.e. \text{significantly different from } 0) \), the
theory that \( y \) has a unit root can be rejected. The \( H_0: \varphi_2 = 0 \) and \( H_a: \varphi_2 < 0 \) of the
existence of a unit root in $y_t$ is the null and alternative hypothesis. Rejection of the null hypothesis implies stationarity in the statistics within the series.

Alternatively, one can use PP unit root tests because they offer a more comprehensive theory of non-stationarity in variables. The difference between ADF and PP tests is that the later uses non-parametric statistical techniques to fit in a reflex adjustment to the Dickey-Fuller process; it does not account for the functional nature of error development for the variable. The autocorrection meted to the procedure allows for autocorrelated residuals without necessitating the addition of lagged variance values to the dependent variable through adoption of the Newey and West (1987) covariance matrix. Even though the conclusions obtained are similar to those from ADF, calculations within the PP test are complex. In a PP test, the automatic selection for bandwidth is engaged and the Newey-West bandwidth spectral estimation is taken into consideration. The default estimator for the distinct unit root is the kernel sum-of-covariance estimator using Bartlett weights. Here, the null hypothesis for this unit root analysis is that the variable has a unit root.

The ADF-GLS tests recommend a simplified alteration of ADF unit root tests whereby statistics undergo de-trending using generalised least squares, removing the explanatory variables before running the regression test. The general assumption is that ADF-GLS has same supremacy as the Dickey-Fuller in terms of analysing the nonexistence of a deterministic tendency and enhanced supremacy when an unidentified deterministic drift exists.
The NP test consists of four separate test statistics founded on the GLS de-trended data. The values are improved types of Philips and Perron $Z_\alpha$ and $Z_t$ values, the Bhargava (1986) $R_1$ statistic and the Elliott et al. (1996) point optimal statistic from which the adapted test statistics are calculated.

The KPSS test is different from others due to the assumption that this series trends stationarily under the null hypothesis. KPSS statistics are fixed on residuals from the ordinary least-squares regression of the time-series variable on the exogenous variables. The recounted critical value statistics for the Lagrange Multiplier (LM) are established from some asymptotic outcomes observed at KPSS. In a KPSS test, one first reverses the null hypothesis that favours the unit root and the alternative hypothesis that proves stationarity so as to check if the series will reject the theory of stationarity.

### 4.3.3.2 Test for heteroskedasticity effects

Heteroskedasticity is the circumstance in which variance of a statistic is imbalanced across the range that a second value had predicted it would be located. The standard error module for panel data presumes that turbulences contain homoscedastic errors and continuous serial correlation via unsystematic individual effects. These could be constricting suppositions for many panel-data processes. The LM analysis is useful for identifying the presence of multiple correlations in addition to the chance outcomes obtained when a series exhibits homoskedasticity. When investigating ARCH effects, one may put to practice the LM test as explained by Engle (1982). Before a volatility model can be developed, there is need to evaluate the residuals of the mean equation for ARCH effects. The test is performed on the squared residuals of the calculated mean equation, and the null hypothesis being tested implies an absence of autocorrelation.
amongst them. The alternative hypothesis, on the other hand, declares that there is autocorrelation in the squared residuals. Rejecting the null hypothesis means that it can be accepted that evidence exists supporting the scenario that ARCH effects present. The researcher used 12 lags, as is done by Tsay (2005), amongst others.

4.3.3.3 Testing for VAR number of lags and stability

In model selection, two procedures were used to test the VAR model order $p$ by using the modified information and standard selection criteria. The significance of parameters was tested for each specific lag order of the VAR model ($p_n < p_{n+1}$). The null hypothesis is nested within the alternative hypothesis and can be tested by applying sequential modified likelihood ratio (LR) – the modified information criteria. The maximised log likelihood when a VAR is

$$l = c + \frac{m}{2} \ln|\vartheta^{-1}|$$

(4.27)

where $\vartheta$ is the variance-covariance matrix of the residuals from the VAR equations, with $k$ variables is fitted to $m$ observation points. When $p_n$ lags are used, the maximised log likelihood is

$$l_0 = c + \frac{m}{2} \ln|\vartheta_0^{-1}|$$

(4.28)

and when $p_{n+1}$ lags are used the maximised log likelihood is

$$l_1 = c + \frac{m}{2} \ln|\vartheta_1^{-1}|$$

(4.29)

The LR test is carried out as follows by starting from the maximum lag to test the hypothesis that the coefficients on lag are jointly zero using the $\chi^2$ statistics

$$LR = -2(l_0 - l_1) = m(\ln|\vartheta_0| - \ln|\vartheta_1|) \sim \chi^2(\psi)$$

(4.30)

It remains to determine the number of DF, $\psi$. Its value equals the number of restrictions imposed in determining the null hypothesis. Additionally, estimating $p$ using final
prediction error (FPE) and Model-develop (AIC, SC, and HQ) – standard informational criteria. For the FPE, a best model is the one that minimises the following:

\[
FPE = \delta_m \left( 1 + \frac{2p}{m - p} \right) \tag{4.31}
\]

where \( \delta_m \) is the residual sum of squares. Thus, a VAR model is selected that shows significant of LR and minimises the information criteria (FPE, AIC, SC and HQ).

The analysis of terms in a VAR model necessitates that involved variables be in a state of stationary covariance. A discussion of the inverse roots of the defined AR polynomial is provided by Lütkepohl (2005). The predictable VAR is believed to be stable, i.e. stationary, if every one of its roots contains modulus smaller than one and lies inside the unit circle. It should be observed that the restricted VAR fulfils the stability condition because no root is found externally regarding the unit circle. If the VAR is not stable, certain results such as impulse response are not valid.

4.3.3.4 Testing whiteness of VAR residuals

If a VAR\((p)\) model has been fitted to the data, two tests were used to check the whiteness of the residuals. First, the Portmanteau test checks the null hypothesis

\[ H_0: E(u_t u'_{t-i}) = 0, \quad i = 1, \ldots, h \]

against the alternative that at least one autocovariance and, hence, one autocorrelation is nonzero. The test statistic has the form

\[
Q_h = T \sum_{j=1}^{h} tr(\hat{\Gamma}_j^{*} \hat{\Gamma}_0^{-1} \hat{\Gamma}_j \hat{\Gamma}_0^{-1}) \tag{4.32}
\]

where \( \hat{\Gamma}_j = T^{-1} \sum_{t=i+1}^{T} tr(\hat{u}_t u'_{t-i}) \). If the \( \hat{u}_t \) are residuals from a stable VAR\((p)\) process, \( Q_h \) has an approximate \( \chi^2(n^2h - K^*) \) distribution under the null hypothesis. Here \( K^* \) denotes the number of estimated VAR parameters, not counting the parameters
related to the deterministic terms. The limiting $\chi^2$ distribution is strictly valid only if $h \to \infty$ at a suitable rate with growing sample size. The following adjusted portmanteau statistic is also available,

$$Q_h^* = T^2 \sum_{j=1}^{h} \frac{1}{T-j} tr(f_j^* f_{0}^{-1} \hat{f}_0^{-1})$$  \hspace{1cm} (4.33)

Second, an LM test for residual autocorrelation can also be constructed if parameter restrictions are imposed on a VAR model. This test is based upon the following auxiliary regressions:

$$\hat{u}_t = \xi_{1,1} y_{t-1} + \cdots + \xi_{1,p} y_{t-p} + \Gamma D_t + \xi_{2,1} \hat{u}_{t-1} + \cdots + \xi_{2,h} \hat{u}_{t-h} + \varepsilon_t$$  \hspace{1cm} (4.33)

where $D_t$ is the diagonal matrix. The null hypothesis is: $H_0: \xi_{2,1} = \cdots = \xi_{2,h} = 0$ and correspondingly the alternative hypothesis is of the form $H_1: \exists \xi_i \neq 0$ for $i = 1, 2, \ldots, h$.

The test statistic is defined as:

$$LM_h = T(n - tr(\tilde{\Sigma}_R^{-1} \tilde{\Sigma}_e))$$  \hspace{1cm} (4.34)

where $\tilde{\Sigma}_R$ and $\tilde{\Sigma}_e$ assign the residual covariance matrix of the restricted and unrestricted model, respectively. The test statistic $LM_h$ is distributed as $\chi^2(hn^2)$.

### 4.3.3.5 Multicollinearity

Multicollinearity comes about when there exist high correlations amongst two or more predictor variables. This situation implies that more than one variable can be used to predict the other, thus bringing into existence the problem of information redundancy. One can identify instances of multicollinearity by calculating the correlation coefficients for the provided statistics. Perfect multicollinearity exists when the coefficient $r$ is equal to $+1$ or $-1$ in preciseness. The condition statistic ($\tau$) is shown below:

$$k = \frac{\sqrt{\lambda_{\text{max}}}}{\sqrt{\lambda_{\text{min}}}}$$  \hspace{1cm} (4.35)
where \( \lambda_{\text{max}} \) and \( \lambda_{\text{min}} \) are largest and smallest eigenvalue, respectively. In the absence of collinearity, the eigenvalues, condition indices and conditional numbers shall all equal 1. As the value of collinearity escalates, eigenvalues shall both be larger and less significant when compared to 1. Any eigenvalues that are tending to 0 imply a multicollinearity issue. The increase in collinearity also sparks a rise in condition indices and numbers. According to Belsley et al. (2005), although informal, there exists a rule of the thumb that multicollinearity is a concern when the condition number ranges between values of 15 and 20. Any value that exceeds 30 shows that multicollinearity is a serious problem. The formal detection tolerance [or variance inflation factor (VIF)] for multicollinearity is shown here:

\[
\text{VIF} = \frac{1}{\text{Tolerance}} = \frac{1}{1 - R^2}
\]  

(4.36)

where a tolerance is less than 0.2 or 0.1 and the VIF is greater than 5 or 10 suggests multicollinearity problems.

### 4.4 Summary and conclusion

This study selects FF return of prices to investigate the effect of the hydrocarbon industry on CC over the years; the global oil, NG and coal index is used as a proxy for the global FF industry by using the FF marketing company listed on the global stock exchanges. This research also uses KSA oil index as proxy for the Saudi oil industry. FF prices data are collected from different trusted reliable sources and statistics database. Moreover, the CC data are collected from the global meteorology sources. The economics’ variable, global green index, obtained from the global stock exchange will provide a proxy way of measuring the ‘greening of our society’, based on changes in
policies advanced by developed nations of the world and global acceptance of the idea of clear energy.

According to the presented research methodology, a mixed method has been used. That is, different kinds of models will be built and applied using qualitative and quantitative methods. The methodology chapter has briefly outlined the qualitative (clinical interview) method, which will discussed in more detail in Chapter 5, whereas the application of time-series analysis model will be used to analyse the data gathered from the numerical databases. The times-series methodology will include ARIMA, ARCH/GARCH, ARCH family and the empirical models, namely volatility, VAR and CCA approach for studying links, generalised interdependence, cointegration processes and the linear combination of both set (FF and CC). The qualitative analysis will be applied to achieve the first aim of this study whereas the time-series univariate analysis and multivariate analysis methodology will be needed to study in depth the nature of the dynamic relationships between endogenous FF return pricing of the FF variables and the exogeneous CC variables.

This study will require the researcher to investigate in depth the individual, interaction and interdependence of two main processes, namely FF variables and CC; particularly the KSA’s and other producing countries’ FF prices over time. The study will also test whether the data show a persistent variance within their variations over time. The data will be investigated to check whether they are profoundly seasonal or increasing/decreasing at a faster rate. The change trends should be related to the more dramatic events, and these events will be focused upon for analysis. As noted, in achieving the above, a mixed research methodology will be applied: both quantitative
and qualitative. Using this well-established research methodology, the study will provide the best information and use the most appropriate analytical methods to achieve its aims and objectives.
Chapter 5

Qualitative Analytic
5.1 Introduction

Chapter 5 provides precise qualitative information necessary to achieve the aims of this research and answer the study questions. The chapter emphasises all subsequent steps needed to qualitatively answer the study questions and presents the research design for the qualitative analyses. Many studies have been conducted on the need to swiftly create and implement actions that would halt the substantial production and consumption of FFs and start the cause and call for CC mitigations around the world. As one of the major and wealthiest oil producers in the world, the KSA has also been the centre of discussion and attention on how they will address the CC issues of today. This study was conducted in order to understand the current situation of KSA, the issues and consequences that they face given the probability of the post-oil world, and what the possible actions and methods that can be undertaken in order to fully convince the KSA to support the call for CC extenuations.

Consequently, this chapter discusses the chosen qualitative research design, the criteria for selecting the participants, and instruments to be used in the interviews. Further procedures of data collection, assumptions and limitations, ethical assurances, the results from qualitative analyses and a discussion will be presented. The findings are followed by a summary of the qualitative research that conclude this chapter.

5.2 Rationale

With increasing pressure and calls for a greener future, the KSA is currently facing pressured to take a stand on CC mitigation. Given that their economy is majorly
represented by their oil revenues through their oil exports; while only a very minimal portion of their non-oil economy takes part in their development today, the KSA must now intensify their efforts to ensure their survival once the CC mitigations are fully implemented and agreed upon (Rieger, 2016). The KSA has long weathered many political and economic conflicts in the past which have affected its overall economy as well as its oil industry. The KSA survived all these struggles and conflicts mainly by using ‘oil as their political weapon’ in order to fight and have an advantage over other powerful countries (Haykel et al., 2015).

Today, however, the KSA is being challenged by the need to shift to a greener future, one that does not include or support the ‘burning of FFs’ and continuous mass extraction from their oil fields. It is thus not a surprise that KSA has been hindering the talks and formal processes seeking to build a framework that would fully implement global policies supporting CC mitigation. From the various conferences and conventions on CC, KSA has continued to confound various reasons and provide unclear stances towards the global vision to address CC issues. As Looney (2016) reported, other countries have negatively viewed KSA as a country that has indeed been actively refusing to agree on a global deal that would require them to limit their carbon footprints and output. This study should then address the gap on how KSA can sustain part of their economy in the process of ratifying deals on CC mitigation.

5.3 Nature of the analysis

This study uses a qualitative research design that aims to discover the current situation of the challenges that KSA faces to save their oil-based economy along with incessant demands to address CC issues. Interviews with the highest-ranking employees indicate
how they hold substantial responsibility in making managerial decisions and have access to data, climate actions and policies. Interviewees were from the Ministry of Energy, Industry and Mineral Resources, different Chief Executive Officers from FF companies and an economist (focus group). The interview answers were analysed using a qualitative thematic approach with the aim of discovering these participants’ most meaningful with regard to their experiences working in the oil industry. Sufficient information should then be available to allow identification of KSA’s background as an oil-based economy, their reasons for eluding formal agreements on CC, the consequences of CC mitigations on the nation and other producing countries and the future of the country and other exporting nations in a post-oil world.

According to Eisner (1991), qualitative research places emphasis on the ‘presence of voice in the text’ (p. 36), which implies that participants’ perceptions should be described and reported fully under that approach. Therefore, employees’ experiences as stakeholders of different FF companies in the Middle East would greatly help shed light on the economic and environmental issues that KSA is facing today. Eisner (1991) also discussed that a qualitative study employs various sources of evidence that can address the study’s questions. This description of a qualitative study matches the researcher’s aim to conduct interviews as well as validate them through interview notes and observations in the process of analysis.

According to Opdenakker (2006), face-to-face interview, by offering time-and-place synchronous communication, can provide the interviewer with much additional information that can enhance the research. Meanwhile, Patton (1990) highlighted that because qualitative studies place more significance on the meanings and interpretations
of participants’ perceptions and experiences, the number of interviewees is not strict as long as the researcher is able to capture the essence of the data. However, Guest et al. (2006) recommend that ‘saturation’ often occurs after 12 participants in a study. This is consistent with experience of Latham (2013) during a recent study where saturation occurred around 11 participants. In addition, for practical reasons Crouch and McKenzie (2006) stated that fewer than 20 participants in qualitative research helps an investigator build and maintain a close connection and hence improve the open and frank exchange of data. This can support mitigate some of the bias and validity threats inherent in a qualitative study. For practical reasons, the number of interview should be large enough to allow for diversity of options but small enough to permit everyone to contribute; around 7–10 participants is optimal, but can range from 3 to 15 (Morgan, 1996). Accordingly, the sample size for many qualitative research studies is 7–15 interview participants. Thus, 15 participants works very well for most qualitative interview studies.

Finally, the qualitative research was deemed more appropriate for this chapter as the statistical data from a quantitative study would not be sufficient to fully explain the economy and environmental issues; instead, the employees’ personal perceptions and experiences would be more useful in explaining the events, issues, consequences and future of the KSA and its economy amidst CC mitigation efforts.

5.4 Purpose of the qualitative analysis

The purpose of this chapter is to explore KSA’s current oil economy and environment as well as how their oil-based economy will be affected by the continuous calls for CC mitigation. Upon completion, the researcher aims to determine how the KSA’s oil
management structure came to be in the context of the extreme events they faced in the last decades. Moreover, the study aims to report on how KSA’s management sector dealt with various CC policies. The study will also report on how KSA is adapting to changes in CC policies occurring in the world today. Meanwhile, the researcher will also discuss the nature of relationships between FF production and prices in KSA and other producer countries both at present and in the future. Table 5.1 contains the complete and overall of the qualitative research questions (RQ) and thematic categories for RQ1.

**Table 5.1: Overall questions of the qualitative research.**

<table>
<thead>
<tr>
<th>Research question</th>
<th>Thematic Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>RQ2 How the KSA management structure of FF sector dealt with the CC policies such as KP (1997)</td>
<td></td>
</tr>
<tr>
<td>RQ3 How KSA is adapting to the changes in CC policies that appear in the world today − the consumers of FF who are now becoming more ‘greener’ − effects of the greening of our society</td>
<td></td>
</tr>
<tr>
<td>RQ4 The nature of relationships between the FF production and prices in KSA and other producer countries − in in past and present</td>
<td></td>
</tr>
<tr>
<td>RQ5 How KSA and other producer countries economy can survive without ‘burning FFs’ in future</td>
<td></td>
</tr>
<tr>
<td>RQ6 How the fuel energy powered in future can be cleaner, greener and sustainable − one that avoids CC phenomenon without lower the living standards in the KSA and other producer countries</td>
<td></td>
</tr>
<tr>
<td>RQ7 The consequences of the FF production and price fall or rise related to CC issues in the short-, medium- or long-term in relation to KSA and other producer countries</td>
<td></td>
</tr>
</tbody>
</table>

Further, the researcher also seeks to explain through participant interviews how KSA’s and other producer countries’ economies can survive without ‘burning FFs’ in future, as well as how future fuels can be cleaner, greener and sustainable – thereby avoiding CC phenomena without the need to lower citizen living standards in KSA and other producer countries. Finally, another aim is to review the consequences of the FF
production and price fall/rise related to CC issues in the short-, medium- or long-term in relation to KSA and other producer countries.

5.5 Theoretical framework

Chapter 5 presents the conceptual frameworks and theoretical orientation of qualitative part of this research. Chapter 5 specifies the theories used as a basis for this research, classifies the factors of greatest interest and defines the interconnection between FF and CC. The theoretical framework combines a number of questions and present an entirely original understanding of the topic. The conceptual analysis is based on the current body of literature for identification of gaps as well as development of a logical argument for the country of interest and interrelationships among FF exporting nations.

Eisenhart (1991) defined a theoretical framework as a foundation that guides research to further examine hidden layers of an issue that relies on a formal theory. The qualitative framework presented in Chapter 5 is largely based on the relevant information on economic and non-economic schemas. The importance of FF prices fully reflects all available information that justifies the use of movement in prices as a test of usefulness of economic and non-economic information. The information is deemed relevant if this evidence has a significant association with FF market values. However, behavioural economics theorists point out the existence of speculative mania and controlling the market as examples of human use of FF acting as the possible missing link that explains such anomalies in pricing FF.

The FF industry is facing greater policy risks and is subject to a relatively large range of theoretically significant fluctuations in future earnings, leading to possibly greater FF
market value variance. However, beginning in 1997, CC derivatives were offered, include a range of CC variables such as temperature, rain, wind and snow. To minimise the impacts of adverse CC, FF firms often bought climate derivatives to protect their investments. Greater predictability and stability tend to reassure investors and result in raised shareholder value. In essence, CC risks inject uncertainty in earnings and cash flows caused by non-catastrophic climate events such as hurricanes, floods, tornados and windstorms.

Correspondingly, given growing global efforts to reduce GHG emissions, shareholders could see the value of their FF industry investments drop (Dumas, 2006). The mitigation of carbon emissions brings opportunities and risks for the FF industry. On the opportunity side, alternative markets and product opportunities can be explored, which may affect the market value of the FF sector. FF-producing nations associated with hydrocarbons are shifting to greener and clean technological products. As a result of long-term capital investment and carbon-intensive products, the FF industry is significantly exposed to competitive and physical risks resulting from CC, which could significantly affect the wealth of shareholders by influencing their mood and decision-making and, consequently, the stock returns, and hence, the FF industry’s market value as whole. On the other hand, the risks include unpredictable changes in demand and influences on the supply chain, alteration in products and constraints in access to new reserves.

This study’s theoretical framework draws on paradigms from various fields such as environmental science and finance. The analysis that this study develops provides insights into the logical consequences of the possible interrelationship between FF and
CC. In addition, the FF industry serves as a classic example of decision making under uncertainty such that qualitative analysis will reveal vital information about climate policies and carbon-constrained economies.

### 5.6 Qualitative analysis design

The current research study’s qualitative research design uses a qualitative thematic analysis. The method of analysis was chosen for the study because it provides significance to the actual perceptions and meanings of the experiences of the individuals being studied. Thematic analysis involves steps such as investigating, pinpointing and recording of themes within a specific data set (Guest et al., 2011). Themes serve as the major categories for the analysis and assist in describing the phenomena, and they are related to the research problem under investigation. This method of research entails extensive description and organisation of data. Thematic analysis not only entails counting phrases but also identification of both explicit and implicit ideologies within a particular set of data (Guest et al., 2011).

Thematic analysis can be classified into two categories. The first category involves those methods that are theoretically and epistemologically linked. Methods in this category include interpretive analysis and conversation analysis. The second category involves those methods of analysis that are not tied to theory and epistemology and can therefore be applied to a range of epistemological and theoretical perspectives. The independence of the thematic analysis makes it a useful and flexible research tool that enables detailed and rich analysis of complex data.
This approach was chosen based on the logic that a rigorous thematic approach has the ability to yield an insightful analysis that answers particular RQ. Further, this method complemented the study questions by facilitating an examination of the interview data from the perspective of two different approaches: (1) a data-driven perspective based on coding in an inductive way and (2) the study question aspect to check if the data were consistent with the study questions and providing sufficient information. Therefore, conducting interviews with policy makers in the focus group of a FF company or an economist were seen as options out of many that give insight into the phenomenon under examination.

The sampling strategy used is often essential to the success of a case study because such persons not only offer insights into a matter but also can recommend sources of contrary or corroboratory evidence (Yin, 2013). Meanwhile, because interviews were the primary method of data collection, it was therefore vital to be mindful of the nature of the data collection method in earlier phases. The conceptual framework for this chapter on the thematic analysis of interviews was mainly based upon the technical positions of Braun and Clarke (2006). According to them, thematic analysis is used in identifying, analysing and also reporting of patterns or themes within a particular dataset. The thematic analysis is contingent upon six steps that help create and establish important themes and patterns as discussed next.

**Step 1: Data familiarisation**

This step involves researchers familiarising themselves with the relevant data to come to the analysis with some pre-knowledge of the data, and possibly approximately initial analytic thoughts or interests. Following the data collection process, the researcher
transcribes the data in written form. Sources of the transcribed data can include speeches, interviews and television programmes (in this case, interviews). The research ought to establish a criterion for data transcription before the transcription phase to increase dependability. Non-verbal and verbal conversations are drawn upon in this stage to aid in better understanding the collected data. After completion of this stage, the researcher ought to be familiar with all the data content, including identification of patterns. To ensure coding efficacy and accuracy, the patterns need to be recorded for reference purpose. Completion of the transcription process gives the researcher control over the collected data that address the question under investigation.

**Step 2: Initial code generation**

This phase involves the generation of original codes from the transcribed data. These codes assist in identification of the data features that are of interest to the analyst. The codes represent the segments and elements assessed to be present in the phenomenon under investigation. Coding entails data analysis although a difference exists between the data coded and analysed units. In this phase, the data are assigned tags and labels in accordance to the research question. The purpose of coding is to reconceptualise and transform the data.

**Step 3: Theme search**

This step involves reorganising the codes into themes. It entails analysis the codes and consideration of how different codes combine to create themes. Visual representations are employed when sorting the codes into themes. Additionally, mind maps and tables are used to organise the codes into themes. This step ends with the collection of all relevant themes and sub-themes.
Step 4: Review of themes

This phase of thematic analysis entails refining the established themes. Themes are refined in two levels. The first level reviews the themes at the stage of coded data extracts whereas the second level involves consideration of individual theme validity regarding the data set. This step presents the researcher with ideas about the different themes and their relation to the data.

Step 5: Naming and defining the reviewed themes

This step entails identification of the data aspects to be captured, the link to the themes as well as what makes the themes relevant. This involves writing a detailed analysis of the individual themes and establishing the background of every theme. Additionally, the themes are refined to ascertain whether they contain sub-themes.

Phase 6: Report delivery

This phase incorporates conducting the final analysis and writing up the end report. In producing the final report, the researcher should identify all themes that are helpful in addressing the RQ. The analysis should offer logical, coherent and interesting facts about the data in terms of the themes.

5.6.1 Challenges and strategies of thematic analysis

This method of analysis is not without challenges. The most common challenge in this method is the failure to conduct an analysis of the collected data. For example, thematic analysis requires deep scrutiny of the collected data, not merely collecting extracts and putting them together without analysing the contents (Antaki et al., 2003). On the same note, an unconvincing analysis can be the result of using limited examples from the data. Another challenge with thematic analysis is the probability that a mismatch will
occur between the data and associated analytic claims. In such a situation, the data presented are unable to offer adequate support for the claims or else they suggest another interpretation that contradicts the claims.

For a researcher to conduct an effective thematic analysis, various strategies ought to be utilised. For example, the collected data should be analysed for completeness and screened for coding. This ensures that the themes derived from the data are actual representations of the research question. Another strategy for effective thematic analysis is ensuring that the theories match the analytic claims of the research (Charmaz and Belgrave, 2012). Consideration of the above strategies will result in an effective thematic analysis for the problem under investigation, which ranks this approach amongst the best qualitative research methods available.

5.6.2 Questions and themes in thematic analysis

There is a limit to the number of questions that a piece of qualitative research can address in general. Qualitative research involves multiple questions, all of which require answers and usually involves a primary question that serves as the foundation of the project. Some RQ are broad in nature, and researchers attempt to answer them by honing in on specific questions that are facets of the broader question (Table 5.1). Therefore, attempts to answer such a narrow question may also provide a solution to the broader question. In addition to the overall question, qualitative research also involves asking questions that participants respond to in the course of interviews or focus groups (Guest et al., 2011). Additionally, questions guide data analysis and coding. The questions can be independent and not related in any way.
There are many ways of identifying themes in a thematic analysis. For example, one way of identifying themes is observing repetitive words in a dataset. Word repetitions in a given context represent the thoughts of the respondents. Another possible way of establishing themes in a thematic analysis is by understanding indigenous categories. This involves a search for local and unfamiliar terms in the given dataset (Dey, 1993). Finally, themes can be determined by looking at keywords in context.

5.7 Data collection, participants and analysis

The intent of this chapter is to gather and examine data regarding the perspectives of the research participants towards FF and CC. The central intent is to understand the issues and links between the management, policies and the future of energy and the environment as experienced by the interviewee. The main benefit of interviews is to gain insight into perspectives of issues and gather valuable information’s that enables the researcher to answer the study question. The researcher followed five steps in the process of gathering the data needed for the study from the focus group:

- First, the researcher sent an e-mail to the seven different FF organisations in the Middle East describing the purpose and aims of the study as well as contact information of the researcher. The e-mail also requested permission to allow the researcher to interview their employees.

- The second step entailed contacting employees who were allowed by their organisations to participate in the study. Upon further communication regarding what their role in the current study would be, the researcher then sent the willing participants a brief explanation of the research nature and contributors' rights. In this second step of the data collection process, the researcher asked participants about their most convenient time and method for the interviews to be conducted.
• The third step was conducting the actual interviews with the 15 participants. Interviews were audio-recorded and the researcher also took notes to assure that all data gathered were supported and validated upon completion. During the interviews, the researcher used a questionnaire or form that was created to ensure that all questions and concerns with regard to the study would be discussed and covered in the interviews. Furthermore, when there were unclear responses, the researcher asked the participants to repeat and clarify their answers.

• The fourth step was transcription of the recorded interviews whereby the researcher transformed the audio files into written documents. A large amount of words were generated from the interviews, even without the questions from the interview forms. These transcriptions were then sent back to the 15 participants for checking, which was the fifth and final step of the data gathering process.

• In the final step, the researcher performed a check by asking participants to review their transcribed interviews. Participants were allowed to edit or add their interviews responses if they deemed that the content recorded were incorrect or unfitting. This final step enabled the researcher to ensure that all data collected were accurate and thus valid for use in the data analysis or thematic analysis of the interviews.

The current study’s primary data source was the interviews conducted with 15 participants. These participants were chosen using a ‘purposeful’ or ‘purposive sampling’ whereby the researcher directly recruited participants from focus group deemed potentially able to provide the answers to the ‘information-rich’ case being
explored. Thus, the researcher only approached individuals possessing great knowledge and information regarding the RQ.

In addition, to compile and analyse the data, all participant responses need to be appropriately coded. After the coding of the interviews, the files were uploaded on *NVivo11* software (by QSR International) to analyse and organise unstructured data and allow the researcher to sort, classify and arrange information through activities such as establishing relationships or finding a unique statement that show different opinions in the data. This aids in the systematic tabulation of the number of occurrences and references of the formulated themes. It must be noted that the themes exhibiting the highest number of occurrences were considered the ‘major themes’ of the study (> 50%), while those with less-frequent occurrences or the unusual or unique statement that occurred from one participant were considered ‘minor themes’ of the study (≤ 50%).

### 5.8 Evidence of trustworthiness

When dealing with individual contributors, researchers should rigorously adhere to the following considerations. Interviews can considered an intrusion into respondents’ private lives with regard to time allocated, sensitivity level of questions asked, and high standard that should be maintained. Hence, these elements should be examined at all phases of the interview process. That is, interviewers should provide attain informed consent before participants actually contribute to the research: a critical stage that investigators should adhere to during the whole study project. However, a challenge to investigators would be openness of the interview circumstances because participant familiarity with these may lead them to more disclose information.
Informed consent contains information that protects the participants’ rights avoids causing them any harm. Investigators should assure that that respondents’ personal information is kept strictly confidential and anonymous, e.g. with pseudonyms used in place of actual names and ensuring that all recorded data about their identities will be safeguarded for five years and destroyed thereafter. More importantly, however, participants should be told that their participation is voluntary and know they can withdraw from the research without giving any reason and with no penalties and consequences; participants also have to know that they will derive no direct benefit from participation in the research.

The following confirms that the methodology of the current study follows the criteria and characteristics of qualitative research. The first criteria achieved in the study was credibility. To ensure the credibility of the study findings, the recruited participants had years of experiences and knowledge on the process and conditions of the FF market/industry and CC policies. Through interviews, their knowledge was discovered by their recounting their first-hand perceptions and experiences. The second principle was transferability of the study, wherein employees from different FF companies in the Middle East guaranteed that the perceptions gathered included data that could be generalised under various contexts and settings. Accordingly, the data may also be applied by other major oil-producing countries in their transition to the probable post-oil world. Finally, dependability was established as the researcher noted the main points of the participants' interviews while listing observations to support the participants’ responses. Furthermore, response-checking was also performed during the final step of the data collection to ensure that the data were correct, clear and complete for data analysis.
5.9 Empirical analyses

The findings of this chapter were derived from the qualitative thematic analysis of the focus group. This section will present the findings developed from the data gathering and examined using the theoretical framework constructed for this chapter. No participants from the chosen focus group withdrew or cancelled their interviews. In addition, there are two key approaches to writing up the qualitative research results (Burnard et al., 2008). The first is simply to report main findings under each major and minor theme or category, using appropriate specific quotes to exemplify those findings. This is accompanied by a separate discussion linking to the chapter discussing the results in relation to the existing study. The second is different in that it incorporates the discussion into the results, but otherwise it is the same. Each research question in this chapter was used as a thematic category or basis of analysis in order to adequately address them later on. Only one appropriate verbatim quote was used that was judged to be vital and that presents the theme of each RQ. Figure 5.1 contains an overview of the analysis process in the qualitative method.

![Figure 5.1: Conceptual representation of iterative process of qualitative analysis.](image)

5.9.1 Qualitative RQ1 findings

Extreme events refer to events that cause disruptions in the political power and economies of oil-producing countries. These extreme conditions are mostly political in
nature and may include but are not limited to political conflict. Political conflict can be instigated by either internal or external influences. The Gulf has had many years of conflict, which in turn threaten oil production/prices and management. Given that the oil sector is ‘very’ volatile, there is a need to have proper systems of management in place. KSA has always been a keen participant in the region’s oil industry. The concern of this study is to analyse the responses of KSA management in these critical times. Thus, the first question addressed through thematic analysis of the interviews focused on KSA’s management structure of FF production and prices in extreme events. From the analysis, four major themes emerged, all addressing how the KSA management structures were impacted by political events and conflicts. Table 5.2 contains the findings from the qualitative analysis for RQ1.

Table 5.2: Breakdown of themes analysis for RQ1.

<table>
<thead>
<tr>
<th>Thematic categories</th>
<th>Theme</th>
<th>Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Tally</td>
</tr>
<tr>
<td>Part I</td>
<td>• Posing of embargo by cutting of oil production, leading to surging oil price inflation.</td>
<td>15</td>
</tr>
<tr>
<td>Part II</td>
<td>• Ensured the ability to regulate and maintain the competitiveness of the oil price market coming from another oil production and price shock.</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>• Flooding the market with cheap oil to attract new clients and reduce the competition.</td>
<td>1</td>
</tr>
<tr>
<td>Part III</td>
<td>• Ensured the stability of oil supply and global market price.</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>• Ensured growth and prosperity for KSA and other OPEC members.</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>• Opened the issue of the diminishing environmental resources.</td>
<td>1</td>
</tr>
<tr>
<td>Part IV</td>
<td>• Continued oil production over the years; developed KSA’s economy further despite the crisis.</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>• Highlighted the importance and role played of the KSA’s oil production.</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>• Emphasised the status of KSA with its weight over market competitiveness.</td>
<td>1</td>
</tr>
</tbody>
</table>
Chapter 5  Qualitative Analytic

**RQ1 thematic categories Part I findings**

The first event was the Yom Kippur War in 1973, which was the first conflict believed to have majorly affected the oil market and its structure. Under the first category, one major theme emerged and resulted in the imposition of an embargo by cutting oil production, leading to surging oil prices. This event displayed KSA’s influence over oil production and price to the global community. All the focus group participant identified the following theme.

**Major Theme 1: Imposing of an embargo by cutting of oil production, leading to surging oil prices**

Participant (A2) stated that the 1973 conflict led to the first oil crisis, which resulted in oil price rises that greatly affected industries, companies and consumers as a whole. Furthermore, as KSA and other Arab nations cut their production, the resultant price shocks scared consumers and heightened the energy crisis, which was felt around the world. This move led the oil prices to rise up to ‘four times’ and NG price inflation reached high percentage in six months, which also greatly affected various countries’ economies:

> The first oil prices crisis of 1973 resulted in escalating inflation and a price spiral that directly affected consumers and various industries. Arab nations cut production, thus creating the FF price shocks, consumer panics and a consciousness of an imminent energy crisis. The effects of the price pressures would be felt in the future. By the time the embargo ended, oil prices went up from $3 to $12 and led to soaring gas prices (400% in 6 months) and contributed to a major economic downfall in America and other countries. This situation caused a staggering economic blow. Estimates showed that, for example, the extrapolated future cost to the US would equal the deadweight tax of up to 5% of gross national product in continuity (Interviewee (A2), Researcher, 2017).

**RQ1 thematic categories Part II findings**

From this conflict, another major theme shared by focus group participants emerged. Almost all interviewed participants indicated that the second event ensured the ability to
regulate and maintain the competitiveness of the oil price market coming from another oil production and price shock. From the qualitative analysis of the interviews with the focus group participants, one minor theme was also developed.

**Major Theme 2: Ensuring the ability to regulate and maintain competitiveness of the oil price market coming from another oil production and price shock**

Furthermore, Participant (A5) again echoed how the 1979 crisis led to the formation of KSA’s policy to be implemented as a response to threats of instability and price shocks. Participant (A5) explained how KSA (key player) succeeded in working with other OPEC members during the Iraq-Iran conflict to minimise potential worldwide effects of the pause in production from Iran, shocking oil price inflation and another potential energy crisis within the same decade. Fossil fuel management was strengthened wherein strategies to regulate both supplies and prices were developed in order to stabilise the oil market around the world:

> In 1979, another oil crisis occurred and it was spurred by the events in Iran. To deal with the market disturbances OPEC institutionalised adjustment strategies that, today, impact price volatility and dismay measures for market stabilisation. Since Iran had been one of OPEC initiators, the Iranian revolution and the Iraq-Iran conflict strongly affected FF governance in KSA. These events had seriously halted oil production in Iran, thus leading the oil prices to a record high and causing another global energy crisis in the same decade. By adjusting their supplies and prices, KSA and other OPEC members tried and succeeded to stabilise the situation. Today, the price of FFs varies for a number of reasons and KSA to have powerful influence over the global markets (Interviewee (A5), Researcher, 2017).

**Minor Theme 1: Flooding the market with cheap oil to attract new clients and reduce the competition**

Participant (A7) shared how KSA established strategies that would guarantee an oil supply to new customers as well as monitor prices accordingly. KSA benefitted from the 1970s conflicts because it flooded the oil market in order to dominate oil supplies at
that time. This event displayed KSA’s oil power by increasing their production capacity and their control over most importing countries needing oil:

Oil prices inflated and the world was deemed to be experiencing another oil shock similar to the one in 1973. This event was less burdensome to market but led to uncertainties in terms of global oil supply and consequent higher prices because the length of time shock. However, KSA took the chance to flood the oil market to get import clients and reduce the competition by creating lack of technology and capital for the conflicting parties. Through modifications of its own supply and prices, KSA acted as a key player in ensuring the controllability of the global oil markets. (Interviewee (A7), Researcher, 2017).

**RQ1 thematic categories Part III findings**

The third event discussed was the Gulf wars in 1991 and 2003. More than half of the focus group participants believed that the KSA served to ensure stability of the oil supply and its global market price. Regarding this event, the analysis also had two minor themes or other significant perceptions.

**Major Theme 3: Ensuring the stability of oil supplies and global market prices**

Participant (A6) shared how another political conflict allowed KSA to act as stabiliser of the global oil market. With Iraq’s inability to fully function and produce oil due to its political instability, KSA again saved the global oil market. KSA compensated for the loss of supply and aided in stabilising the oil market and oil prices:

Gulf oil exporters were (and still are) crucial important suppliers of oil to the world economy. This significance and growing oil import dependence was the main reason for the US intervention in the Kuwait crisis during the 1990s. KSA identified itself closely with the economic and political interests of the US and the major European states, while taking into account the balance of forces in the GCC. The 1990 ‘oil shock’ of went out to be much less severe than the two oil crises of the 1970’s. After the loss of Kuwaiti and Iraqi supplies, the prices of oil initially rocketed from $18 (pre-invasion) a barrel to slightly above $40. But they fell back to roughly $21, as greater shipments came in from other producers and global demand lagged. In that light, the crisis underestimated the unique position of KSA. Not even the total boycott of Iraqi and Kuwaiti oil was of great significance to the global economy as long as KSA boosted its output to compensate for the supply loss (Interviewee (A6), Researcher, 2017).
Minor Theme 1: Ensuring growth and prosperity for KSA and other producing countries

In the interview, a participant shared the said theme, stating that these conflicts provided growth and prosperity for KSA and other producing countries. Participant (A9) had a different perspective on KSA’s role during the two Gulf wars. For Participant (A9), KSA manipulated the oil price and delayed other countries’ growth and progress:

The two Gulf wars were events that further confirmed the notion that oil is the strategic resource of the modern world and way for growth. Saudi Arabia positioned itself as a pro-western country ally and once again had the crucial role in harmonising the global oil market. Both events were ‘oil wars’ resulting in price shocks which on the one hand have provided wealth and prosperity for the swing producer KSA and other OPEC members, while hindering the growth and development of other countries (Interviewee (A9), Researcher, 2017).

Minor Theme 2: Opening the issue of diminishing environmental resources

Only one of the focus group shared the said theme; Participant (A14) opined that the Gulf wars, which were oil-centric conflicts, affected and opened the eyes of the more developed countries regarding the need to review environmental protection given the economic and global changes happening at that time:

The two Gulf wars were oil-based wars and American invasions of Iraq. During the 2008 downcycle, the world faced a decline in oil prices which significantly reduced the profits and growth of oil producers from exporting countries such KSA. These events have affected the perspective of the developed countries on subject of FF extraction, renewable energy, as well as macro-economic policies and conventions tackling CC and environmental protection (Interviewee (A14), Researcher, 2017).

RQ1 thematic categories Part IV findings

The fourth conflict that affected the global oil market structure was the global financial crisis in 2007–2008. The NVivo11 software indicated that only one major and two minor themes could be derived from the thematic analysis of the interviews. The
participants believed that KSA’s decision to have continue their oil production despite the crises in previous years further developed their economy.

**Major Theme 4: Continuing oil production over the years developed KSA’s oil sector further despite the crises**

Participant (A1) explained KSA’s commitment to be the top source of oil. Amidst the 2007–2008 global financial crisis, the KSA kept pumping and propelling their oil fields. As the other countries were economically suffering, the KSA was busy developing and strengthening their oil power:

> While many economies around the world were severely and negatively affected by the 2007–2008 global financial crisis, the Saudi economy demonstrated resilience and strong economic growth in spite of oil price fluctuations in 2008. When the global economy was teetering on the brink, KSA’s oil wells kept pumping, developing and discovering oilfield. It is vital to note that the KSA still holds over 20% of the world ‘proven’ oil supplies, and it is rumoured that the likely figure is closer to 40%, due to undeclared oilfields (Interviewee (A1), Researcher, 2017).

**Minor Theme 1: Highlighting the importance and role played by KSA’s oil production**

Participant (A12) echoed how KSA was able to prepare for the global financial crisis that occurred in 2008. For Participant (A12), KSA reduced their oil production compared to previous years in order to balance the global oil market and prevent price drops in order to gain more profit (production costs between $2 and $5):

> During the 2007–2008, the occurring fall in oil prices took place against the backdrop of the global financial crisis. Economies all around the world slowed down and the demand for oil dropped greatly. KSA decided to undertake its common actions. By cutting production it sought to bring stability to global prices. Even though many of the world economies were experiencing a downfall, KSA achieved steady growth both in the oil and non-oil sector. This growth was driven by the previous surpluses from oil production and the policies the country implemented during the time. However, the cost of production varies between the oil field, but general the cost of Saudi oil averages well under $5/bbl, most likely in the $2 to $5 range (Interviewee (A12), Researcher, 2017).
Minor Theme 2: Emphasising the status of KSA’s weight over market competitiveness

Participant (A3) discussed how the KSA did not lower its oil production as befitted a key player in the global financial crisis. Contrary to the other producing countries decision to cut oil production given the lack of global demand for oil; the KSA used their surpluses and maximise the previously established oil policies that benefitted them greatly:

During 2007–2008, the occurring fall in oil prices took place against the backdrop of the global financial crisis. Economies all around the world slowed down and the demand for oil dropped greatly. The producing countries such as OPEC decided to undertake its common actions. By cutting production it sought to bring stability to global prices. KSA had a small decrease in oil production in the first quarter and steady production (2nd and 3rd quarter) and rise the oil production by the end of the year. This was mainly the result of large oil revenue surpluses during the previous years which were utilised to and were able to use these cover shortfalls of profit in 2007 and 2008. KSA was not interested in a repeat of previous events, in which it bore the burden of slashing production, and increasing prices for other producing (who continued producing at the same pace), thus hurting its own bottom line. In spite of hurting its own bottom line, Saudi Arabia experienced economic growth in the 2007–2008 period and further backed up by petrodollar reserves from the past. The KSA adopted a policy of defending their market share and finding new clients even with global benchmark prices low (Interviewee (A3), Researcher, 2017).

5.9.2 Qualitative RQ2 findings

CC has been an issue of concern and scientists have warned that global warming poses big dangers to human survival on the continent. In light of these imminent threats, the world’s powers countries came together to chart the way forward to manage CC. After the COP meeting, CC policies demanded that all countries observe measures to scale down and possibly eliminate the threat of global warming. This subsection addresses the reaction of KSA to such climate policies that may affect production, prices, sale and distribution in the FF sector. Thus, the second question addressed in the study was how the KSA’s FF-sector management structure dealt with CC policies. One crucial protocol
and Action Plan included in the exploration of this study is the KP (1997). One major and three minor themes were discovered to address and discuss the second research question (Table 5.3).

Table 5.3: Breakdown of themes in analysis for RQ2.

<table>
<thead>
<tr>
<th>Thematic</th>
<th>Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Promised to invest on environmental protection and CC justification; however, target results were not achieved.</td>
<td>11 73%</td>
</tr>
<tr>
<td>• Position of KSA as major oil-producing country and the revenue of FF sector under Kyoto policy.</td>
<td>4 27%</td>
</tr>
<tr>
<td>• Identification of ‘developed and developing’ countries as well as focus on technology and finance.</td>
<td>2 13%</td>
</tr>
<tr>
<td>• Reviewing formal agreements; demand fairness in the policies.</td>
<td>2 13%</td>
</tr>
</tbody>
</table>

Major Theme 5: Promised to promote and invest on environmental protection and climate change justification; however, target results were not achieved

Participant (A2) also echoed how the KSA approved of and supported the KP, wherein they pledged to invest a significant amount of money in order to push forward environmental protection and other acts to address CC. However, the participant stated that the KSA was also censured because they did not fulfil their promise for support:

The KSA ratified the KP. In accordance with the requirements of the Protocol, the Kingdom agreed to invest significant amounts of money in support for environmental protection and CC mitigation while reaching the set GHG targets. However, the country has often been criticised for not achieving much in that segment and production level. KSA stated their concerns associated to actions aimed at CC mitigation and environmental protection with a specific emphasis on the differentiation of obligations between developing and developed countries (Interviewee (A2), Researcher, 2017).

Minor Theme 1: Position of KSA as major oil-producing country and the revenue of FF sector under Kyoto policy

Participant (A6) stated that KSA was willing to adhere to regulations intended to lessen the effects of CC arising from emissions of their oil production. However, they also
warned that such modifications would greatly affect the overall structure of their economy, which is majorly focused on oil as their main resource:

CC had an impact on FF management in KSA and producer oil countries. These conventions are among others such as The KP (1997). KSA has approved the KP on CC. Upon signing the Protocol, KSA expressed the hope such a framework would slow CC, but it also highlighted the fact that it expects to lose billions of dollars in oil market as signatory countries take steps to reduce their GHG emissions (Interviewee (A6), Researcher, 2017).

Minor Theme 2: Identification of ‘developed and developing’ countries as well as focus on technology and finance

Participant (A10) stated that the KP indicated a need to identify the difference between roles that should be filled by developing and developed countries. Furthermore, the KSA expressed the need to further develop technology and finance that would help them achieve their goals to mitigate CC:

With respect to the KP, KSA clearly stated that the Action Plan was not created to replace or supersede the UNFCCC. KSA opined that the focus of the plan should be on technology and finance which are enabling developmental factors. Furthermore, KSA advocated the role of developing countries in the future management of GHG emissions, a topic that was strongly underscored by the Plan (Interviewee (A10), Researcher, 2017).

Minor Theme 3: Reviewing formal agreements; demand fairness in policies

Participant (A7) emphasised how the KSA fought strongly to ensure fair CC enforcement for developing countries. Such efforts should ensure a reasonable distribution of obligations related to CC mitigation among the world's biggest polluters. This should help avoid changing CC mitigation obligations to focus on developing countries:

KSA has been arguing on behalf of all OPEC members that itself and other oil-producing countries are unfairly targeted by CC mitigation policies. The KSA’s negotiating position is reasonably advanced not only [from] the perspective of protecting its private national interest but also in confirming that developed countries comply with current treaty commitments without completely shifting the responsibility and consequences unfairly to the developing world. This policy should be aimed to oblige realistic and reasonable efforts by the world’s
biggest sources of pollution to finally give back and prevent further environmental damages from occurring. Moreover, KSA continued examining and promoting the rights of the developing countries (Interviewee (A7), Researcher, 2017).

5.9.3 Qualitative RQ3 findings

The world is dynamic, especially in the light of technology and globalisation. The campaign to end globalisation and to promote green energy has become a global phenomenon. Most people now demand green energy in their homes and offices. This may affect global FF consumption. In fact, research suggests that global consumption of FF may decline in the next decade. Therefore, there is need for the oil-producing countries to develop strategies that will help them survive in the face of the threat from green energy production. Thus, RQ3 of the study was to examine how KSA is adjusting to the changes and modifications in CC policies currently emerging. The question asked how KSA is planning to respond to FF consumers who are now becoming greener. From the thematic analysis of the interviews with the focus group, one major theme and two minor themes were developed. Table 5.4 contains the themes that address the third research question of the research.

Table 5.4: Breakdown of theme analysis for RQ3.

<table>
<thead>
<tr>
<th>Thematic</th>
<th>Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>■ Developing research on renewable technology to address CC policies.</td>
<td>9   60%</td>
</tr>
<tr>
<td>■ Eluding clean environment of our universe and society efforts.</td>
<td>3   20%</td>
</tr>
<tr>
<td>■ Developing policy programs targeted to the renewable energy awareness.</td>
<td>4   27%</td>
</tr>
</tbody>
</table>

Major Theme 6: Developing research on renewable technology to address CC policies

This major theme was mentioned in nine responses by interview participants. Participant (A11) stated that with the greater calls for a greener society, KSA has been
working on gaining more investors in order to develop their technology targeting research into renewable sources. However, they were more concerned about the need for technological assistance to develop their other options with the call for a greener future:

KSA is concerned that discussions on mitigating the effects of CC tend to point out oil and carbon-based fuels as the problem, rather than trying to reduce all GHG emissions as defined by the UNFCCC. Further, KSA is working on the development of technology transfer, specifically on renewable-energy sources and in attracting foreign direct investment in these domains. With respect to work and development towards a greener economy, KSA is recognised as a developing economy in the UN climate meetings, the world’s rich countries are hesitant to invest their own resources to help the Kingdom transition to a greener economic model. On the other side of the spectrum, the KSA petroleum minister said that the people of KSA believe that FFs not only should, but will be part of the global climate solution in future. In addition, they believe that science should not be the premise for addressing issues and efforts related to CC (Interviewee (A11), Researcher, 2017).

Minor Theme 1: Eluding clean environment of global and society’s efforts

This was observed by 20% of the total sample population interviewed. Participant (A3) explained how KSA has been evading greening efforts. For this participant, KSA has been working to improve the talks and formal agreements on greening as they are in danger of being affected by a reduction in their revenue and the downfall of their oil-based economy:

KSA has recognised the fact that in the long-term, we will be talking about a post-oil global economy. However, the role the country has played in the creation of various conventions on greening implies that this transition might not be smooth since it puts the current social reality of the Kingdom at risk. Even though the Kingdom represents one of the richest and most propulsive countries of the world, it is still viewed as a developing country in terms of environment protection and greening of the world. A major drawback of the Kingdom’s adaptation lies in the fact that despite its economy growth it is keen on evading new policies and initiatives that will, in part, cut down the oil-generated revenues. The KSA recognised the need to diversify its economy and to become less carbon-dependent. Nevertheless, KSA and other oil producers will take an active role in the mitigation processes only if the developed countries provide funds and other forms of support (Interviewee (A3), Researcher, 2017).
Minor Theme 2: Developing policy programs targeted towards renewable energy awareness

Four participants shared the theme of the current qualitative study for RQ3. Participant (A8) explained the Vision 2030 document produced by KSA with the aim of addressing key issues of CC mitigation. They identified the importance of renewable-energy sources as their main solution and a retreat from their oil-based economy in the future:

Recently, KSA has been taking a more proactive approach towards sustainable development in the post-oil economy. The 2015 strategy named Vision 2030 is one of the county’s latest accomplishments in addressing CC and development. This program identifies renewable energy as one of the backbones of economic diversification away from oil. The target set by this plan refers to the production about 9.5 gigawatts of power from renewable-energy sources. Parameters impacting the novel energy mix development include (1) the development of an adequate value chain; considering the economics of hydrocarbons saved; (2) processes of desalination and electricity management; (3) demand patterns; (4) technology issues and developments; and (5) physical and regulatory frameworks and requirements. The Kingdom has taken on various initiatives in developing the renewables sector but also in improving the performance of FFs. Much hope is put into the solar energy revolution as one of the key drivers of future development (Interviewee (A8), Researcher, 2017).

5.9.4 Qualitative RQ4 findings

The FF industry is multifaceted and has many players and stakeholders. Research has shown that the decisions and policies of one FF-producing country may affect the prices of FF in another country. Therefore, there is need to analyse the relationship between oil-producing countries and the prices of their fuels. This is important because it helps explain what has informed the prices of oil around the world in the past. Thus, the fourth research question of this study is an inquiry into the nature of links between FF production and prices in KSA as well as other major producers of FF around the world. In RQ4, the analysis found one major theme and one minor significant perception. Table 5.5 reports the themes of the study and frequency of their appearance.
Table 5.5: Breakdown of theme analysis for RQ4.

<table>
<thead>
<tr>
<th>Thematic</th>
<th>Occurrence</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• At present, supply and prices are steady or even low despite the political and economic conflicts; KSA and other exporting countries still refuse to reduce oil production.</td>
<td>11</td>
<td>73%</td>
</tr>
<tr>
<td>• During the past, political and economic issues heavily affected the FF supply and demand; with shocking price inflations.</td>
<td>4</td>
<td>27%</td>
</tr>
</tbody>
</table>

**Major Theme 7: At present, supply and prices are steady or even low despite political and economic conflicts; KSA and other exporting countries still refuse to reduce oil production**

The 10th major theme was mentioned by 87% of respondents. Participant (A5) indicated that at present, KSA and other producers has refused to cut or show significant decreases their oil production despite low oil prices and surplus supplies. This act indicates a change in their oil policies, especially for Saudi. Although it has been reported that oil prices are expected to increase going forward, the current trend is a steady decline in energy services:

As compared to past actions of raising or lowering oil production to balance global oil markets, KSA did not cut petroleum production in late 2014–2015, even as oil prices went down and global supplies of oil rose. There was perceptible anxiety between the producers from declining their oil production. Still, the US produced more than twice the hydrocarbons as KSA in 2015 as the global report point. Additionally, there is currently no indication now [that] KSA plans to have remarkable reductions in its current level of petroleum production. Studies show that sustained growth for oil and rising or continued high prices are the most likely trends with respect to estimates of population growth, prosperity, lifestyle, [and] demand in the industrial sector (Interviewee (A5), Researcher, 2017).

**Minor Theme 1: During the past, political and economic issues heavily affected the FF supply and demand, with shocking price inflations**

Participant (A2) echoed how important political and economic occurrences have affected oil production and prices in KSA in the past. Previously, when disturbances arose, oil prices would normally increase and demand from the developed countries would greatly surge or grow as well:
Significant political and economic events in the past have had an impact on the price of FFs in KSA and the rest of the world. Past experiences have shown that during war times, oil prices would normally go up because big suppliers in the Middle East were often at war, whereas developed economies (e.g. US, some Asian countries) were simultaneously facing growing demand as a result of economic growth. In addition, the other producing countries cannot cover the need and demand leading to increase the oil prices, [so] here comes the role of Saudi (Interviewee (A2), Researcher, 2017).

5.9.5 Qualitative RQ5 findings

The debate over green and sustainable energy has come to the forefront. Despite the efforts of oil companies and oil-producing countries to affirm their confidence in FFs even in the face of green energy, doubts remain that KSA and other exporting countries can maintain their positions in the future. Therefore, there is need to investigate the alternatives that oil countries have for the future. Hence, through the qualitative thematic analysis of the interviewed with the focus group, majority of the participants indicated that the KSA and other countries may start concentrate on the evolution of the non-oil sectors by diversifying their economy. Meanwhile, one minor theme that emerged was the act or method of increasing use renewable-energy sources (Table 5.6).

Table 5.6: Breakdown of the theme analysis for RQ5.

<table>
<thead>
<tr>
<th>Thematic</th>
<th>Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Focusing on diversifying their economy or the development of the non-oil sectors.</td>
<td>12 80%</td>
</tr>
<tr>
<td>- Focusing on renewable-energy sources and energy storage.</td>
<td>7 47%</td>
</tr>
</tbody>
</table>

Major Theme 8: Focusing on diversifying their economy or development of the non-oil sectors

According to the 11th major theme of the study, all 12 of the participant interviewed revealed the need for diversifying their economy away from the FF sector and boosting the growth of other sectors. Participant (A8) lengthily explained that as an oil-producing
country and a nation that has built its wealth through their FFs, it will be extremely difficult to transform and shift both their economy and mindset as a nation. For Participant (A8), KSA must now start to diversify their economy. This means that the KSA must start developing their non-oil sectors and find a way to survive and flourish without burning FFs in the coming years:

Surviving without FFs in the future poses great challenges for both oil-exporting and oil-importing countries. The world’s dependence on FFs is summed up in the concerns of the G20 and the International Monetary Fund on whether the next financial breakdown will be caused by bursting of the carbon bubble. In the unlikely scenario that all investors pulled out of FFs at once, the result would be much more dangerous than in 2008. In order to research survival in the post-oil world, KSA and other countries have to intensively work on the diversification of their economy. The process of diversification does not only assume shifting to renewable or cleaner energy, but also requires a paradigm shift towards the development of the non-oil sectors. KSA has played around with diversification of its economy for many years with limited success. Its economy remains dependent on hydrocarbons. In KSA, part of the problem is the conservative nature of the economy which has impacted educational system and the business climate, and the labour market dependent on expatriate skills etc. All these factors limit the flow of foreign direct investment into the Kingdom which would strengthen the non-oil development. In that light, the post-oil future of KSA (and many other countries) calls for changes in policies and the mindset of the government which would spill over to the business sector and other dimensions of the society (Interviewee (A8), Researcher, 2017).

**Minor Theme 1: Focusing on renewable-energy sources and energy storage**

Another important perception was the need to concentrate on alternative-energy sources, which was shared by 47% of the participants. Participant (A4) shared that exploitation of the environment is no longer acceptable given that the past and current generations have largely destroyed it. Therefore, KSA must work to develop and advance their renewable resources available in order to save and sustain the environment. The participant highlighted that there is a need for KSA and its people to strongly commit to reforms in order to achieve successes and improvements in the future:
Living on the exploitation of FFs is no longer possible in terms of environmental sustainability. KSA and oil-producing country have to shift towards renewable energy and energy storage. These countries have potential for renewables mainly due to climate conditions and geography. However, this potential has to be realised and accompanied with great reforms of the economy and the society (Interviewee (A4), Researcher, 2017).

5.9.6 Qualitative RQ6 findings

Perhaps the biggest dilemma that KSA and other exporting countries are facing is how to make their fuel ‘clean fuel’. The demands placed upon oil-producing countries to produce clean energy are massive. Therefore, there is a need for these countries to figure out how they are going to eliminate harmful products such as CCs from their fuel sources. In addition, oil countries have to figure out what to do in case oil production is affected in the future. A major question is what measures have been put in place to mitigate any future economic crisis in case oil prices plummet. Thus, the sixth research question concerned the energy of the future and the living standards of FF-producing countries in terms increasing renewable energy. The analysis of the interviews indicated three themes, with two major themes and one minor theme found from the data (Table 5.7).

Table 5.7: Breakdown of the theme analysis for RQ6.

<table>
<thead>
<tr>
<th>Thematic</th>
<th>Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changing the mindset of the Saudi Arabians on their perceptions on clean and renewable energy.</td>
<td>8 53%</td>
</tr>
<tr>
<td>Maximising and developing the KSA’s abundant renewable-energy sources.</td>
<td>8 53%</td>
</tr>
<tr>
<td>Developing formal and fair agreements between countries and companies.</td>
<td>4 27%</td>
</tr>
</tbody>
</table>

Major Theme 9: Changing the mindset of Saudi Arabians regarding their perceptions of clean and renewable energy

This theme of RQ6 concerned the need to shift the attitude of Saudi Arabians in terms of their understanding and acceptance of green energy. The dilemma centred on the
relative importance of the economy versus the environment. The major theme received eight mentions by the study population. Participant (A8) shared that the living standards in KSA and other countries will not be lowered as long as these countries are able to prepare for and realise the impact of living in world with clean energy. The participant then added that citizens of oil-producing nations must realise the abundance of renewable energy in their lands and turn their attention to developing them instead of trying to perpetuate FF-based economies:

The world has anticipated the transformational impact of ‘green energy’. Clean energy can refer to a variety of solutions from electricity, wind and solar energy to biomass. In the case of KSA, a ‘greener’ future would presuppose the usage of solar power. Along with having some of the world’s most abundant oil fields, KSA also has some of the world’s most intense sunlight as well as vast areas of open desert seemingly fit for solar-panel arrays. The fact that KSA and some producing countries, a FF giant, has turned to the concept solar is one of the clearest signs that solar energy has become a source of power. However, in order to assure sustainable growth and development, alternative ideas have to materialise starting from policies and regulatory frameworks to changes in the private sector, but also in consumers’ expectations. For example, many Saudi people think of cheap energy as a birth right and any increase in prices would be hugely abhorred. In economic terms, development and value creation in the long-run also calls for the evolution of the renewables sector of a country. Depending on the level of predictable demand for alternative source and the capabilities of an economy, activities should evolve to more capital-intensive activities and complex (Interviewee (A8), Researcher, 2017).

**Major Theme 10: Maximising and developing KSA’s abundant renewable-energy resources**

RQ6’s second major theme was mentioned by 53% of the study interviewers. Participant (A5) also added that KSA, along with the other oil-dependent countries, must work together to strengthen and improve their renewable-energy value chain. The participant recommended this can be achieved by investing more into research efforts on the available renewable sources of energy in their land:

Today, it is a well-known fact that the people of KSA believe that FFs can be utilised in the fight against negative impacts of CC. This is further supported by the World energy council stating that the dominance of FFs will remain indisputable for at least four decades (maybe) even if countries take on active
environment policies. Such a situation is, in my opinion possible, over the long-term. In the short-term, changes may lead to energy crisis similar to those experienced in the second half of the 20th century. In the medium- and long-terms, extensive reforms are needed. These reforms should include changes in the legal and regulatory frameworks; changes in state organisation should also be viewed as a possible outcome. Additionally, it will be necessary to reduce dependence on the state and strengthen the capacity of the private sector. Further, KSA and producer countries will have to strengthen the renewable energy value chain, including research and development and manufacturing, among other stages (Interviewee (A5), Researcher, 2017).

**Minor Theme 1: Developing formal and fair agreements between countries and companies**

The first minor theme of the RQ6, with four mentions, was the establishment of official, reasonable and fair agreements between parties. Participant (A13) added that a greener environment and future may be attained without lowering living standards in KSA though use of proper assessments, investments and agreements by KSA with other countries as well as the other businesses involved. For Participant (A13), the transition entails extensive developments and changes; therefore, KSA must work to ensure that they are well protected and supported by other countries and businesses around the world:

A sustainable clean future is possible if KSA and other producer countries turn to the production and usage such a transition requires great investments, cooperation between countries for a greater good is highly desirable. KSA and other countries have to provide the infrastructure and the regulatory framework for this transition. While transitioning to a low-carbon economy, KSA and other producers will have to assess their strengths and weaknesses and adjust the usage of alternative sources accordingly. A transition to a cleaner economic model also requires a shift in the minds of the people. It is well-known that many people in KSA see the country’s oil dominance as given. In other words, in order to keep the current living standard as well as to improve the well-being of people, great reforms are needed. Investing in natural capital will drive of economic growth that is eco-sustainable. One of the risk is that there is no assurance that the gains of green growth can be evenly distributed (Interviewee (A13), Researcher, 2017).
5.9.7 Qualitative RQ7 findings

FF prices not only affect consumers but also operations and production of exporting countries. Different perspectives may be applied to the study of such a relationship. However, at this juncture, it is to understand how rises and/or falls in oil prices may affect CC issues. From the qualitative thematic analysis of the interviews, one major theme and two minor themes were established (Table 5.8).

<table>
<thead>
<tr>
<th>Thematic</th>
<th>Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowering of oil prices lead to increased oil consumption and further destruction of resources if no formal agreements on CC mitigations are established.</td>
<td>12 80%</td>
</tr>
<tr>
<td>Using current oil revenues to develop science and technology on sustainable energy.</td>
<td>5 33%</td>
</tr>
<tr>
<td>Needing the cooperation of world powers to develop formal CC mitigation actions.</td>
<td>1 7%</td>
</tr>
</tbody>
</table>

**Major Theme 11: Lowering of oil prices lead to increased oil consumption and further destruction of resources if no formal agreements on CC mitigations are established**

In this major theme, concern was expressed regarding the rise oil production and intensified conflict between oil producers due to cheap oil if parties did not develop CC mitigation measures. Overall, there were 12 occurrences of this theme by 80% of study participants. Participant (A15) echoed that further extraction processes by KSA and other oil-producing countries may lead to greater damages especially in the long-run. With the declining prices, greater consumption is expected and saving the environment would be put on hold. Therefore, such a trend could negatively affect and risk the current platforms for CC mitigation:

In terms of CC and environmental impacts, costs are generated at every stage of the FF supply chain. Extraction processes can lead to air and water pollution and damage the quality of life for local communities. Transporting fuels from the mine or well can produce air pollution and generate serious accidents and spills. Burning the fuels causes toxins and global warming emissions. Waste products
are also dangerous to public health and the environment. Understanding these impacts is crucial for evaluating the true cost of FFs. The effects of fighting CC are believed to effective only in the long-run. Uncertainties and risks attached to CC mitigation and environment protection have an impact on production and prices in the FF sector. Great changes will lead to strong price volatility (Interviewee (A15), Researcher, 2017).

Minor Theme 1: Using current oil revenues to develop science and technology on sustainable energy

Participant (A13) recommended that in order to avoid the consequences of large oil production, producer countries must start investing their revenues into discovering ways to manage and mitigate CC. This participant shared the need for further and more intensive research:

The progress of a majority of countries around the world has been the result of FFs. With respect to the notion of time, it is hard to analyse CCs in the short-term. It is my opinion that there is still a lot of research needed in order to discover the ‘truth’ about the promise and peril of CC. With that in mind, one should consider the possibility that FF management may be a part of the answer leading to CC mitigation. That may, of course, be a costly task. Further, I believe that in the longer-run, the effect of price shocks will average out and the developments of science and technology will have a stronger impact on CC (Interviewee (A13), Researcher, 2017).

Minor Theme 2: Needing cooperation from global powers to develop formal CC mitigation actions

The second minor theme that emerged was the need for G8 to communicate to develop the most effective CC mitigation actions and promote energy efficiency. Participant (A7) stated that stronger support, collaboration and assistance may be needed from global powers in order to develop formal and stronger CC mitigation efforts:

The analysis of medium- and long-term effects of efforts aimed at environment protection and fighting CC has to be conducted with respect to the relationship between major world powers and oil giants, e.g. the US, UK and Russia. Today, more than ever, this relationship is particularly affected by number of events in the world. Moreover, the scepticism that some countries promote related to the phenomenon of climate conditions will be subject to critical assessment only in the long-run when the effects of CC will not only be visible but also measurable (Interviewee (A7), Researcher, 2017).
The optimal qualitative analysis classification tree structure containing 26 branches remaining at the end of the pruning is shown in Figure 5.2 to provide a visual display of this study’s findings. In Figure 5.2, the themes indicated by green arrows occur between 73% and 100%, blue arrows denote occurrences between 33% and 60% and red arrows indicate occurrences between 7% and 27%. Accordingly, a total of 11 major themes were found, identified by eight green arrows and five blue arrows indicating occurrences between 50–60%.

![Figure 5.2: Qualitative analysis classification tree.](image)

### 5.10 Summary and conclusion

The researcher has reported the findings of a study of the different roles that KSA has played in the global oil market. However, oil production in exporting countries has been affected by many factors over the years. The main four events show the effects of management of production and pricing in the FF sector. Therefore, the qualitative thematic analysis of the interviews revealed a number of themes that explain KSA’s FF-sector management during the four events. First, KSA imposed an embargo by cutting...
their oil production, leading to surging oil price inflation. Second, KSA ensured its ability to regulate and maintain competitiveness of the oil price market as the global oil market was coming from another oil production and price shock. Third, KSA’s role was such that they ensured the stability of oil supplies and global market prices. Finally, KSA’s continued oil production over the years paid off and further developed their economy despite these crises. However, what is most interesting is these conflicts or events confer advantages or benefits upon producing countries. KSA has taken advantage of most of these conflicts to establish itself as an oil regulator working to maintain reliable oil supplies and prices.

The study had addressed how KSA’s FF sector managed CC policies, especially KP targets. KSA promised to invest in environmental protection and CC mitigation efforts. In addition, the identification of developed and developing countries was furthered and a focus on technology and finance was deliberated. However, KSA reviewed formal agreements given their desire to protect their economy because they feared reductions in FF revenue. Instead of recoiling in the face of a looming threat, KSA steered oil producers to support the production and reduce the fairness in the CC policies. These actions indicate KSA’s importance in managing, forming and even hindering such policies.

Additionally, this study reveals that the FF industry is under threat from green energy. This might not be obvious at the moment, but may become a significant issue in the future. Climate action might therefore need to consider the reaction of FF-producing countries to the green energy threat and the several measures put in place to support green energy. Some studies provided another primary recommendation, namely the
need for FF producers to focus on diversifying their economies or develop their non-FF sectors (Alghamedi, 2014; Fattouh and Sen, 2015; Alomran and Stancati, 2016). In addition, a cleaner, greener and sustainable country – one that avoids CC phenomena without lower living standards in the Kingdom of Saudi Arabia – can be accomplished by changing the mindset of Saudi citizens regarding their perceptions of clean and renewable energy. Lastly, the analysis herein indicated that the main consequence of the FF production and price falls or rises related to CC issues in relation to the Kingdom of Saudi Arabia and other producer countries was that falling oil prices lead to increased oil consumption. Such an impact may contribute to further destruction of resources if no formal agreements on CC mitigations are established.

In conclusion, the findings of this chapter of the study clearly show that KSA must formally address its stand on CC mitigations as well as the economy’s future in the likely future scenario of an oil-free world. After years and decades of becoming a global leader and oil powerhouse, change is pushing the KSA to slowly move away from their traditional source of revenue and search for alternatives that they can employ and dominate in the future. The literature and interviews with participants provided evidence that such change is unavoidable, and KSA must finally take their stand on what actions they can undertake to help mitigate CC. As the study participants suggested, KSA should now intensify their efforts to use science and technology to develop their other abundant and available resources and seek business trades and investments that would diversify their economy in the long-run. Furthermore, the findings of the study emphasised that these change may also start from changing the mindsets of Saudi citizens to start to consider the damages that caused the CC and adjust to the needed modifications and effects of the previous exploitation of resources.
Chapter 6

Quantitative I: Time Series Analysing

Using Stochastic Volatility Models
6.1 Introduction

The stochastic model is used in Chapter 6 to investigate aspects of the variables, specifically several areas of the FF variable set [oil (global and KSA), global (NG and coal)], along with the CC variable set [global (green energy index, CO₂ emissions, temperature and precipitation) and KSA (temperature and precipitation)]. The volatility phenomenon of the CC variables and the long-term relations with the FF markets is explored using modelling and economic forecasting methods. The use of modelling and forecasting includes decades of testing and evaluating methods, particularly in reducing errors, where hypothesis rejection or acceptance may occur inaccurately. Forecasting is used in a variety of different applications, specifically economic, where results are critical to the conclusions. The risk is that the volatility of markets and forecasting or modelling may exclude potential investment decisions in favour of decisions that have performed well in modelling and forecasting. Risks in investing are also related to human decisions, such as those with the pricing of FFs, which are mediated by markets and consumption.

Similarly, the results of CC may be influenced by values that directly impact the volatility, such as changes in consumption of FF or variables that are yet to be identified. This research uses KAS, recognised in economics as an economic engine, which is able to detect changes with a higher rate of performance in advanced economic studies. Selection of KAS was also due to the lack of market and environmental literature using volatility-based models for environmental stochastic processes. The assumption of constant volatility is often violated in financial markets; one way to model such patterns is to allow the volatility to depend upon its history. The time-
varying volatility of financial markets returns can be described through conditional variance family models. This methodology also focuses on studying the volatility phenomenon to determine if one of these models outperforms the other models significantly in forecasting the conditional volatility for different variables.

6.2 Purpose

This chapter’s overall aim is to examine the behaviour of each time series of the two sets (FF and CC) and the consequent effect of the CC variable set on the market value of the FF industry. Since this industry significantly contributes to CC, the behaviour of the capital market can have an enormous influence on the market value of FF companies. Chapter 6 divides the data into in-sample and out-sample periods. The in-sample period reflects the time series between 1 January 1978 to 31 December 2014, which serves to generate model forecasts. The out-of-sample period, which reflects the time series between 1 January 2015 to 30 June 2016, serves to generate forecast accuracies. The primary intentions of the study are to fit an appropriate stochastic model to

- Explore the behaviour and estimate the volatility pattern of the selected variables using symmetric and asymmetric models;
- Analyse the appropriateness of conditional variance family models that capture significant facts about variables and fits more appropriately; and
- Determine the value relevance of CC variable set in the context of the FF industry.

Three main themes are studied; first, the structure of the modelling framework will be examined with respect to the error distribution and conditional mean. The purpose is to
gain insight into how the expected error distribution and different methods for the conditional mean influence the in-sample and out-of-sample fit, regardless of the specific conditional variance model being used. Second, the models will be examined to see whether more complex methods, which are able to display more of the stylised facts and characteristics of variable volatility, give a better in-sample and/or out-of-sample fit than more parsimonious models. Third, it will be determined whether the model with the best in-sample fit produces the best out-of-sample volatility prediction. The purpose of the analysis is, thus, not only to evaluate whether the conditional volatility models provide accurate predictions but, also, to evaluate whether the more complex methods outperform the more parsimonious models.

6.3 Statistical analysis of time series data

Table 6.1 presents the results of the first section of the analysis. The examination of the time series data began with descriptive statistics, which introduces the variables used in this study and evaluates them for mean, median, standard deviation (SD), skewness and kurtosis from 1 January 1978 to 30 June 2016. Descriptive statistics serve the purpose of reporting the data gathered in a manageable description. The average-to-median ratios for the variables are within unit proximity and the standard deviation is small, which depicts a low degree of variation. Results also show that the mean average of global oil prices, at 0.299, is higher than those of R_Y2, and higher than NG at 0.213. The mean for coal prices is found to be the highest, at 0.578, where the maximum is lower than both oil prices (global and Saudi) but still lower than the 15.619 in R_Y3.

Testing, during the process of descriptive analysis, is completed using kurtosis and skewness to determine normality; the expectations is that the values of skewness will
range between −1 and +1 for normality. From these results, kurtosis is not found within normal ranges for any of the variables, with the exception of global CO₂ emission (Table 6.1). The values for skewness are close to zero for majority of the variables: whilst six variables produced negatives (FF variables, \( R_{X_1} \) and \( S_{X_5} \)), which may be interpreted as skewed left, four variables produced positives, interpreted as skewed right. Here, the kurtosis for the variables was also measured, which depicts whether the data peaks or flat lines relative to normal distributions, with 3.0 as the expected value (as the results come closer to 3.0, the results develop a more Gaussian peaked appearance); only four variables satisfied this condition (\( S_{X_2} \), \( S_{X_3} \), \( S_{X_4} \) and \( S_{X_5} \)).

In Table 6.1, Jarque-Bera statistics are used to examine the null hypothesis \( H_0 \) to see if the data are of a normal distribution. All Jarque-Bera statistics are greater than the critical value 5.99, and this leads to the conclusion that the null hypothesis of normality is rejected. As we can see from the below Figure 6.1, the same information is also given by QQ plots of the selected time series (a probability plot, which is a graphical method for comparing two probability distributions by plotting their quantiles against each

---

Table 6.1: Descriptive statistics of the FF and CC variables.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Median</th>
<th>Maximum</th>
<th>Minimum</th>
<th>SD</th>
<th>Skewness</th>
<th>Kurtosis</th>
<th>Jarque-Bera</th>
</tr>
</thead>
<tbody>
<tr>
<td>( R_{Y_1} )</td>
<td>0.299</td>
<td>0.451</td>
<td>27.55</td>
<td>−28.39</td>
<td>7.956</td>
<td>−0.442</td>
<td>4.255</td>
<td>45.33</td>
</tr>
<tr>
<td>( R_{Y_2} )</td>
<td>0.272</td>
<td>0.429</td>
<td>21.40</td>
<td>−26.66</td>
<td>7.405</td>
<td>−0.458</td>
<td>4.242</td>
<td>45.86</td>
</tr>
<tr>
<td>( R_{Y_3} )</td>
<td>0.213</td>
<td>0.153</td>
<td>15.61</td>
<td>−25.89</td>
<td>4.290</td>
<td>−0.368</td>
<td>7.708</td>
<td>43.71</td>
</tr>
<tr>
<td>( R_{Y_4} )</td>
<td>0.578</td>
<td>0.000</td>
<td>20.69</td>
<td>−28.19</td>
<td>6.179</td>
<td>−0.613</td>
<td>6.784</td>
<td>304.6</td>
</tr>
<tr>
<td>( R_{X_1} )</td>
<td>0.648</td>
<td>1.220</td>
<td>19.94</td>
<td>−26.64</td>
<td>6.950</td>
<td>−0.704</td>
<td>4.678</td>
<td>92.40</td>
</tr>
<tr>
<td>( S_{X_2} )</td>
<td>0.001</td>
<td>−0.136</td>
<td>1.981</td>
<td>−1.612</td>
<td>1.000</td>
<td>0.213</td>
<td>1.887</td>
<td>27.35</td>
</tr>
<tr>
<td>( S_{X_3} )</td>
<td>0.314</td>
<td>0.311</td>
<td>1.072</td>
<td>−0.277</td>
<td>0.235</td>
<td>0.255</td>
<td>2.826</td>
<td>6.691</td>
</tr>
<tr>
<td>( S_{X_4} )</td>
<td>2.90E−7</td>
<td>0.010</td>
<td>3.241</td>
<td>−2.447</td>
<td>1.000</td>
<td>0.051</td>
<td>2.347</td>
<td>8.418</td>
</tr>
<tr>
<td>( S_{X_5} )</td>
<td>0.000</td>
<td>0.119</td>
<td>1.457</td>
<td>−1.884</td>
<td>1.000</td>
<td>−0.187</td>
<td>1.555</td>
<td>42.87</td>
</tr>
<tr>
<td>( S_{X_6} )</td>
<td>2.16E−6</td>
<td>−0.234</td>
<td>3.380</td>
<td>−1.216</td>
<td>0.999</td>
<td>1.156</td>
<td>3.802</td>
<td>115.4</td>
</tr>
</tbody>
</table>

Note: FF variable set: \( R_{Y_1} \): Global oil price return, \( R_{Y_2} \): Saudi oil price return, \( R_{Y_3} \): Global NG prices return, and \( R_{Y_4} \): Global coal prices return. CC variable set: \( R_{X_1} \): Green energy index return, \( S_{X_2} \): Global CO₂, \( S_{X_3} \): Global temperature, \( S_{X_4} \): Global precipitation, \( S_{X_5} \): Saudi temperature, and \( S_{X_6} \): Saudi precipitation.
other), which show that both large positive and negative fluctuation are responsible for non-normality of these data series.

Figure 6.1: Q-Q plots of FF and CC variables

6.4 Data stationarity test

First, our time series data gathered from different sources will be subjected to a unit root tests to determine which time series are stationary. A series is said to be stationary if its mean, variance and autocorrelation are constant over time. Most statistical forecasting methods are based on the assumption that a time series can be rendered approximately stationary through the use of mathematical transformations. Using differencing to stationarizes a time series is an important part of the process of fitting univariate and multivariate models. Such statistics are useful as descriptors of future behaviour only if
the series is stationary. Thus, this study uses five-unit root tests: ADF, PP, Ng-Perron, DF-GLS and KPSS to investigate the stationarity property of the time series (Table 6.2).

<table>
<thead>
<tr>
<th>Variables</th>
<th>ADF t-Stat</th>
<th>PP Adj. t-Stat</th>
<th>Ng-Perron M Za</th>
<th>M Zt</th>
<th>DF-GLS t-Stat</th>
<th>KPSS LM-Stat.</th>
<th>Asymptotic critical value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( R_{Y_1} )</td>
<td>A -16.22***</td>
<td>-15.92***</td>
<td>-213.5</td>
<td>-10.32</td>
<td>-16.23</td>
<td>0.124</td>
<td>level 1% 5% 10%</td>
</tr>
<tr>
<td>( R_{Y_1} )</td>
<td>B -16.20***</td>
<td>-15.90***</td>
<td>-213.1</td>
<td>-10.31</td>
<td>-16.16</td>
<td>0.108</td>
<td>ADF and PP</td>
</tr>
<tr>
<td>( R_{Y_2} )</td>
<td>A -16.82***</td>
<td>-16.63***</td>
<td>-217.5</td>
<td>-10.42</td>
<td>-16.82</td>
<td>0.119</td>
<td></td>
</tr>
<tr>
<td>( R_{Y_2} )</td>
<td>B -16.80***</td>
<td>-16.61***</td>
<td>-217.3</td>
<td>-10.42</td>
<td>-16.80</td>
<td>0.108</td>
<td></td>
</tr>
<tr>
<td>( R_{Y_1} )</td>
<td>A -18.69***</td>
<td>-18.91***</td>
<td>-226.3</td>
<td>-10.61</td>
<td>-18.71</td>
<td>0.131</td>
<td>Ng-Perron Test</td>
</tr>
<tr>
<td>( R_{Y_1} )</td>
<td>B -18.67***</td>
<td>-18.90***</td>
<td>-225.2</td>
<td>-10.60</td>
<td>-18.41</td>
<td>0.095</td>
<td></td>
</tr>
<tr>
<td>( R_{Y_2} )</td>
<td>A -16.39***</td>
<td>-16.37***</td>
<td>-192.2</td>
<td>-9.785</td>
<td>-13.89</td>
<td>0.238</td>
<td></td>
</tr>
<tr>
<td>( R_{Y_2} )</td>
<td>B -16.40***</td>
<td>-16.39***</td>
<td>-210.1</td>
<td>-10.24</td>
<td>-15.78</td>
<td>0.106</td>
<td>A -3.444 -2.868 -2.570</td>
</tr>
<tr>
<td>( R_{X_1} )</td>
<td>A -16.71***</td>
<td>-16.69***</td>
<td>-5.746</td>
<td>-1.640</td>
<td>-2.094</td>
<td>0.074</td>
<td>B -3.280 -1.730 -1.420</td>
</tr>
<tr>
<td>( R_{X_1} )</td>
<td>B -16.70***</td>
<td>-16.68***</td>
<td>-206.7</td>
<td>-10.16</td>
<td>-15.37</td>
<td>0.076</td>
<td></td>
</tr>
<tr>
<td>( S_{X_1} )</td>
<td>A 0.307</td>
<td>2.533</td>
<td>1.940</td>
<td>1.313</td>
<td>0.933</td>
<td>2.653</td>
<td>A -2.569 -1.942 -1.616</td>
</tr>
<tr>
<td>( S_{X_1} )</td>
<td>B 0.549</td>
<td>0.110</td>
<td>1.076</td>
<td>0.579</td>
<td>0.590</td>
<td>0.623</td>
<td>B -3.480 -2.890 -2.570</td>
</tr>
<tr>
<td>( \Delta S_{X_1} )</td>
<td>A -3.572***</td>
<td>-25.57***</td>
<td>-5.916</td>
<td>-1.689</td>
<td>-2.588</td>
<td>0.697</td>
<td></td>
</tr>
<tr>
<td>( \Delta S_{X_1} )</td>
<td>B -27.57***</td>
<td>-27.57***</td>
<td>-217.3</td>
<td>-10.42</td>
<td>-27.36</td>
<td>0.126</td>
<td>A 0.739 0.463 0.347</td>
</tr>
<tr>
<td>( S_{X_1} )</td>
<td>A -1.743</td>
<td>-3.433***</td>
<td>-1.176</td>
<td>-0.361</td>
<td>-0.417</td>
<td>2.459</td>
<td>B 0.216 0.146 0.119</td>
</tr>
<tr>
<td>( \Delta S_{X_1} )</td>
<td>A -16.65***</td>
<td>-10.06***</td>
<td>-5.600</td>
<td>-2.236</td>
<td>-1.623</td>
<td>0.540</td>
<td></td>
</tr>
<tr>
<td>( \Delta S_{X_1} )</td>
<td>B -16.66***</td>
<td>-10.52***</td>
<td>-210.7</td>
<td>-10.26</td>
<td>-28.99</td>
<td>0.051</td>
<td></td>
</tr>
<tr>
<td>( S_{X_1} )</td>
<td>A -5.846***</td>
<td>-7.245***</td>
<td>-6.304</td>
<td>-2.213</td>
<td>-1.795</td>
<td>0.050</td>
<td></td>
</tr>
<tr>
<td>( S_{X_1} )</td>
<td>B -5.830***</td>
<td>-7.227***</td>
<td>-14.59</td>
<td>-2.883</td>
<td>-2.590</td>
<td>0.052</td>
<td></td>
</tr>
<tr>
<td>( \Delta S_{X_1} )</td>
<td>A -2.116</td>
<td>-3.486***</td>
<td>1.107</td>
<td>0.838</td>
<td>-0.767</td>
<td>1.058</td>
<td></td>
</tr>
<tr>
<td>( \Delta S_{X_1} )</td>
<td>B -2.378</td>
<td>-3.424***</td>
<td>0.068</td>
<td>0.186</td>
<td>-1.935</td>
<td>0.820</td>
<td></td>
</tr>
<tr>
<td>( S_{X_1} )</td>
<td>A -24.70***</td>
<td>-12.30***</td>
<td>5.852</td>
<td>1.734</td>
<td>-1.927</td>
<td>0.055</td>
<td></td>
</tr>
<tr>
<td>( S_{X_1} )</td>
<td>B -24.67***</td>
<td>-12.31***</td>
<td>-57.59</td>
<td>-5.235</td>
<td>-2.952</td>
<td>0.055</td>
<td></td>
</tr>
<tr>
<td>( \Delta S_{X_1} )</td>
<td>A -4.175***</td>
<td>-12.30***</td>
<td>-7.008</td>
<td>-2.010</td>
<td>-3.419</td>
<td>0.127</td>
<td></td>
</tr>
<tr>
<td>( \Delta S_{X_1} )</td>
<td>B -4.252***</td>
<td>-12.31***</td>
<td>-20.45</td>
<td>-3.466</td>
<td>-10.08</td>
<td>0.117</td>
<td></td>
</tr>
</tbody>
</table>

Note:
\( \Delta \) first difference, A: intercept, B: intercept and trend, and *** ** * indicate significance at the 1% 5% and 10% levels, respectively.
The ADF, Ng-Perron and DF-GLS tests are chosen basins upon Schwarz information criterion (SIC).
The critical value for ADF and PP tests can be obtained from MacKinnon (1996, one sided p-value).
The critical value for Ng-Perron, DF-GLS and KPSS tests can be found in Table 1 of Ng and Perron (2001), Elliott-Rothenberg-Stock (1996) and Kwiatkowski-Phillips-Schmidt-Shin (1992), respectively.

As we know, the time series of FF prices are generally not stationary, so to convert them into stationary time series, we proceed to compute the return of these prices using continuous transformation (see Chapter 4). Overall, Table 6.2 shows that time intercept, intercept and trend and a unit root could affect the variables. The null hypothesis \( (H_0) \) of
a unit root is rejected, indicating that the time series area is stationary, referring to the variables FF return variables, green energy index return and precipitation (global and Saudi). However, unit root tests confirm that global CO$_2$ and temperature (global and Saudi) data series accept the alternative hypothesis ($H_a$) but are stationary at first difference.

### 6.5 Heteroskedasticity test: ARCH/GARCH effects

Heteroskedasticity testing is important due to the need to understand the statistical dispersion, specifically because this method addresses error risks in time series where errors can increase with each additional observation. This test leads the researcher to detect a time-varying phenomenon in the conditional volatility and therefore to propose different types of methods to capture these dynamics. To determine if the sample has a best model fit for these specific parameters, a variety of different models were considered in exploration of the hypothesis. ARCH model along with GARCH has an advantage in short-periods with larger increases in variation; however, they can be used to detect gradual increases in a larger sample and to examine conditional heteroskedasticity. The null hypothesis is contrasted with the alternative hypothesis for assessing the statistical significance of the model, which is as follows: for there is no ARCH/GARCH family effect ($H_0$) and for there is an ARCH/GARCH family effect ($H_a$).

<table>
<thead>
<tr>
<th>Table 6.3: ARCH/GARCH family effect test.</th>
</tr>
</thead>
<tbody>
<tr>
<td>F-statistic</td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Obs$^*$R-squared</td>
</tr>
</tbody>
</table>

*Note:***, **, * indicate significance at the 1%, 5% and 10% levels, respectively.*
The test of ARCH/GARCH effects are presented in Table 6.3, showing the acceptance of each hypothesis that identifies the model acceptance in the ARCH/GARCH family effect for all variables identified. The number of observations times R-squared is evaluated against a chi-square distribution, and the Obs*R-squared and F-statistics of with a probability less than 1% show that the null hypothesis ($H_0$) is rejected in cases where we run the ARCH/GARCH family models. This demonstrates that we have established that the conditional variance is time-varying, requiring that these models be explored for goodness-to-fit and the criteria be identified for acceptance of the model in these variable sets. The following sections explore the results and the potential errors in each set.

### 6.6 Modelling volatility and estimation results

The following subsections will consider how each of the various models are used and how successful they are in managing forecasting with all of the variables overall. We implemented the stochastic models in MATLAB (R2014a), which is a powerful mathematical software program used globally by scientists and engineers. MATLAB has built-in functions that allow the user to determine model parameters ($p, q$) spontaneously; the only requirement in this system is the data series to be examined.

The value of the parameter set used in this method is defined by whether it can lead to small values of AIC, SC and HQ and minimal errors between the actual and forecast values. The results of the different models are consistent regardless of which model criteria metric is used to quantify their performances and the p-values for the all the parameters (except the intercept) and constants are less than the critical value at the 5% level, therefore, the terms are significant. A variety of methods can be used to identify
and reduce the occurrences of errors in the data. Using more than one method is recommended in the cases of these models, due to the importance of forecasting successfully, without creating unnecessary errors caused due to modelling. In each of the tables the best possible forecasting results, per variable, are noted and considered in the conclusion.

6.6.1 ARIMA analysis

The ARIMA models is used for forecasting FF return and CC variables, for checking model components, structural and deterministic components in data series models and their estimation based on regression data series model methods. The results of the ARIMA modelling are presented in Table 6.4 and are compatible with the goals of the research and criteria matrices.

<table>
<thead>
<tr>
<th></th>
<th>$R_{Y1}$</th>
<th>$R_{Y2}$</th>
<th>$R_{Y3}$</th>
<th>$R_{Y4}$</th>
<th>$R_{X1}$</th>
<th>$R_{X2}$</th>
<th>$R_{X3}$</th>
<th>$R_{X4}$</th>
<th>$\Delta S_{X1}$</th>
<th>$\Delta S_{X2}$</th>
<th>$\Delta S_{X3}$</th>
<th>$\Delta S_{X4}$</th>
<th>$S_{X1}$</th>
<th>$S_{X2}$</th>
<th>$S_{X3}$</th>
<th>$S_{X4}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_0$</td>
<td>0.335</td>
<td>0.297</td>
<td>0.327</td>
<td>0.548</td>
<td>0.704</td>
<td>8.45E-6</td>
<td>0.001</td>
<td>0.013</td>
<td>0.001</td>
<td>0.010</td>
<td>0.010</td>
<td>0.010</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\alpha_1$</td>
<td>0.621</td>
<td>-0.556</td>
<td>0.730</td>
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</table>
Chapter 6 Quantitative I: Time Series Analysing Using Stochastic Volatility Models

In general, the estimation shows that most CC variables (ΔS_{X2}, ΔS_{X3}, S_{X4}, ΔS_{X5}, and S_{X6}) are more sensitive to lagged values than to new surprises in the FF value; the model also has a longer memory. This indicates that the ARIMA may not be the best model to predict or capture the volatility of FF variables; other models should be investigated as well. Table 6.4, shows the estimated parameter value for each FF and CC variable set in the model. If the estimate value of the mean term (\( \alpha_0 \)) is nearly zero, this means it does not add value to the model. Figure 6.2 includes the graphs used to depict the results for the forecasting of the out-of-sample ARIMA model, where the forecast is proved with a 95% confidence interval.

![Figure 6.2: Forecast of out-of-sample data of ARIMA models.](image-url)
In the economic world, ARCH/GARCH is used to identify the relations of the mean and variances of returns over time to select a well-performing model. Table 6.5 includes the estimation result of the ARCH/GARCH models. The result of the goodness-of-fit of the ARCH/GARCH model shows the significance of the parameter estimates and accuracy of the out-of-sample data. The Model-develop and Model-accuracy criteria have lower values than the ARIMA, indicating a better model fit than ARIMA model.

By visual inspection of Figure 6.3, it can be noted that the data series has volatility clustering, which indicates long-memory. Extreme values tend to be adjacent to extreme values and small values are adjacent to small values. The conditional variance of the data series is persistent; the larger the persistence, the longer will be the volatility
clustering periods. It can also be stated that the R_Y3 react in a stronger manner to immediate shocks, as α₁ amounts to 0.366 compared to the other variables. However, the lagged volatility parameter β₃ is larger for R_Y4 amounting to 0.527. Therefore, for R_Y4, the volatility on the previous day has more impact on the contemporaneous volatility than the shock on the previous day.

Figure 6.3: The plot of residual, actual and fitted model.
6.6.3 **TGARCH analysis**

The threshold GARCH model was developed to address the challenges in volatility occurring as a result of positive or negative shocks. This is particularly important in research regarding energy products, including FF, that have high risks to shocks, either resulting from drastic changes in climate patterns or changes in competition. TGARCH considers both risks, rather than just one, and was introduced specifically to address the higher risks of negative shocks. The TGARCH focuses on creating a solution for asymmetric shocks to volatility. The results obtained from Table 6.6 show a negative shock reduces the volatility of the data series more than a positive shock of the same magnitude during the sample under consideration. Compared to the previous models, the MSE measures are more successful in the case of the following variables: \( R_{Y_1} \), \( R_{Y_2} \), \( R_{Y_3} \), \( R_{Y_4} \) and \( R_{X_1} \); at 2.550, 2.797, 1.419, 2.817 and 2.330, respectively.

### Table 6.6: The estimation result of the TGARCH models.

<table>
<thead>
<tr>
<th></th>
<th>( R_{Y_1} )</th>
<th>( R_{Y_2} )</th>
<th>( R_{Y_3} )</th>
<th>( R_{Y_4} )</th>
<th>( \Delta S_{X_1} )</th>
<th>( \Delta S_{X_2} )</th>
<th>( S_{X_4} )</th>
<th>( S_{X_3} )</th>
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<td>0.243</td>
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<td>40.08</td>
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<td>0.876</td>
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<tr>
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<td>0.767</td>
<td>0.876</td>
<td>0.517</td>
<td>152.9</td>
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<td>0.361</td>
<td>2.686</td>
<td>1.374</td>
<td>1.437</td>
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- AIC: 6.755, 6.654, 5.259, 5.775, 6.542, -1.831, -2.775, 1.374, 2.668
- HQ: 6.798, 6.686, 5.299, 5.800, 6.574, -1.806, -2.796, 1.399, 2.686
Similarly, the measures are more successful in the CC variable set, as follows: $R_{X_1}$: 2.330, $\Delta S_{X_2}$: 0.768, $\Delta S_{X_3}$: 0.767, $S_{X_4}$: 0.799, $\Delta S_{X_5}$: 0.317 and $S_{X_6}$: 0.245; both sets are supported by other Model-accuracy criteria. The $\beta$ parameter was found close to one in most FF and CC variable sets; this shows the presence of high volatility in the time series. However, we can, at the same time, state that these shocks/innovations fade away in the long-run. In the TGARCH model, the $\gamma$ asymmetry parameter is different from zero at confidence level (95%), so we can state that this allows asymmetry to exist, depending on the negative and positive effects on increasing data series volatility.

### 6.6.4 EGARCH analysis

The exponential GARCH model can use a standard normal variable, which benefits larger samples and exploration, including that of the current research testing. In this research, EGARCH has value that results from various variables able to be influenced directly by negative shocks and positive shocks. The estimation result of EGARCH models is presented in Table 6.7. Advantages of EGARCH are the ability to control for errors and the strength it has with larger samples. Controlling for errors is especially important because it can contribute to higher accuracy ratings. EGARCH gives better forecast performance results based on out-of-sample statistics, as compared to the previous models. The asymmetric effect captured by the parameter estimate $\gamma$ was either positive or negative and significant in the EGARCH suggesting the presence of leverage effect.
### Table 6.7: The estimation result of EGARCH models.

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<tr>
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<th>( R_{Y_1} )</th>
<th>( R_{Y_2} )</th>
<th>( R_{Y_3} )</th>
<th>( R_{Y_4} )</th>
<th>( \Delta S_{X_3} )</th>
<th>( \Delta S_{X_4} )</th>
<th>( S_{X_5} )</th>
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<td>0.006</td>
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<td>0.194</td>
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<td>0.008</td>
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</table>

#### 6.6.5 PARCH analysis

The power ARCH process is expected to increase the power of the model by allowing the SD to be estimated or imposed based on the needs of the data. Table 6.8 shows the estimation results of the PARCH models and the performance of the FF and CC variables. The coefficient \( \gamma \) is negative for all the samples except \( S_{X_4} \) and \( S_{X_6} \). This result further validates the assumption that a negative shock has the potential to reduce volatility more than a positive shock, thus suggesting asymmetric effects in the volatility of the variables.
6.6.6 Return-Relevant model analysis

The overall aim of the empirical models in this study is to analyse the interdependent relation between the FF industry and CC, and to observe the consequent effect of this relationship on the market value of the industry. Long-term CC effects on the FF industry are complex and vary along and across the supply and production chain (AMP, 2005). Ball and Brown (1968) presented a value-relevance study and provided event and association research methodologies. The data is deemed value-relevant if it has a weighty association with stock market value (Barth, 2000). Bettman (2007) describe several empirical studies that demonstrate the significance of information characteristics in explaining the contemporaneous prices of share or their value relevance. This area developed quickly to encompass a wide array of study areas, methodologies and designs. Clemens (2006) stated that environmental data has received the most attention.

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<th>R_Y1</th>
<th>R_Y2</th>
<th>R_Y3</th>
<th>R_X1</th>
<th>R_X2</th>
<th>ΔS_X3</th>
<th>ΔS_X4</th>
<th>S_X5</th>
<th>S_X6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.424</td>
<td>0.181</td>
<td>0.124</td>
<td>0.010</td>
<td>0.579</td>
<td>0.009</td>
<td>0.004</td>
<td>0.062</td>
<td>0.034</td>
</tr>
</tbody>
</table>

| Variance Equation | α_0  | 0.187| 0.584| 0.030| 0.021| 0.676  | 0.018  | 0.124| 1.026| 0.249| 0.273|
|                  | α_1  | 0.210| 0.108| 0.022| 0.197| 0.023  | 0.171  | 0.067| 0.143| 0.022| 0.053|
|                  | α_2  | -    | 0.012| -    | 0.062| 0.121  | -      | 0.133| 0.142| -    | -    |
|                  | β_1  | 0.576| 0.201| 0.877| 0.116| 0.031  | 0.676  | 0.029| 0.683| 0.093| 0.238|
|                  | β_2  | 0.185| 0.212| -    | 0.595| 0.234  | 0.077  | 0.625| -    | 0.158| 0.618|
|                  | β_3  | -    | 0.459| -    | -    | 0.537  | -      | -    | 0.618| -    | -    |
|                  | γ    | -0.215| -0.385| -0.960| -0.098| -0.358  | -0.247 | -0.686| 0.752| -0.156| 0.010|

| AIC | 6.794| 6.651| 5.225| 5.731| 6.546| 1.177  | -1.901 | 2.705| 1.054| 1.894|
| SC  | 6.865| 6.740| 5.279| 5.803| 6.645| 1.249  | -1.830 | 2.768| 1.161| 1.985|
| HQ  | 6.822| 6.686| 5.246| 5.759| 6.886| 1.205  | -1.873 | 2.730| 1.096| 1.930|
| MSE | 1.495| 1.575| 2.897| 1.003| 2.037| 0.143  | 0.155  | 0.373| 0.169| 0.453|
| RMSE| 1.223| 1.255| 1.702| 1.001| 1.427| 0.378  | 0.394  | 0.611| 0.411| 0.673|
| MAE | 0.428| 0.513| 0.571| 0.405| 0.408| 0.132  | 0.138  | 0.202| 0.144| 0.219|
| MAPE| 8.589| 10.81| 23.22| 20.36| 13.12| 14.52  | 15.20  | 23.06| 15.90| 25.07|
| Theil's U1 | 0.043| 0.045| 0.133| 0.080| 0.054| 0.088  | 0.092  | 0.139| 0.096| 0.153|
| Theil's U2 | 0.020| 0.026| 0.260| 0.172| 0.0581| 1.094  | 1.094  | 1.094| 1.094| 1.094|

**Table 6.8: The estimation result of the PARCH models.**
in the value-relevance literature. The relation between FF market behaviour and environmental data has become a vital area of examination and contributes to research on value-relevance.

In the FF market, the relevant independent variables are shown in the following Return-Relevant Model $R_{Y_i}$ (where $i = 1, 2, 3, 4$). Thus, FF Return is a function of $R_{Y_1}$, $R_{Y_2}$, $R_{Y_3}$ and $R_{Y_4}$ which could be affected by $R_{X_1}$, $\Delta S_{X_2}$, $\Delta S_{X_3}$, $S_{X_4}$, $\Delta S_{X_5}$ and $S_{X_6}$ (see Chapter 4). The heteroskedasticity test is applied to discover out the presence of ARCH/GARCH effect in the residuals of the data return series [$FF\text{ Returns} = F(R_{X_1},\Delta S_{X_2},\Delta S_{X_3},S_{X_4},\Delta S_{X_5} \text{ and } S_{X_6})$]. From Table 6.9, the ARCH-LM test statistics are inferred to be highly significant. The null hypothesis of ‘no ARCH effect’ is rejected at the 5% level; which indicates the presence of ARCH/GARCH effects in the residuals of the prices returns in the data series models. After volatility clustering is confirmed with data series and stationarity tests (Table 6.9) and heteroscedasticity effect tests, the study focuses on finding the best fitted model to the data return series. Table 6.10 presents the value relevance of CC in the context of the FF variable set.

<table>
<thead>
<tr>
<th>Dependent</th>
<th>Independent</th>
<th>F-statistic</th>
<th>Obs*R-squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{Y_1}$</td>
<td>$R_{X_1}, \Delta S_{X_2}, \Delta S_{X_3}, S_{X_4}, \Delta S_{X_5}, S_{X_6}$</td>
<td>33.67**</td>
<td>31.50**</td>
</tr>
<tr>
<td>$R_{Y_2}$</td>
<td>$R_{X_1}, \Delta S_{X_2}, \Delta S_{X_3}, S_{X_4}, \Delta S_{X_5}, S_{X_6}$</td>
<td>25.87**</td>
<td>24.59**</td>
</tr>
<tr>
<td>$R_{Y_3}$</td>
<td>$S_{X_4}, \Delta S_{X_5}, S_{X_6}$</td>
<td>10.18**</td>
<td>10.01**</td>
</tr>
<tr>
<td>$R_{Y_4}$</td>
<td>$S_{X_4}, \Delta S_{X_5}, S_{X_6}$</td>
<td>11.59**</td>
<td>11.36**</td>
</tr>
</tbody>
</table>

Note: ***, **, * indicate significance at the 1%, 5% and 10% levels, respectively.

FF variable set: $R_{X_1}$: Global oil price return, $R_{Y_1}$: Saudi oil price return, $R_{Y_2}$: Global NG prices return, and $R_{Y_3}$: Global coal prices return.

CC variable set: $R_{X_1}$: Green energy index return, $\Delta S_{X_2}$: Global CO$_2$, $\Delta S_{X_3}$: Global temperature, $S_{X_4}$: Global precipitation, $\Delta S_{X_5}$: Saudi temperature, and $S_{X_6}$: Saudi precipitation.
Chapter 6 Quantitative 𝚰: Time Series Analysing Using Stochastic Volatility Models

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Table 6.10: The estimation result of the empirical model of FF variable set.
ARIMA
RY2 RY3

RY4

RY1

Constant −0.25 −0.34 0.25

0.01

0.03 −0.11 0.06

0.58 −0.07 −0.07 −0.12 0.54

0.70

1.00

0.87

RY1

ARCH/GARCH
RY2 RY3 RY4

RY1

TGARCH
RY2 RY3

PARCH
RY2 RY3

RY4

0.08 −0.07 0.09

0.09 −0.01 −0. 33 0.01

0.28

1.08

0.97

1.01

0.97

0.90

0.04 −0.19 0.01 −0.03 0.04 −0.15 0.06

0.03

0.03 −0.11 −0.05

RY4

RY1

EGARCH
RY2 RY3

RY4

RY1

Mean Equation

RX1

0.73

0.74

∆SX2

0.14

0.32 −0.05 0.11 −0.01 0.04 −0.08 −0.06 0.09

∆SX3

−0.46 −3.89 −3.60 −1.35 −0.44 0.16 −0.43 0.91 −0.43 0.57 −0.77 0.94 −0.78 0.54

SX4

0.28

∆SX5

−0.86 −0.85 0.60 −0.07 −0.02 −0.12 0.06

0.41 −0.06 −0.04 0.25

SX6

1.17

1.12

0.39

0.50

0.05

0.03

0.03

0.05

𝛼0

-

-

-

-

0.03

0.04

0.04 −0.14 0.05

0.02

𝛼1

0.33

0.31

1.12

1.28

0.13

0.03

0.05

0.11

0.19

𝛼2

0.65 −0.02 −0.15 −1.29

-

0.02

0.46

0.01

-

𝛼3

−0.26 −0.33 −0.27 0.34

-

0.25

-

-

-

𝛼4

−0.77

-

𝛽1

0.01

𝛽2

−0.88 −0.11 0.21

𝛽3

0.12

𝛽4

0.87 −0.48

0.03

0.13

0.20

0.10

0.02

0.98

0.02

0.02 −0.06 0.34

1.07

0.98

0.04

0.89

0.02 −0.06 −0.02 0.41

0.99

0.01

0.21 −0.03 −0.45 0.38

0.03 −0.05 −0.07 −0.06 0.07

0.19 −0.04 −0.03 0.19

0.05 −0.04 −0.06 0.08

0.06

0.03

1.02

0.39

0.05

0.22

0.29 −0.04 −0.05 −0.01 0.31

0.01 −0.02 −0.09 0.03

0.09

0.01

0.14

0.09

0.03

0.02 −2.97 −0.69 −0.07 −2.27 0.05

0.05

0.03

0.02

0.29

0.22

0.07

0.13

0.12

0.17

0.09

0.13

0.05

0.14

0.22

-

0.11

0.27

0.17

0.03

-

0.14

0.08

0.15

0.02

0.05

-

0.03

0.16

0.02

-

-

0.029

-

0.16

0.01

Variance Equation

-

1.06

-

0.06 −1.09 −0.97 0.72

0.42

-

-

-

-

-

0.01

-

-

-

-

-

0.06

-

-

-

0.17

0.39

0.69

0.71

0.08

0.08

0.06

0.70

0.15

0.02

0.07

0.48

0.03

0.61

0.29

0.95

0.10

0.07

-

-

-

0.10

0.42

0.37

-

0.64

0.13

0.08 0.013 0.61

-

0.36

0.16

-

-

0.46

-

-

-

0.56

0.05

-

-

-

0.64

0.17

-

-

-

-

-

-

-

-

0.42

-

-

-

-

-

-

-

-

-

-

-

0.03

-

𝛾

-

-

-

-

-

-

-

-

0.06

0.08

0.03

0.01 −0.85 −0.32 −0.02 −1.28 −0.05 −0.04 −0.14 −0.13

AIC

6.34

6.14

5.63

5.30

5.01

4.96

5.32

5.15

5.01

4.95

5.26

5.14

5.01

4.94

5.06

4.89

4.99

4.94

5.23

5.07

SC

6.49

6.29

5.80

5.42

5.13

5.08

5.41

5.25

5.14

5.08

5.41

5.27

5.18

5.06

5.18

5.04

5.14

5.08

5.34

5.19

HQ

6.40

6.20

5.70

5.35

5.06

5.01

5.36

5.19

5.06

5.01

5.32

5.19

5.08

4.99

5.11

4.95

5.05

5.00

5.27

5.12

MSE

22.2

14.6

45.2

41.7

1.24

1.72

1.64

1.48

1.28

1.81

7.15

2.77

1.23

1.52

1.44

1.19

1.26

1.79

1.21

3.07

RMSE

4.72

3.82

6.72

6.46

1.11

1.31

1.28

1.21

1.13

1.34

2.67

1.66

1.11

1.23

1.20

1.09

1.12

1.33

1.10

1.75

MAE

4.08

3.33

5.10

4.79

0.89

1.02

0.47

0.83

0.90

1.06

0.90

1.29

0.89

0.93

0.55

0.87

0.36

1.05

0.58

1.18

MAPE

48.1

63.6

184

387

18.2

18.0

63.0

19.6

19.9

20.6

17.7

26.4

18.0

19.7

20.3

15.6

14.1

20.6

42.3

34.0

Theil's U1 0.20

0.15

0.80

0.29

0.04

0.04

0.11

0.05

0.04

0.05

0.22

0.07

0.04

0.04

0.09

0.04

0.08

0.05

0.09

0.07

Theil's U2 0.40

0.36

1.98

0.44

0.09

0.11

0.21

0.01

0.10

0.12

0.37

0.06

0.09

0.05

0.63

0.04

0.17

0.12

0.43

0.02

Results indicate that the 𝛼1 results show that the FF industry’s return is positively and
significant associated with the previous ‘t’ return. A significant ARCH/GARCH shows
that t volatility correlates with the previous t volatility for the FF return index. The sum
of the ARCH/GARCH coefficients are statistically significant; this is close to unity,
demonstrating that the shock will persist into many future periods and that FF price
returns have consistent volatility and variance. The results also show that the coefficient
𝛾 has the expected sign both in the TGARCH (positive and significant) models and in
the EGARCH and PARCH (negative and significant) (Table 6.10).


The result indicated that the best fitted models, both in asymmetric and in symmetric effect, for Return-Relevant Models $R_{Y_1}$ and $R_{Y_4}$ are EGARCH, for Return-Relevant Models $R_{Y_2}$ and $R_{Y_3}$ are PARCH-based on the model criteria metrics (Table 6.10). These models have a strong leverage effect, which means that bad news has more influence on stock return price volatility than good news supporting the idea that most investors tend to remember bad shocks longer than good news. Thus, when bad information appears in the FF market, it is rather difficult to value the flows of positive information.

6.7 Summary and conclusion

Conditional volatility models enabled the researcher to gather more information regarding the behaviour and performance of variables using symmetric and asymmetric models. Return-Relevant Modelling volatility is essential in determining the extent the capital market incorporates CC and green energy index information in the index valuation of the FF industry by determining whether the CC variable set influences FF equity return. The best-fitting model for each variable can be seen in the significance indicated and varies with a larger portion of the variables responding. In this case, the PARCH model is superior to the previous models for the CC samples analysed: global (CO$_2$, temperature, precipitation) and Saudi (temperature and precipitation); the best fitting model for the FF variable set and $R_{X_1}$ is the EGARCH model. This shows that advanced and complicated models perform better than any of the other models for the given data series (Tularam and Saeed, 2016). The empirical results in this research confirm the existence of a significant relationship between the CC variable set and returns on investments (FF variable set). The results also support that that CC
information is value-relevant and that rational FF stockholders appropriately price CC information. Nevertheless, these relations are more significant on a longer-term basis.

Business’ and customers’ responses to CC influence their use of energy and in turn their energy demand from FF industry. Thus, FF companies are subject to a larger degree of CC risk and to significant variances in incomes, making it essential for investors to integrate CC-related data into a stock’s market valuation. Modelling and forecasting play a vital role during the entire process of advising policy makers (for both FF and CC). Perfect decision making is achieved when changes are viewed from two perspectives: current events and what is likely to occur in the potential future events. As uncertain a prediction might seem, policy makers are compelled to consider its validity in their decision making.

Ideally, policy makers would base their decisions on accurate predictions to tighten their policies and achieve ultimate outcomes that differ from those predicted. Marketing strategists use data acquired from various predicting models and consider only the most accurate models for developing, formulating and implementing marketing strategies. As a consequence, the organisations and entities whose main activities rely on the FF industry find such predictions especially useful for formulating their policies and marketing strategies to adapt to future changes in the FF market and CC issues. As a result, with accurate knowledge of the flow of public money and of the regular patterns in FF consumption and demand, they can modify FF prices in such a way to avoid damaging the financial capability of their organisations or otherwise affect their organisations’ objectives and impose more CC policies that affect the FF industry.
Chapter 7

Quantitative II: Multivariate Time-Series Analysis
Chapter 7 examines the extent of integration or interdependence among several variables. The first objective is to develop models of dynamic linkages among FF set variables [oil market (global and KSA) and global (NG and coal) returns], CC set variables [green energy index and global (CO\textsubscript{2}, temperature and precipitation) and KSA (temperature and precipitation)] and the two sets of variables using a VAR framework. The second objective is to examine the nature of dependencies among variables during three periods: Period 1 (1 January 1978–28 February 1997), before the KP; Period 2 (1 March 1997–30 June 2016), after the KP and Period 3 (1 January 1978–30 June 2016), before and after the KP. This chapter evaluates variable performance and causalities within the FF industry, CC variables and both sets over periods of growth, shocks and green policies. This information can help stockholders and organisations make vital investment decisions. In addition, IRA, VDA and GCA are performed. The results are analysed to identify influential variables, how one variable may affect another variable and the speed and nature of interaction among variables.

The contributions of this chapter are threefold. To the best of our knowledge, this is the first study to examine interdependence among variables during different periods, i.e. Periods 1, 2 and 3. Second, and most importantly, this study compares the performance of four FF indices and six CC variables. We investigate the profitability of FF-related investments and CC-related issues to determine which FF indices global capital will flow into or out of, how this influences FF investors globally, the relations among CC set variables and how the set variables affect each other. To address these issues and achieve the objective of this study, the following hypotheses are tested empirically.
Hypothesis 1: The return prices of FF set variables influence each other during the different periods.

Hypothesis 2: The CC set variables influence each other during the different periods.

Hypothesis 3: A negative or positive relation exist between FF and CC set variables during the different periods.

### 7.2 Descriptive statistics and pre-estimation analyses

The descriptive statistics are showed in Table 7.1. The Jarque-Bera statistics are (> 5.99), and therefore, the null hypothesis (H₀) of normality is rejected. The kurtosis exceeds the considerably normal distribution value of 3, except for Sₓ₄ and Sₓ₅ in Periods 1 and 2, which means that they are leptokurtic.

<table>
<thead>
<tr>
<th>Table 7.1: Descriptive statistics and unit root.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period 1</td>
</tr>
<tr>
<td>Rₓ₁</td>
</tr>
<tr>
<td>Rₓ₂</td>
</tr>
<tr>
<td>Rₓ₃</td>
</tr>
<tr>
<td>Rₓ₄</td>
</tr>
<tr>
<td>Rₓ₅</td>
</tr>
<tr>
<td>Sₓ₁</td>
</tr>
<tr>
<td>Sₓ₂</td>
</tr>
<tr>
<td>Sₓ₃</td>
</tr>
<tr>
<td>Sₓ₄</td>
</tr>
<tr>
<td>Sₓ₅</td>
</tr>
</tbody>
</table>

| Period 2 | Mean | Median | Maximum | Minimum | SD | Skewness | Kurtosis | Jarque-Bera | Unit root test |
| Rₓ₁     | 0.647  | 1.436 | 20.49 | -28.39 | 8.691 | -0.685 | 3.981 | 27.46 | Stationarity at level |
| Rₓ₂     | 0.593  | 1.555 | 20.24 | -26.66 | 8.373 | -0.609 | 3.631 | 18.21 | Stationarity at level |
| Rₓ₃     | 0.392  | 0.519 | 14.35 | -25.89 | 5.188 | -0.477 | 5.571 | 72.67 | Stationarity at level |
| Rₓ₄     | 1.077  | 1.636 | 20.69 | -28.19 | 8.399 | -0.651 | 4.045 | 26.93 | Stationarity at level |
| Rₓ₅     | 0.645  | 1.465 | 19.94 | -26.64 | 8.434 | -0.653 | 3.820 | 22.99 | Stationarity at level |
| Sₓ₁     | 0.892  | 0.873 | 5.187 | -3.338 | 1.569 | 0.145 | 3.953 | 9.829 | Stationarity at ∆ |
| Sₓ₂     | 0.006  | 0.007 | 0.305 | -0.279 | 0.106 | 0.083 | 3.598 | 6.717 | Stationarity at ∆ |
| Sₓ₃     | 0.004  | -0.080 | 3.241 | -2.280 | 1.028 | 0.175 | 2.463 | 8.977 | Stationarity at level |
| Sₓ₄     | -0.010 | 0.028 | 1.003 | -1.121 | 0.549 | -0.100 | 1.855 | 13.06 | Stationarity at ∆ |
| Sₓ₅     | 0.002  | -0.237 | 3.380 | -1.216 | 1.007 | 1.211 | 4.056 | 67.50 | Stationarity at level |

Note: The unit root test includes: ADF, PP, Ng-Perron, DF-GLS, and KPSS.
The size sample is quite large and skewness does not reach ±1 or −1, except for the variable $S_{X_6}$ in Periods 1 and 2. The null hypothesis of a unit root has been rejected, which means that the FF variables’ return, $R_{X_1}$, $S_{X_4}$ and $S_{X_5}$ series do not have the unit root problem and the data series are stationary. Moreover, the unit root test rejects the null hypothesis ($H_0$) of a unit root and specifies that the series $S_{X_2}$, $S_{X_3}$, and $S_{X_5}$ are stationary at first difference (Table 7.1).

### 7.3 Empirical analyses and discussion

#### 7.3.1 Analysis based on correlation matrix between variables

Table 7.2 shows the correlation coefficients between different FF markets. As seen, the correlation coefficient between global oil and Saudi oil return prices was $r = 0.919$, 0.969 and 0.949 during Periods 1, 2 and 3, respectively, at 1% positive significance. The correlation coefficients between oil return prices (global and Saudi) and the return prices for NG and coal were weak and not statistically significant during Period 1. However, during Periods 2 and 3, coal return had strong positive relations ($p < 0.01$) with oil market variables ($R_{Y_1}$ and $R_{Y_2}$) and NG returns, respectively. The correlations between $R_{Y_3}$ and global and Saudi oil return prices were significant at a 5% level during Periods 2 and 3. This correlation analysis indicates that the FF set variables became increasingly associated over time. According to the theory of financial integration, this means that common stochastic trends in returns emerge and the specification of dynamic paths towards greater integration between returns on equities (Kearney and Lucey, 2004).
Table 7.2: Correlation matrix between FF traits.

<table>
<thead>
<tr>
<th>Period</th>
<th>R_{Y_1}</th>
<th>R_{Y_2}</th>
<th>R_{Y_3}</th>
<th>R_{Y_4}</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.919***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.038</td>
<td>0.066</td>
<td>0.076</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>0.969***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.241**</td>
<td>0.240**</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>0.962***</td>
<td>0.930***</td>
<td>0.432***</td>
</tr>
<tr>
<td></td>
<td>0.716***</td>
<td>0.721***</td>
<td>0.405***</td>
<td>1</td>
</tr>
</tbody>
</table>

Note:
***, ** and * indicate significance at 1%, 5% and 10% levels, respectively.

Table 7.3: Correlation matrix between CC traits.

<table>
<thead>
<tr>
<th>Period</th>
<th>R_{X_1}</th>
<th>∆S_{X_2}</th>
<th>∆S_{X_3}</th>
<th>S_{X_4}</th>
<th>∆S_{X_5}</th>
<th>S_{X_6}</th>
<th>∆S_{X_7}</th>
<th>S_{X_8}</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>−0.049</td>
<td>1</td>
<td>0.095</td>
<td>0.217**</td>
<td>1</td>
<td>−0.056</td>
<td>−0.019</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.043</td>
<td>0.243**</td>
<td></td>
<td>0.047</td>
<td>0.028</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>−0.002</td>
<td>0.276**</td>
<td>0.077</td>
<td>0.006</td>
<td>0.064</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>−0.019</td>
<td>−0.528***</td>
<td>0.507***</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>−0.170</td>
<td>1</td>
<td>−0.162</td>
<td>0.305***</td>
<td>1</td>
<td>0.140</td>
<td>0.039</td>
</tr>
<tr>
<td></td>
<td></td>
<td>−0.221</td>
<td>−0.217</td>
<td>0.312***</td>
<td>1</td>
<td></td>
<td>0.023</td>
<td>−0.039</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.160</td>
<td>0.499***</td>
<td>0.440***</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note:
***, ** and * indicate significance at 1%, 5% and 10% levels, respectively.

The correlation matrix for the six variables in the CC set is shown in Table 7.3. As demonstrated by the similarity among the time periods, most correlations with R_{Y_1} were weak, except for the negative link with global variables (CO\textsubscript{2} and temperature) during Period 2, which demonstrated a low (10%) significance level. The results indicate that the relation between global variables (CO\textsubscript{2} and temperature) was significant during Period 1 (p < 0.05) and Periods 2 and 3 (p < 0.01). Moreover, a significant relation
was evident between variables ($S_{X_4}$ and $\Delta S_{X_5}$) and global temperature at $p < 0.05$ and $S_{X_6}$ at $p < 0.01$ during the three periods. The correlation coefficient between $\Delta S_{X_5}$ and $S_{X_4}$ was positive ($r = 0.312$ and 0.294) at significance levels of 1% and 5% for Periods 2 and 3, respectively. A correlation (5% significance) was found between global CO$_2$ and Saudi temperature, and a low (10%) significance level was found between $\Delta S_{X_3}$ and $S_{X_6}$ during Periods 2 and 3 (Table 7.3).

Table 7.4: Cross-correlation matrix between FF and CC traits.

<table>
<thead>
<tr>
<th>Period 1</th>
<th>$R_{Y_1}$</th>
<th>$R_{Y_2}$</th>
<th>$R_{Y_3}$</th>
<th>$R_{Y_4}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{X_1}$</td>
<td>-0.099</td>
<td>-0.087</td>
<td>-0.073</td>
<td>0.063</td>
</tr>
<tr>
<td>$\Delta S_{X_2}$</td>
<td>-0.274&quot;</td>
<td>-0.070</td>
<td>-0.020</td>
<td>-0.228&quot;</td>
</tr>
<tr>
<td>$\Delta S_{X_3}$</td>
<td>-0.112&quot;</td>
<td>-0.040</td>
<td>-0.068</td>
<td>-0.206&quot;</td>
</tr>
<tr>
<td>$S_{X_4}$</td>
<td>-0.037</td>
<td>-0.049</td>
<td>-0.077</td>
<td>-0.101</td>
</tr>
<tr>
<td>$\Delta S_{X_5}$</td>
<td>-0.117&quot;</td>
<td>-0.016</td>
<td>0.054</td>
<td>-0.065</td>
</tr>
<tr>
<td>$S_{X_6}$</td>
<td>0.073</td>
<td>0.074</td>
<td>0.023</td>
<td>0.064</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Period 2</th>
<th>$R_{Y_1}$</th>
<th>$R_{Y_2}$</th>
<th>$R_{Y_3}$</th>
<th>$R_{Y_4}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{X_1}$</td>
<td>0.092&quot;&quot;&quot;</td>
<td>0.980&quot;&quot;&quot;</td>
<td>0.343&quot;&quot;&quot;</td>
<td>0.957&quot;&quot;&quot;</td>
</tr>
<tr>
<td>$\Delta S_{X_2}$</td>
<td>-0.232&quot;&quot;</td>
<td>-0.236&quot;&quot;</td>
<td>-0.051</td>
<td>-0.329&quot;&quot;</td>
</tr>
<tr>
<td>$\Delta S_{X_3}$</td>
<td>-0.224&quot;&quot;</td>
<td>-0.117&quot;</td>
<td>-0.095</td>
<td>-0.212&quot;</td>
</tr>
<tr>
<td>$S_{X_4}$</td>
<td>0.047</td>
<td>0.024</td>
<td>0.012</td>
<td>0.065</td>
</tr>
<tr>
<td>$\Delta S_{X_5}$</td>
<td>-0.217&quot;&quot;</td>
<td>-0.189&quot;&quot;</td>
<td>0.025</td>
<td>-0.140&quot;</td>
</tr>
<tr>
<td>$S_{X_6}$</td>
<td>-0.027</td>
<td>-0.018</td>
<td>0.105</td>
<td>-0.011</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Period 3</th>
<th>$R_{Y_1}$</th>
<th>$R_{Y_2}$</th>
<th>$R_{Y_3}$</th>
<th>$R_{Y_4}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{X_1}$</td>
<td>0.626&quot;&quot;&quot;&quot;&quot;</td>
<td>0.654&quot;&quot;&quot;&quot;&quot;</td>
<td>0.358&quot;&quot;&quot;&quot;&quot;</td>
<td>0.799&quot;&quot;&quot;&quot;&quot;</td>
</tr>
<tr>
<td>$\Delta S_{X_2}$</td>
<td>-0.240&quot;&quot;&quot;</td>
<td>-0.243&quot;&quot;&quot;</td>
<td>-0.025</td>
<td>-0.356&quot;&quot;&quot;</td>
</tr>
<tr>
<td>$\Delta S_{X_3}$</td>
<td>-0.217&quot;&quot;</td>
<td>-0.125&quot;&quot;</td>
<td>-0.118&quot;&quot;</td>
<td>-0.205&quot;&quot;</td>
</tr>
<tr>
<td>$S_{X_4}$</td>
<td>0.068</td>
<td>0.054</td>
<td>-0.017</td>
<td>0.091</td>
</tr>
<tr>
<td>$\Delta S_{X_5}$</td>
<td>-0.225&quot;&quot;</td>
<td>-0.217&quot;&quot;</td>
<td>0.069</td>
<td>-0.154&quot;</td>
</tr>
<tr>
<td>$S_{X_6}$</td>
<td>0.061</td>
<td>0.055</td>
<td>0.106</td>
<td>0.004</td>
</tr>
</tbody>
</table>

Note: *** and * indicate significance at 1%, 5% and 10% levels, respectively.

Generally, the variables in the FF and CC sets were weakly correlated during Period 1 (Table 7.4). However, some correlations were significant, i.e. the correlation between coal price return and variables ($\Delta S_{X_2}$ and $\Delta S_{X_3}$) (5%) and that between global oil return and $\Delta S_{X_2}$ and variables ($\Delta S_{X_3}$ and $\Delta S_{X_5}$) at 5% and 10% significance levels, respectively. However, the situation was quite different during Period 2: $R_{X_1}$ was strongly positively correlated with the FF set variables ($R_{Y_1}$, $R_{Y_2}$, $R_{Y_3}$ and $R_{Y_4}$). The correlation coefficients between other sets of variables, however, remained weak at $p <
0.1, such as $R_{Y_2}$ and global temperature and between variables ($R_{Y_4}$ and $\Delta S_{X_5}$).

Nevertheless, some, such as global oil return and variables ($\Delta S_{X_1}$, $\Delta S_{X_3}$ and $\Delta S_{X_5}$) and between Saudi (oil return and temperature) were significant (5%). Generally, the same correlation effect between set variables was found for Period 3, with the exception of a 10% significance level between NG return and global temperature (Table 7.4).

### 7.3.2 Lag order based on simulations for vector autoregressive

Before estimating the VAR model, the stationarity of the time series should be established by first testing the unit root (see Chapter 6 and Table 7.1). Selecting the optimal lag before constructing the VAR is important because a trade-off is involved in the selection of the number of lags, i.e. too low a number may lead to poor model specification, while too high a number may lead to loss of too many degrees of freedom. Therefore, an optimal selection should allow the residuals of the estimated model to constitute individual white noise.

Several criteria are used to select optimal lag (i.e. LR, FPE, AIC, SC and HQ). These are all objective functions related to the trade-off between model parsimony and reduction in the model’s sum of squares. Combining these criteria results in more practical lag orders, which results in an accurate system (Hatemi-J and Hacker, 2009). Thus, a lag order selection test was performed, and based on several of the five criteria, a lag order of two was indicated. Table 7.5 shows a significant lag length (two) for FF, CC and the combined set variables for Periods 1, 2 and 3.
Table 7.5: Results for each criterion for statistically significant lag (length two) in the VAR model.

<table>
<thead>
<tr>
<th>Set</th>
<th>Period</th>
<th>Lag</th>
<th>LogL</th>
<th>LR</th>
<th>FPE</th>
<th>AIC</th>
<th>SC</th>
<th>HQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>FF</td>
<td>1</td>
<td>2</td>
<td>2354</td>
<td>45.87</td>
<td>1376</td>
<td>20.88</td>
<td>21.42</td>
<td>21.09</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2</td>
<td>2492</td>
<td>30.72</td>
<td>4166</td>
<td>21.98</td>
<td>22.52</td>
<td>22.20</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2</td>
<td>5194</td>
<td>70.03</td>
<td>8838</td>
<td>22.74</td>
<td>23.06</td>
<td>22.86</td>
</tr>
<tr>
<td>CC</td>
<td>1</td>
<td>2</td>
<td>150.7</td>
<td>198.8</td>
<td>2.97E-07</td>
<td>1.998</td>
<td>3.168</td>
<td>2.470</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2</td>
<td>1431</td>
<td>175.2</td>
<td>0.020</td>
<td>13.12</td>
<td>14.29</td>
<td>13.59</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2</td>
<td>2656</td>
<td>319.9</td>
<td>0.006</td>
<td>11.88</td>
<td>12.59</td>
<td>12.16</td>
</tr>
<tr>
<td>FF and CC</td>
<td>1</td>
<td>2</td>
<td>2425</td>
<td>292.3</td>
<td>0.005</td>
<td>23.01</td>
<td>26.16</td>
<td>24.28</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2</td>
<td>2942</td>
<td>238.3</td>
<td>0.383</td>
<td>27.41</td>
<td>30.55</td>
<td>28.67</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2</td>
<td>7538</td>
<td>421.4</td>
<td>202.8</td>
<td>33.69</td>
<td>35.57</td>
<td>34.43</td>
</tr>
</tbody>
</table>

Note:
FF variable set: \( R_{Y1} \): Global oil price return, \( R_{Y2} \): Saudi oil price return, \( R_{Y3} \): Global NG prices return, and \( R_{Y4} \): Global coal prices return.
CC variable set: \( R_{X1} \): Green energy index return, \( \Delta S_{X2} \): Global CO\(_2\), \( \Delta S_{X3} \): Global temperature, \( S_{X4} \): Global precipitation, \( \Delta S_{X5} \): Saudi temperature, and \( S_{X6} \): Saudi precipitation.

### 7.3.3 Vector autoregressive system stability

VAR provides a useful framework to investigate both long-term relations and short-term dynamics of the variables in a system. Prior to conducting an econometric analysis, a stability test should be performed. Testing the stability of a dependent variable is essential, because if a VAR model is unstable or stationary, some tests, such as IRA, become invalid. The stability of a VAR model can be tested by calculating the roots of its characteristic polynomial. Here, the necessary and sufficient condition of stability is that all characteristic roots lie within the unit circle such that the characteristic polynomial is of full rank and all variables are stationary. Note that a stability test was performed for all periods. The roots of the characteristic VAR polynomial were determined as defined by the FF, CC and combined variables, and were specified for two lags.

As shown in Table 7.6, the specified models were stable, i.e. all VAR values were less than 1. This means that the modulus latent root was less than 1 and was polynomial...
non-singular with a non-zero determinant, and that the system was a stationary stochastic process that can reach convergence. The results in Figure 7.1 clearly indicate that the inverse roots of the AR characteristic polynomials lie within the complex unit circle; thus, the models will converge (i.e. lagged variable values will not have a compounding effect on each other and contemporary values will stabilize over time).

Table 7.6: VAR roots of characteristic polynomials.

<table>
<thead>
<tr>
<th>Period 1</th>
<th>FF set</th>
<th>Period 2</th>
<th>Period 3</th>
<th>CC set</th>
<th>Period 2</th>
<th>Period 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>RM</td>
<td>RM</td>
<td>RM</td>
<td>RM</td>
<td>RM</td>
<td>RM</td>
<td>RM</td>
</tr>
<tr>
<td>-0.18 - 0.54i</td>
<td>0.57</td>
<td>0.44 - 0.25i</td>
<td>0.50</td>
<td>-0.16 - 0.47i</td>
<td>0.50</td>
<td>0.80 - 0.46i</td>
</tr>
<tr>
<td>-0.18 - 0.54i</td>
<td>0.57</td>
<td>0.44 - 0.25i</td>
<td>0.50</td>
<td>-0.16 - 0.47i</td>
<td>0.50</td>
<td>0.80 - 0.46i</td>
</tr>
<tr>
<td>0.24 - 0.41i</td>
<td>0.47</td>
<td>-0.17 - 0.35i</td>
<td>0.38</td>
<td>0.36 - 0.24i</td>
<td>0.44</td>
<td>0.13 - 0.70i</td>
</tr>
<tr>
<td>0.24 - 0.41i</td>
<td>0.47</td>
<td>-0.17 + 0.35i</td>
<td>0.38</td>
<td>0.36 + 0.24i</td>
<td>0.44</td>
<td>0.13 + 0.70i</td>
</tr>
<tr>
<td>0.40</td>
<td>0.41</td>
<td>-0.03 - 0.34i</td>
<td>0.34</td>
<td>0.20 - 0.36i</td>
<td>0.41</td>
<td>-0.22 - 0.39i</td>
</tr>
<tr>
<td>0.08 - 0.23i</td>
<td>0.25</td>
<td>-0.03 + 0.34i</td>
<td>0.34</td>
<td>0.20 + 0.36i</td>
<td>0.41</td>
<td>-0.22 + 0.39i</td>
</tr>
<tr>
<td>0.08 + 0.23i</td>
<td>0.25</td>
<td>-0.05 - 0.14i</td>
<td>0.15</td>
<td>-0.12 - 0.20i</td>
<td>0.23</td>
<td>-0.40 - 0.19i</td>
</tr>
<tr>
<td>-0.19</td>
<td>0.19</td>
<td>-0.05 + 0.14i</td>
<td>0.15</td>
<td>-0.12 + 0.20i</td>
<td>0.23</td>
<td>-0.40 + 0.19i</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Period 1</th>
<th>FF and CC set</th>
<th>Period 2</th>
<th>Period 3</th>
<th>Period 1</th>
<th>FF and CC set</th>
<th>Period 2</th>
<th>Period 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>RM</td>
<td>RM</td>
<td>RM</td>
<td>RM</td>
<td>RM</td>
<td>RM</td>
<td>RM</td>
<td>RM</td>
</tr>
<tr>
<td>0.80 + 0.46i</td>
<td>0.92</td>
<td>0.80 + 0.46i</td>
<td>0.93</td>
<td>0.80 + 0.46i</td>
<td>0.92</td>
<td>-0.15 - 0.35i</td>
<td>0.39</td>
</tr>
<tr>
<td>0.80 - 0.46i</td>
<td>0.92</td>
<td>0.80 - 0.46i</td>
<td>0.93</td>
<td>0.80 - 0.46i</td>
<td>0.92</td>
<td>-0.15 + 0.35i</td>
<td>0.39</td>
</tr>
<tr>
<td>-0.04 + 0.68i</td>
<td>0.69</td>
<td>0.14 + 0.71i</td>
<td>0.72</td>
<td>0.06 + 0.69i</td>
<td>0.69</td>
<td>0.16 - 0.32i</td>
<td>0.35</td>
</tr>
<tr>
<td>-0.04 - 0.68i</td>
<td>0.69</td>
<td>0.14 - 0.71i</td>
<td>0.72</td>
<td>0.06 - 0.69i</td>
<td>0.69</td>
<td>0.16 + 0.32i</td>
<td>0.35</td>
</tr>
<tr>
<td>-0.21 - 0.43i</td>
<td>0.48</td>
<td>-0.22 + 0.59i</td>
<td>0.63</td>
<td>-0.16 + 0.49i</td>
<td>0.52</td>
<td>-0.24 - 0.32i</td>
<td>0.38</td>
</tr>
<tr>
<td>-0.21 + 0.43i</td>
<td>0.48</td>
<td>-0.22 - 0.59i</td>
<td>0.63</td>
<td>-0.16 - 0.49i</td>
<td>0.52</td>
<td>-0.24 + 0.32i</td>
<td>0.38</td>
</tr>
<tr>
<td>0.40 + 0.25i</td>
<td>0.47</td>
<td>-0.41 - 0.19i</td>
<td>0.45</td>
<td>0.25 + 0.34i</td>
<td>0.42</td>
<td>0.19 + 0.32i</td>
<td>0.37</td>
</tr>
<tr>
<td>0.40 - 0.25i</td>
<td>0.47</td>
<td>-0.41 + 0.19i</td>
<td>0.45</td>
<td>0.25 - 0.34i</td>
<td>0.42</td>
<td>0.19 - 0.32i</td>
<td>0.37</td>
</tr>
</tbody>
</table>

Note:
No root lies outside the unit circle.
R: Root and M: Modulus.
### 7.3.4 Testing the adequacy of vector autoregressive model

In addition to testing VAR model stability, we also tested for white noise relative to the residual terms. Residual tests focus on VAR Portmanteau tests (Table 7.7) and residual serial correlation LM tests (Table 7.8) for autocorrelations. Both tests show that the null hypothesis of no serial autocorrelation in residuals cannot be rejected for lag order \( h \) (in this case, lag two), \( H_0: V_1 = V_2 = \ldots = V_h = 0 \). The tests were performed for the three periods under consideration and separately for the FF, CC and combined variable sets. The VAR of FF, CC and the combined trait models can be considered representative and stable.

![Figure 7.1: Inverse roots of AR characteristic polynomials.](image-url)
Table 7.7: VAR residual Portmanteau tests for autocorrelations.

| Period | FF set | | CC set | |  |
| --- | --- | --- | --- | --- |
| Lags | QS | AQS | QS | AQS | DF | Lags | QS | AQS | QS | AQS | QS | AQS | DF |
| 1 | 1.136 | 1.141 | 0.912 | 0.916 | 0.762 | 0.763 | NA | 1 | 59.55 | 59.82 | 51.91 | 52.13 | 100.8 | 101.1 | NA |
| 2 | 2.472 | 2.489 | 1.931 | 1.944 | 2.296 | 2.305 | NA | 2 | 104.6 | 105.3 | 77.09 | 77.54 | 152.5 | 153.1 | NA |
| 3 | 23.85 | 24.16 | 22.63 | 22.91 | 19.33 | 19.45 | 16 | 3 | 150.7 | 151.9 | 130.8 | 132.0 | 256.1 | 257.2 | 36 |
| 4 | 40.11 | 40.70 | 42.08 | 42.71 | 35.63 | 35.89 | 32 | 4 | 201.8 | 204.2 | 171.3 | 173.2 | 306.4 | 307.9 | 72 |
| 5 | 62.91 | 64.01 | 53.72 | 54.61 | 65.57 | 66.16 | 48 | 5 | 252.4 | 255.7 | 211.7 | 214.5 | 359.7 | 361.8 | 108 |

Note:
QS: Q-Stat; and AQS: Adj Q-Stat.
Null hypothesis: No serial correlation at lag order $h$.
***, ** and * indicate significance at 1%, 5% and 10% levels, respectively.
NA: Test is valid only for lags greater than the VAR lag two.

Table 7.8: VAR residual serial correlation LM test for the three variable sets.

| Period | FF set | | CC set | |  |
| --- | --- | --- | --- | --- |
| Lags | LM-Stat | | LM-Stat | |  |
| 1 | 23.69 | 22.83 | 30.44 | 153.7 | 137.8 | 123.6 |
| 2 | 11.94 | 12.17 | 20.95 | 43.40 | 32.79 | 50.61 |
| 3 | 20.28 | 20.63 | 18.11 | 56.31 | 31.08 | 41.03 |
| 4 | 16.67 | 19.89 | 16.92 | 55.99 | 43.63 | 56.85 |
| 5 | 8.727 | 12.12 | 18.85 | 52.85 | 42.48 | 57.05 |

Note:
Null hypothesis: No serial correlation at lag order $h$.
***, ** and * indicate significance at 1%, 5% and 10% levels, respectively.
Probs for FF, CC, and combined variables from Chi-square with 16, 36 and 100 DF, respectively.
7.3.5 Vector autoregressive estimates

Initially, VAR analysis was performed to determine which variables are linked significantly. After completing the model specification tests, VAR equations were constructed for the system of dynamic FF variables. $R_{Y_1}$, $R_{Y_2}$, $R_{Y_3}$ and $R_{Y_4}$ have a significant coefficient, as either an influential or influenced variable. Consequently, there is significant interdependence among all variables, which supports the findings from the correlation analysis (Table 7.2 to 7.4). The VAR was estimated based on the weighted returns of each FF market for Periods 1, 2 and 3 as follows.

**FF VAR Equations (Period 1)**

$$R_{Y_1,t} = -0.057 R_{Y_1,t-1} + 0.073 R_{Y_1,t-2} + 0.507 R_{Y_2,t-1} - 0.308 R_{Y_2,t-2} - 0.065 R_{Y_3,t-1}$$

$$+ 0.183 R_{Y_3,t-2} + 0.131 R_{Y_4,t-1} + 0.210 R_{Y_4,t-2} - 0.094$$

$$R_{Y_2,t} = 0.059 R_{Y_1,t-1} + 0.335 R_{Y_1,t-2} + 0.286 R_{Y_2,t-1} - 0.472 R_{Y_2,t-2} - 0.031 R_{Y_3,t-1}$$

$$+ 0.138 R_{Y_3,t-2} + 0.0003 R_{Y_4,t-1} + 0.121 R_{Y_4,t-2} - 0.077$$

$$R_{Y_3,t} = -0.010 R_{Y_1,t-1} - 0.002 R_{Y_1,t-2} + 0.080 R_{Y_2,t-1} + 0.029 R_{Y_2,t-2} + 0.070 R_{Y_3,t-1}$$

$$- 0.044 R_{Y_3,t-2} - 0.017 R_{Y_4,t-1} + 0.062 R_{Y_4,t-2} + 0.015$$

$$R_{Y_4,t} = 0.050 R_{Y_1,t-1} - 0.027 R_{Y_1,t-2} - 0.051 R_{Y_2,t-1} + 0.060 R_{Y_2,t-2} - 0.051 R_{Y_3,t-1}$$

$$+ 0.018 R_{Y_3,t-2} + 0.219 R_{Y_4,t-1} + 0.025 R_{Y_4,t-2} + 0.076$$

**FF VAR Equations (Period 2)**

$$R_{Y_1,t} = -0.001 R_{Y_1,t-1} + 0.487 R_{Y_1,t-2} - 0.100 R_{Y_2,t-1} - 0.635 R_{Y_2,t-2} + 0.039 R_{Y_3,t-1}$$

$$- 0.131 R_{Y_3,t-2} + 0.369 R_{Y_4,t-1} + 0.113 R_{Y_4,t-2} + 0.354$$

$$R_{Y_2,t} = 0.048 R_{Y_1,t-1} + 0.497 R_{Y_1,t-2} - 0.065 R_{Y_2,t-1} - 0.662 R_{Y_2,t-2} + 0.071 R_{Y_3,t-1}$$

$$- 0.094 R_{Y_3,t-2} + 0.201 R_{Y_4,t-1} + 0.165 R_{Y_4,t-2} + 0.361$$

$$R_{Y_3,t} = -0.043 R_{Y_1,t-1} - 0.160 R_{Y_1,t-2} + 0.335 R_{Y_2,t-1} + 0.060 R_{Y_2,t-2} + 0.106 R_{Y_3,t-1}$$

$$+ 0.052 R_{Y_3,t-2} - 0.238 R_{Y_4,t-1} + 0.197 R_{Y_4,t-2} + 0.295$$

$$R_{Y_4,t} = 0.136 R_{Y_1,t-1} + 0.552 R_{Y_1,t-2} - 0.231 R_{Y_2,t-1} - 0.581 R_{Y_2,t-2} + 0.077 R_{Y_3,t-1}$$

$$- 0.134 R_{Y_3,t-2} + 0.332 R_{Y_4,t-1} - 0.039 R_{Y_4,t-2} + 0.872$$
**FF VAR Equations (Period 3)**

\[
R_{Y_1,t} = 0.115 R_{Y_1,t-1} + 0.214 R_{Y_1,t-2} + 0.216 R_{Y_2,t-1} - 0.444 R_{Y_2,t-2} - 0.001 R_{Y_3,t-1} \\
- 0.029 R_{Y_4,t-2} - 0.022 R_{Y_4,t-1} + 0.204 R_{Y_4,t-2} + 0.168 \tag{7.a9}
\]

\[
R_{Y_2,t} = 0.162 R_{Y_1,t-1} + 0.414 R_{Y_1,t-2} + 0.114 R_{Y_2,t-1} - 0.553 R_{Y_2,t-2} + 0.034 R_{Y_3,t-1} \\
- 0.016 R_{Y_3,t-2} - 0.066 R_{Y_4,t-1} + 0.141 R_{Y_4,t-2} + 0.180 \tag{7.a10}
\]

\[
R_{Y_3,t} = -0.084 R_{Y_1,t-1} - 0.029 R_{Y_1,t-2} + 0.196 R_{Y_2,t-1} + 0.039 R_{Y_2,t-2} + 0.098 R_{Y_3,t-1} \\
+ 0.022 R_{Y_3,t-2} - 0.060 R_{Y_4,t-1} + 0.087 R_{Y_4,t-2} + 0.147 \tag{7.a11}
\]

\[
R_{Y_4,t} = 0.136 R_{Y_1,t-1} + 0.183 R_{Y_1,t-2} - 0.143 R_{Y_2,t-1} - 0.208 R_{Y_2,t-2} + 0.033 R_{Y_3,t-1} \\
- 0.079 R_{Y_3,t-2} + 0.261 R_{Y_4,t-1} - 0.014 R_{Y_4,t-2} + 0.462 \tag{7.a12}
\]

Here, each equation expresses a single dependent variable in period \( t \) in terms of all variables in the set for two earlier periods. Equation (7.a1) demonstrates that during Period 1, the Saudi oil price of return had strong positive (coeff.: 0.507) and negative (coeff.: −0.308) effects on \( R_{Y_1} \), and NG return had weak negative (lag one) and medium positive (lag two) effects on \( R_{Y_1} \). In addition, for coal return, lags of one and two had positive and moderate impacts on the global oil price of return. The effects of other FF variables on Saudi oil price returns are given by Equation (7.a2). Global oil return had a small positive (lag one) and moderately high (lag two) influence on \( R_{Y_2} \). Similarly, \( R_{Y_3} \) had a low negative (lag one) and a moderate positive (lag two) impact on Saudi oil return, while coal return had low positive (lag one) and medium (lag two) effects on \( R_{Y_2} \). Equations (7.a3) and (7.a4), *i.e.* for \( R_{Y_3} \) and \( R_{Y_4} \), respectively, indicate that these variables were weakly impacted by the other three corresponding variables in the positive or negative direction.

With the VAR system, the coefficient estimates for the FF variables during Period 2 indicate that a strong lag (two) for \( R_{Y_1} \) and \( R_{Y_2} \) influenced \( (R_{Y_2} \text{ and } R_{Y_4}) \text{ and } (R_{Y_1} \text{ and } R_{Y_4}) \), respectively, and NG had a positive low (lag one) effect on \( R_{Y_1}, R_{Y_2} \text{ and } R_{Y_4} \) and
a medium negative (lag two) effect on $R_{Y_1}$ and $R_{Y_4}$. Relative to lags of one and two, $R_{Y_4}$ had medium effect on $R_{Y_2}$ and $R_{Y_3}$ (Equations (7.a5) – (7.a8)). Equation (7.a9) demonstrates that $R_{Y_2}$ had a moderate positive effect (lag one) and a strong negative effect (lag two) on $R_{Y_1}$, while the global oil price of return had a medium positive (lag one) and strong (lag two) effect on $R_{Y_2}$ (Equation (7.a10)). Lags of one and two relative to FF return had low positive and negative effects on $R_{Y_3}$, except for lag one of $R_{Y_2}$, which had medium influence on NG (Equation (7.a11)). The coal return VAR Equation (7.a12) indicates that oil market variables ($R_{Y_1}$ and $R_{Y_2}$) had medium positive and negative impacts (lag one and two), respectively.

The following VAR equations were constructed to demonstrate the effects among the CC variables.

- **CC VAR Equations (Period 1)**

<table>
<thead>
<tr>
<th>Equation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{Xi,t} = 0.308 R_{Xi,t-1} - 0.118 R_{Xi,t-2} + 5.078 \Delta S_{X2,t-1} + 3.958 \Delta S_{X2,t-2} - 1.212 \Delta S_{X6,t-1}$</td>
<td>(7.a13)</td>
</tr>
<tr>
<td>$\Delta S_{X2,t} = 8.785E-5 R_{Xi,t-1} + 8.934E-5 R_{Xi,t-2} - 0.426 \Delta S_{X2,t-1} - 0.175 \Delta S_{X2,t-2}$</td>
<td>(7.a14)</td>
</tr>
<tr>
<td>$\Delta S_{X3,t} = -0.0004 R_{Xi,t-1} + 0.0003 R_{Xi,t-2} + 0.118 \Delta S_{X2,t-1} - 0.190 \Delta S_{X2,t-2}$</td>
<td>(7.a15)</td>
</tr>
<tr>
<td>$\Delta S_{X4,t} = -0.005 R_{Xi,t-1} - 0.005 R_{Xi,t-2} + 1.688 \Delta S_{X2,t-1} - 3.607 \Delta S_{X2,t-2} + 0.148 \Delta S_{X3,t-1}$</td>
<td>(7.a16)</td>
</tr>
<tr>
<td>$\Delta S_{X5,t} = 0.004 R_{Xi,t-1} + 0.001 R_{Xi,t-2} - 0.899 \Delta S_{X2,t-1} - 0.797 \Delta S_{X2,t-2} + 0.024 \Delta S_{X3,t-1}$</td>
<td>(7.a17)</td>
</tr>
</tbody>
</table>

(continued)
\[ S_{X_t, t} = 0.005 R_{X_1, t-1} - 0.006 R_{X_1, t-2} - 1.344 \Delta S_{X_2, t-1} + 2.873 \Delta S_{X_2, t-2} - 0.459 \Delta S_{X_3, t-1} \\
- 0.527 \Delta S_{X_3, t-2} - 0.435 S_{X_4, t-1} - 0.178 S_{X_4, t-2} + 0.509 \Delta S_{X_5, t-1} \\
- 0.125 \Delta S_{X_5, t-2} + 0.348 S_{X_6, t-1} - 0.551 S_{X_6, t-2} - 0.016 \] (7.a18)

\* CC VAR Equations (Period 2) \*

\[ R_{X_1, t} = 0.156 R_{X_1, t-1} - 0.017 R_{X_1, t-2} - 0.349 \Delta S_{X_2, t-1} - 0.495 \Delta S_{X_2, t-2} - 1.045 \Delta S_{X_3, t-1} \\
+ 0.542 \Delta S_{X_3, t-2} + 0.866 S_{X_4, t-1} + 1.006 S_{X_4, t-2} + 0.639 \Delta S_{X_5, t-1} \] (7.a19)

\[ \Delta S_{X_2, t} = -0.002 R_{X_1, t-1} - 0.031 R_{X_1, t-2} - 0.324 \Delta S_{X_2, t-1} - 0.165 \Delta S_{X_2, t-2} \\
- 1.523 \Delta S_{X_3, t-1} + 0.356 \Delta S_{X_3, t-2} - 0.025 S_{X_4, t-1} + 0.176 S_{X_4, t-2} \] (7.a20)

\[ \Delta S_{X_3, t} = -0.002 R_{X_1, t-1} + 0.001 R_{X_1, t-2} - 0.002 \Delta S_{X_2, t-1} + 0.001 \Delta S_{X_2, t-2} \\
- 0.416 \Delta S_{X_3, t-1} - 0.114 \Delta S_{X_3, t-2} + 0.013 S_{X_4, t-1} - 0.012 S_{X_4, t-2} \] (7.a21)

\[ S_{X_4, t} = 0.003 R_{X_1, t-1} - 0.009 R_{X_1, t-2} - 0.051 \Delta S_{X_2, t-1} - 0.028 \Delta S_{X_2, t-2} - 0.329 \Delta S_{X_3, t-1} \\
- 1.230 \Delta S_{X_3, t-2} + 0.475 S_{X_4, t-1} + 0.213 S_{X_4, t-2} - 0.080 \Delta S_{X_5, t-1} \] (7.a22)

\[ \Delta S_{X_5, t} = -0.001 R_{X_1, t-1} + 0.0003 R_{X_1, t-2} - 0.018 \Delta S_{X_2, t-1} - 0.006 \Delta S_{X_2, t-2} \\
+ 0.085 \Delta S_{X_3, t-1} - 0.062 \Delta S_{X_3, t-2} - 0.141 S_{X_4, t-1} - 0.091 S_{X_4, t-2} \] (7.a23)

\[ S_{X_6, t} = 0.007 R_{X_1, t-1} + 0.016 R_{X_1, t-2} + 0.011 \Delta S_{X_2, t-1} - 0.035 \Delta S_{X_2, t-2} - 0.490 \Delta S_{X_3, t-1} \\
- 0.118 \Delta S_{X_3, t-2} - 0.428 S_{X_4, t-1} - 0.365 S_{X_4, t-2} + 0.048 \Delta S_{X_5, t-1} \] (7.a24)

\[ \Delta S_{X_5, t} = 0.001 R_{X_1, t-1} - 0.024 R_{X_1, t-2} - 0.101 \Delta S_{X_2, t-1} + 0.067 \Delta S_{X_2, t-2} - 0.710 \Delta S_{X_3, t-1} \\
+ 0.458 \Delta S_{X_3, t-2} + 0.010 S_{X_4, t-1} + 0.080 S_{X_4, t-2} + 0.198 \Delta S_{X_5, t-1} \] (7.a26)
\[ \Delta S_{X_1, t} = -0.0002 \, R_{X_1, t-1} - 0.001 \, R_{X_1, t-2} - 0.0004 \, \Delta S_{X_2, t-1} + 0.002 \, \Delta S_{X_2, t-2} \\
- 0.415 \, \Delta S_{X_3, t-1} - 0.117 \, \Delta S_{X_3, t-2} + 0.003 \, S_{X_4, t-1} - 0.012 \, S_{X_4, t-2} \tag{7.a27} \\
- 0.009 \, \Delta S_{X_5, t-1} + 0.018 \, \Delta S_{X_5, t-2} - 0.010 \, S_{X_6, t-1} - 0.002 \, S_{X_6, t-2} + 0.005 \\
S_{X_4, t} = 0.001 \, R_{X_1, t-1} - 0.007 \, R_{X_1, t-2} - 0.034 \, \Delta S_{X_2, t-1} - 0.018 \, \Delta S_{X_2, t-2} - 0.117 \, \Delta S_{X_3, t-1} \\
- 0.677 \, \Delta S_{X_3, t-2} + 0.464 \, S_{X_4, t-1} + 0.247 \, S_{X_4, t-2} + 0.047 \, \Delta S_{X_5, t-1} \tag{7.a28} \\
+ 0.965 \, \Delta S_{X_5, t-2} + 0.037 \, S_{X_6, t-1} - 0.081 \, S_{X_6, t-2} + 0.026 \\
\Delta S_{X_6, t} = 0.0003 \, R_{X_1, t-1} - 7.996E-05 \, R_{X_1, t-2} - 0.013 \, \Delta S_{X_2, t-1} - 0.004 \, \Delta S_{X_2, t-2} \\
+ 0.069 \, \Delta S_{X_3, t-1} + 0.104 \, \Delta S_{X_3, t-2} - 0.149 \, S_{X_4, t-1} - 0.103 \, S_{X_4, t-2} \tag{7.a29} \\
+ 0.483 \, \Delta S_{X_5, t-1} - 0.013 \, \Delta S_{X_5, t-2} + 0.088 \, S_{X_6, t-1} + 0.003 \, S_{X_6, t-2} + 0.004 \\
S_{X_6, t} = 0.005 \, R_{X_1, t-1} + 0.011 \, R_{X_1, t-2} + 0.018 \, \Delta S_{X_2, t-1} - 0.021 \, \Delta S_{X_2, t-2} - 0.450 \, \Delta S_{X_3, t-1} \\
- 0.321 \, \Delta S_{X_3, t-2} - 0.427 \, S_{X_4, t-1} - 0.277 \, S_{X_4, t-2} + 0.255 \, \Delta S_{X_5, t-1} \tag{7.a30} \\
- 0.019 \, \Delta S_{X_5, t-2} + 0.226 \, S_{X_6, t-1} - 0.484 \, S_{X_6, t-2} - 0.002 \\
\]

It is evident that the coefficient estimates of the CC VAR model were similar for all three periods. Equations (7.a13), (7.a19) and (7.a25) indicate that \( \Delta S_{X_2}, \Delta S_{X_3}, S_{X_4} \) (lag two, Period 2), \( \Delta S_{X_5} \) (lag two, Period 3) and \( S_{X_6} \) had strong positive and negative effects on \( R_{X_1} \). The VAR coefficient results for global CO\( _2 \) emission (Equations (7.a14), (7.a20) and (7.a26)) suggest strong positive and negative effects due to the lags of global temperature (Periods 2 and 3), \( \Delta S_{X_5} \) (lag 1, Periods 2 and 3) and \( S_{X_6} \) (Period 2). The estimation by Equation (7.a16) was similar to that by Equations (7.a22) and (7.a28), thereby suggesting that \( \Delta S_{X_2} \) (lag one and two, Period 1), \( \Delta S_{X_3} \) (Period 2 and lag two, Period 3) and \( \Delta S_{X_4} \) (lag two, Periods 1 and 3) had a strong relation with global precipitation. Estimations by Equations (7.a17), (7.a23) and (7.a29) show that \( \Delta S_{X_5} \) had low influenced by \( R_{X_1} \) and \( \Delta S_{X_2} \) (lag one and two of Periods 2 and 3), \( \Delta S_{X_3} \) (lag one of Periods 1 and 3, and lag one and two of Period 2) and \( \Delta S_{X_5} \) (lag two of Periods 1, 2 and 3), whereas \( S_{X_4} \) had a negative medium effect on \( \Delta S_{X_5} \) (lag one and two of Periods 1, 2 and 3). A strong result was observed for lag one and two lag of \( \Delta S_{X_2} \) (Period 1), \( \Delta S_{X_3} \)
(Periods 1 and 3), \( S_{X_4} \) (Period 2) also lag one of \( \Delta S_{X_4} \) (Period 2), \( S_{X_5} \) (Period 1 and 3), \( \Delta S_{X_5} \) (Period 1) that effect Saudi precipitation in Equations (7.a18), (7.a24) and (7.a30).

The equations in the VAR system for the combined set of variables capture and evaluate the interdependencies between the multiple time series. Note that all variables in a VAR system are treated symmetrically by including an equation for each variable in the FF and CC sets that explains the given variable’s evolution based on the chosen lags and the lags of all other variables in the model, as shown in the following.

- **FF and CC VAR Equations (Period 1)**

\[
R_{Y_1, t} = -0.085 R_{Y_1, t-1} + 0.054 R_{Y_1, t-2} + 0.587 R_{Y_2, t-1} - 0.305 R_{Y_2, t-2} - 0.100 R_{Y_3, t-1} \\
+ 0.176 R_{Y_3, t-2} + 0.118 R_{Y_4, t-1} + 0.210 R_{Y_4, t-2} + 0.007 R_{X_1, t-1} \\
- 0.034 R_{X_1, t-2} - 32.077 \Delta S_{X_2, t-1} + 10.595 \Delta S_{X_2, t-2} + 1.281 \Delta S_{X_3, t-1} \tag{7.a31}
\]

\[
R_{Y_2, t} = 0.038 R_{Y_1, t-1} + 0.315 R_{Y_1, t-2} + 0.359 R_{Y_2, t-1} - 0.459 R_{Y_2, t-2} - 0.051 R_{Y_3, t-1} \\
+ 0.125 R_{Y_3, t-2} - 0.002 R_{Y_4, t-1} + 0.120 R_{Y_4, t-2} - 0.039 R_{X_1, t-1} \\
- 0.028 R_{X_1, t-2} - 22.234 \Delta S_{X_2, t-1} + 38.269 \Delta S_{X_2, t-2} + 2.264 \Delta S_{X_3, t-1} \tag{7.a32}
\]

\[
R_{Y_3, t} = -0.013 R_{Y_1, t-1} - 0.0004 R_{Y_1, t-2} + 0.073 R_{Y_2, t-1} + 0.019 R_{Y_2, t-2} + 0.01 R_{Y_3, t-1} \\
- 0.045 R_{Y_3, t-2} - 0.048 R_{Y_4, t-1} + 0.048 R_{Y_4, t-2} - 0.033 R_{X_1, t-1} \\
- 0.063 R_{X_1, t-2} - 13.907 \Delta S_{X_2, t-1} - 19.710 \Delta S_{X_2, t-2} - 4.402 \Delta S_{X_3, t-1} \tag{7.a33}
\]

\[
R_{Y_4, t} = 0.059 R_{Y_1, t-1} - 0.018 R_{Y_1, t-2} - 0.069 R_{Y_2, t-1} + 0.049 R_{Y_2, t-2} - 0.042 R_{Y_3, t-1} \\
+ 0.033 R_{Y_3, t-2} + 0.224 R_{Y_4, t-1} + 0.015 R_{Y_4, t-2} - 0.066 R_{X_1, t-1} \\
- 0.001 R_{X_1, t-2} - 1.165 \Delta S_{X_2, t-1} + 40.276 \Delta S_{X_2, t-2} - 0.740 \Delta S_{X_3, t-1} \tag{7.a34}
\]

\[
- 1.066 \Delta S_{X_3, t-2} - 0.312 S_{X_4, t-1} + 0.136 S_{X_4, t-2} - 1.144 \Delta S_{X_5, t-1} \\
+ 0.363 \Delta S_{X_5, t-2} + 0.073 S_{X_6, t-1} - 0.009 S_{X_6, t-2} - 0.121
\]
\( R_{X_1, t} = 0.050 R_{Y_1, t-1} + 0.117 R_{Y_1, t-2} - 0.053 R_{Y_2, t-1} - 0.077 R_{Y_2, t-2} + 0.030 R_{Y_3, t-1} + 0.105 R_{Y_4, t-2} - 0.103 R_{Y_4, t-1} + 0.085 R_{Y_4, t-2} + 0.311 R_{X_1, t-1} - 0.120 R_{X_1, t-2} + 2.530 \Delta S_{X_2, t-1} - 0.279 \Delta S_{X_2, t-2} - 1.294 \Delta S_{X_5, t-1} + 1.619 \Delta S_{X_5, t-2} + 0.346 S_{X_6, t-1} + 0.065 S_{X_6, t-2} - 0.746 \Delta S_{X_5, t-1} - 0.463 \Delta S_{X_5, t-2} - 0.506 S_{X_6, t-1} + 0.541 S_{X_6, t-2} + 0.453 \\
(7.a35) \\
\Delta S_{X_2, t} = -2.542E-05 R_{Y_1, t-1} - 9.872E-05 R_{Y_1, t-2} + 5.717E-05 R_{Y_2, t-1} - 0.0002 R_{Y_2, t-2} + 0.001 R_{Y_3, t-1} + 0.0001 R_{Y_4, t-2} - 0.0002 R_{Y_4, t-1} + 0.001 R_{Y_4, t-2} + 0.0001 R_{X_1, t-1} + 7.812E-05 R_{X_1, t-2} - 0.431 \Delta S_{X_2, t-1} - 0.164 \Delta S_{X_2, t-2} + 0.002 \Delta S_{X_3, t-1} - 0.002 \Delta S_{X_3, t-2} - 0.0002 S_{X_4, t-1} + 0.001 S_{X_4, t-2} - 0.0003 \Delta S_{X_5, t-1} + 0.0002 \Delta S_{X_5, t-2} + 0.001 S_{X_6, t-1} - 0.001 S_{X_6, t-2} + 0.010 \\
(7.a36) \\
\Delta S_{X_3, t} = 0.0004 R_{Y_1, t-1} + 0.002 R_{Y_1, t-2} - 0.001 R_{Y_2, t-1} - 0.001 R_{Y_2, t-2} - 0.002 R_{Y_3, t-1} + 0.003 R_{Y_3, t-2} + 0.002 R_{Y_4, t-1} + 0.001 R_{Y_4, t-2} - 0.001 R_{X_1, t-1} + 0.001 R_{X_1, t-2} + 0.037 \Delta S_{X_2, t-1} - 0.255 \Delta S_{X_2, t-2} - 0.430 \Delta S_{X_3, t-1} - 0.145 \Delta S_{X_3, t-2} - 0.010 S_{X_6, t-1} - 0.012 S_{X_6, t-2} - 0.034 \Delta S_{X_5, t-1} + 0.054 \Delta S_{X_5, t-2} - 0.017 S_{X_6, t-1} + 0.008 S_{X_6, t-2} + 0.003 \\
(7.a37) \\
S_{X_4, t} = 0.007 R_{Y_1, t-1} - 0.012 R_{Y_1, t-2} - 0.005 R_{Y_2, t-1} + 0.019 R_{Y_2, t-2} - 0.026 R_{Y_3, t-1} - 0.017 R_{Y_3, t-2} + 0.018 R_{Y_4, t-1} - 0.030 R_{Y_4, t-2} - 0.005 R_{X_1, t-1} - 0.005 R_{X_1, t-2} + 1.993 \Delta S_{X_2, t-1} - 3.581 \Delta S_{X_2, t-2} + 0.053 \Delta S_{X_3, t-1} - 0.201 \Delta S_{X_3, t-2} + 0.427 S_{X_4, t-1} + 0.287 S_{X_4, t-2} + 0.192 S_{X_5, t-1} + 0.962 \Delta S_{X_5, t-2} + 0.054 S_{X_6, t-1} - 0.127 S_{X_6, t-2} + 0.017 \\
(7.a38) \\
\Delta S_{X_5, t} = 0.003 R_{Y_1, t-1} + 0.003 R_{Y_1, t-2} - 0.003 R_{Y_2, t-1} - 0.004 R_{Y_2, t-2} + 0.003 R_{Y_3, t-1} - 0.002 R_{Y_3, t-2} + 0.0005 R_{Y_4, t-1} + 0.012 R_{Y_4, t-2} + 0.004 R_{X_1, t-1} + 0.0002 R_{X_1, t-2} - 0.819 \Delta S_{X_2, t-1} - 0.830 \Delta S_{X_2, t-2} + 0.021 \Delta S_{X_3, t-1} + 0.241 \Delta S_{X_3, t-2} - 0.153 S_{X_4, t-1} - 0.117 S_{X_4, t-2} + 0.389 \Delta S_{X_5, t-1} + 0.055 \Delta S_{X_5, t-2} + 0.097 S_{X_6, t-1} + 0.011 S_{X_6, t-2} + 0.003 \\
(7.a39) \\
S_{X_6, t} = 0.005 R_{Y_1, t-1} + 0.022 R_{Y_1, t-2} + 0.003 R_{Y_2, t-1} - 0.026 R_{Y_2, t-2} + 0.010 R_{Y_3, t-1} - 0.012 R_{Y_3, t-2} + 0.018 R_{Y_4, t-1} - 0.008 R_{Y_4, t-2} + 0.005 R_{X_1, t-1} - 0.004 R_{X_1, t-2} - 0.993 \Delta S_{X_2, t-1} + 3.325 \Delta S_{X_2, t-2} - 0.406 \Delta S_{X_3, t-1} - 0.551 \Delta S_{X_3, t-2} - 0.432 S_{X_4, t-1} - 0.177 S_{X_4, t-2} + 0.530 \Delta S_{X_5, t-1} - 0.133 \Delta S_{X_5, t-2} + 0.339 S_{X_6, t-1} - 0.552 S_{X_6, t-2} - 0.022 \\
(7.a40) \)
## FF and CC VAR Equations (Period 2)

\[
R_{Y_1, t} = 4.351 \ R_{Y_1, t-1} - 0.990 \ R_{Y_1, t-2} + 4.660 \ R_{Y_2, t-1} - 2.283 \ R_{Y_2, t-2} + 0.044 \ R_{Y_3, t-1} \\
- 0.112 \ R_{Y_1, t-1} + 0.679 \ R_{Y_4, t-1} - 0.082 \ R_{Y_4, t-2} - 9.479 \ R_{X_1, t-1} \\
+ 3.322 \ R_{X_1, t-2} - 0.272 \ \Delta S_{X_2, t-1} - 0.598 \ \Delta S_{X_2, t-2} + 0.816 \ \Delta S_{X_3, t-1} \\
+ 3.477 \ \Delta S_{X_3, t-2} + 0.954 \ S_{X_4, t-1} + 0.681 \ S_{X_4, t-2} + 0.122 \ \Delta S_{X_5, t-1} \\
+ 0.355 \ \Delta S_{X_5, t-2} - 0.232 \ S_{X_6, t-1} - 1.295 \ S_{X_6, t-2} + 1.157 \\
(7.a41)
\]

\[
R_{Y_2, t} = 4.726 \ R_{Y_1, t-1} - 0.521 \ R_{Y_1, t-2} + 5.096 \ R_{Y_2, t-1} - 1.814 \ R_{Y_2, t-2} + 0.080 \ R_{Y_3, t-1} \\
- 0.086 \ R_{Y_1, t-1} + 0.559 \ R_{Y_4, t-1} + 0.013 \ R_{Y_4, t-2} - 10.244 \ R_{X_1, t-1} \\
+ 2.323 \ R_{X_1, t-2} - 0.378 \ \Delta S_{X_2, t-1} - 0.472 \ \Delta S_{X_2, t-2} + 1.303 \ \Delta S_{X_3, t-1} \\
+ 1.285 \ \Delta S_{X_3, t-2} + 1.091 \ S_{X_4, t-1} + 0.373 \ S_{X_4, t-2} + 0.105 \ \Delta S_{X_5, t-1} \\
+ 0.054 \ \Delta S_{X_5, t-2} - 0.469 \ S_{X_6, t-1} - 0.866 \ S_{X_6, t-2} + 1.156 \\
(7.a42)
\]

\[
R_{Y_3, t} = 1.015 \ R_{Y_1, t-1} + 0.615 \ R_{Y_1, t-2} + 1.372 \ R_{Y_2, t-1} + 0.849 \ R_{Y_2, t-2} + 0.114 \ R_{Y_3, t-1} \\
+ 0.053 \ R_{Y_1, t-2} - 0.181 \ R_{Y_4, t-1} + 0.290 \ R_{Y_4, t-2} - 2.161 \ R_{X_1, t-1} \\
- 1.649 \ R_{X_1, t-2} - 0.154 \ \Delta S_{X_2, t-1} - 0.134 \ \Delta S_{X_2, t-2} + 5.959 \ \Delta S_{X_3, t-1} \\
+ 0.364 \ \Delta S_{X_3, t-2} - 0.519 \ S_{X_4, t-1} + 0.465 \ S_{X_4, t-2} + 0.077 \ \Delta S_{X_5, t-1} \\
+ 1.102 \ \Delta S_{X_5, t-2} - 0.011 \ S_{X_6, t-1} - 0.338 \ S_{X_6, t-2} + 0.527 \\
(7.a43)
\]

\[
R_{Y_4, t} = 4.577 \ R_{Y_1, t-1} - 1.137 \ R_{Y_1, t-2} + 4.649 \ R_{Y_2, t-1} - 2.474 \ R_{Y_2, t-2} + 0.084 \ R_{Y_3, t-1} \\
- 0.120 \ R_{Y_1, t-2} + 0.656 \ R_{Y_4, t-1} - 0.242 \ R_{Y_4, t-2} - 9.698 \ R_{X_1, t-1} \\
+ 3.792 \ R_{X_1, t-2} - 0.339 \ \Delta S_{X_2, t-1} - 0.536 \ \Delta S_{X_2, t-2} + 1.526 \ \Delta S_{X_3, t-1} \\
+ 1.565 \ \Delta S_{X_3, t-2} + 1.034 \ S_{X_4, t-1} + 0.586 \ S_{X_4, t-2} + 0.348 \ \Delta S_{X_5, t-1} \\
+ 0.535 \ \Delta S_{X_5, t-2} - 0.174 \ S_{X_6, t-1} - 1.493 \ S_{X_6, t-2} + 1.672 \\
(7.a44)
\]

\[
R_{X_1, t} = 4.585 \ R_{Y_1, t-1} - 0.755 \ R_{Y_1, t-2} + 4.904 \ R_{Y_2, t-1} - 2.0487 \ R_{Y_2, t-2} + 0.063 \ R_{Y_3, t-1} \\
- 0.098 \ R_{Y_1, t-2} + 0.615 \ R_{Y_4, t-1} - 0.038 \ R_{Y_4, t-2} - 9.931 \ R_{X_1, t-1} \\
+ 2.822 \ R_{X_1, t-2} - 0.332 \ \Delta S_{X_2, t-1} - 0.530 \ \Delta S_{X_2, t-2} + 1.264 \ \Delta S_{X_3, t-1} \\
+ 2.391 \ \Delta S_{X_3, t-2} + 1.031 \ S_{X_4, t-1} + 0.528 \ S_{X_4, t-2} + 0.113 \ \Delta S_{X_5, t-1} \\
+ 0.217 \ \Delta S_{X_5, t-2} - 0.325 \ S_{X_6, t-1} - 1.077 \ S_{X_6, t-2} + 1.178 \\
(7.a45)
\]

\[
\Delta S_{X_2, t} = 0.203 \ R_{Y_1, t-1} + 0.041 \ R_{Y_1, t-2} + 0.207 \ R_{Y_2, t-1} - 0.020 \ R_{Y_2, t-2} - 0.013 \ R_{Y_3, t-1} \\
+ 0.009 \ R_{Y_1, t-2} - 0.045 \ R_{Y_4, t-1} + 0.002 \ R_{Y_4, t-2} - 0.369 \ R_{X_1, t-1} \\
- 0.054 \ R_{X_1, t-2} - 0.323 \ \Delta S_{X_2, t-1} - 0.166 \ \Delta S_{X_2, t-2} - 1.370 \ \Delta S_{X_3, t-1} \\
+ 0.662 \ \Delta S_{X_3, t-2} + 0.007 \ S_{X_4, t-1} + 0.170 \ S_{X_4, t-2} + 0.269 \ \Delta S_{X_5, t-1} \\
+ 0.004 \ \Delta S_{X_5, t-2} + 0.135 \ S_{X_6, t-1} - 0.114 \ S_{X_6, t-2} + 1.372 \\
(7.a46)
\]
\[ \Delta S_{X_3, t} = 0.011 R_{Y_1, t-1} + 0.003 R_{Y_1, t-2} + 0.020 R_{Y_2, t-1} + 0.014 R_{Y_2, t-2} - 0.001 R_{Y_3, t-1} \\
+ 0.001 R_{Y_3, t-2} - 0.004 R_{Y_4, t-1} + 0.002 R_{Y_4, t-2} - 0.028 R_{X_1, t-1} \\
- 0.020 R_{X_1, t-2} - 0.002 \Delta S_{X_2, t-1} + 0.002 \Delta S_{X_2, t-2} - 0.425 \Delta S_{X_3, t-1} \quad (7.a47) \\
- 0.105 S_{X_3, t-2} + 0.016 S_{X_4, t-1} - 0.012 S_{X_4, t-2} + 0.006 \Delta S_{X_5, t-1} \\
- 0.012 \Delta S_{X_5, t-2} - 0.004 S_{X_6, t-1} - 0.011 S_{X_6, t-2} + 0.012 \\
\]

\[ S_{X_4, t} = -0.026 R_{Y_1, t-1} + 0.064 R_{Y_1, t-2} - 0.043 R_{Y_2, t-1} + 0.070 R_{Y_2, t-2} + 0.006 R_{Y_3, t-1} \\
+ 0.004 R_{Y_3, t-2} - 0.001 R_{Y_4, t-1} - 0.036 R_{Y_4, t-2} + 0.073 R_{X_1, t-1} \\
- 0.110 R_{X_1, t-2} - 0.053 \Delta S_{X_2, t-1} - 0.030 \Delta S_{X_2, t-2} - 0.505 \Delta S_{X_3, t-1} \quad (7.a48) \\
- 1.303 \Delta S_{X_3, t-2} + 0.462 S_{X_4, t-1} + 0.238 S_{X_4, t-2} - 0.081 \Delta S_{X_5, t-1} \\
+ 1.007 \Delta S_{X_5, t-2} - 0.008 S_{X_6, t-1} - 0.025 S_{X_6, t-2} + 0.102 \\
\]

\[ \Delta S_{X_5, t} = -0.077 R_{Y_1, t-1} + 0.022 R_{Y_1, t-2} - 0.063 R_{Y_2, t-1} + 0.017 R_{Y_2, t-2} + 0.003 R_{Y_3, t-1} \\
+ 0.004 R_{Y_3, t-2} - 0.002 R_{Y_4, t-1} - 0.003 R_{Y_4, t-2} + 0.140 R_{X_1, t-1} \\
- 0.037 R_{X_1, t-2} - 0.016 \Delta S_{X_2, t-1} - 0.002 \Delta S_{X_2, t-2} + 0.069 \Delta S_{X_3, t-1} \quad (7.a49) \\
- 0.095 \Delta S_{X_3, t-2} - 0.144 S_{X_4, t-1} - 0.089 S_{X_4, t-2} + 0.580 \Delta S_{X_5, t-1} \\
- 0.088 \Delta S_{X_5, t-2} + 0.071 S_{X_6, t-1} - 0.009 S_{X_6, t-2} + 0.015 \\
\]

\[ S_{X_6, t} = -0.029 R_{Y_1, t-1} - 0.056 R_{Y_1, t-2} - 0.042 R_{Y_2, t-1} - 0.167 R_{Y_2, t-2} + 0.015 R_{Y_3, t-1} \\
- 0.002 R_{Y_3, t-2} - 0.006 R_{Y_4, t-1} + 0.001 R_{Y_4, t-2} + 0.081 R_{X_1, t-1} \\
+ 0.237 R_{X_1, t-2} + 0.018 \Delta S_{X_2, t-1} - 0.028 \Delta S_{X_2, t-2} - 0.215 \Delta S_{X_3, t-1} \quad (7.a50) \\
- 0.054 \Delta S_{X_3, t-2} - 0.423 S_{X_4, t-1} - 0.383 S_{X_4, t-2} + 0.070 \Delta S_{X_5, t-1} \\
+ 0.083 \Delta S_{X_5, t-2} + 0.117 S_{X_6, t-1} - 0.470 S_{X_6, t-2} + 0.002 \\
\]

- **FF and CC VAR Equations (Period 3)**

\[ R_{Y_1, t} = 0.117 R_{Y_1, t-1} + 0.213 R_{Y_1, t-2} + 0.240 R_{Y_2, t-1} - 0.431 R_{Y_2, t-2} + 0.023 R_{Y_3, t-1} \\
- 0.018 R_{Y_3, t-2} + 0.046 R_{Y_4, t-1} + 0.257 R_{Y_4, t-2} - 0.149 R_{X_1, t-1} \\
- 0.053 R_{X_1, t-2} - 0.066 \Delta S_{X_2, t-1} - 0.279 \Delta S_{X_2, t-2} + 1.847 \Delta S_{X_3, t-1} \quad (7.a51) \\
- 0.073 \Delta S_{X_3, t-2} + 0.249 S_{X_4, t-1} + 0.810 S_{X_4, t-2} + 2.237 \Delta S_{X_5, t-1} \\
- 0.855 \Delta S_{X_5, t-2} - 0.174 S_{X_6, t-1} - 1.195 S_{X_6, t-2} + 0.361 \\
\]

\[ R_{Y_2, t} = 0.163 R_{Y_1, t-1} + 0.409 R_{Y_1, t-2} + 0.145 R_{Y_2, t-1} - 0.537 R_{Y_2, t-2} + 0.060 R_{Y_3, t-1} \\
- 0.004 R_{Y_3, t-2} - 0.008 R_{Y_4, t-1} + 0.194 R_{Y_4, t-2} - 0.132 R_{X_1, t-1} \\
- 0.056 R_{X_1, t-2} - 0.163 \Delta S_{X_2, t-1} - 0.177 \Delta S_{X_2, t-2} + 2.287 \Delta S_{X_3, t-1} \quad (7.a52) \\
- 1.199 \Delta S_{X_3, t-2} + 0.168 S_{X_4, t-1} + 0.638 S_{X_4, t-2} + 2.140 \Delta S_{X_5, t-1} \\
- 0.952 \Delta S_{X_5, t-2} - 0.557 S_{X_6, t-1} - 0.928 S_{X_6, t-2} + 0.368 \\
\]
\[
R_{Y, t} = -0.086 R_{Y, t-1} - 0.035 R_{Y, t-2} + 0.194 R_{Y, t-1} + 0.056 R_{Y, t-2} + 0.093 R_{Y, t-1} \\
+ 0.012 R_{Y, t-2} - 0.051 R_{Y, t-1} + 0.133 R_{Y, t-2} - 0.006 R_{X, t-1} \\
- 0.056 R_{X, t-2} - 0.64 S_{X, t-2} - 0.030 S_{X, t-2} + 0.885 S_{X, t-2} + 0.0199
\]

(7.a53)

\[
R_{X, t} = 0.146 R_{Y, t-1} + 0.179 R_{Y, t-2} - 0.149 R_{Y, t-1} - 0.187 R_{Y, t-2} + 0.061 R_{Y, t-1} \\
- 0.058 R_{Y, t-2} + 0.297 R_{Y, t-1} + 0.031 R_{Y, t-2} - 0.096 R_{X, t-1} \\
- 0.063 R_{X, t-2} - 0.041 S_{X, t-2} - 0.231 S_{X, t-2} + 0.209 S_{X, t-2} \\
- 0.314 S_{X, t-2} - 0.349 S_{X, t-2} + 0.462 S_{X, t-2} + 0.022 S_{X, t-2} \\
+ 0.110 S_{X, t-2} + 0.067 S_{X, t-2} - 1.061 S_{X, t-2} + 0.621
\]

(7.a54)

\[
R_{X, t} = 0.128 R_{Y, t-1} + 0.289 R_{Y, t-2} - 0.169 R_{Y, t-1} - 0.264 R_{Y, t-2} + 0.054 R_{Y, t-1} \\
- 0.020 R_{Y, t-2} - 0.007 R_{Y, t-1} + 0.114 R_{Y, t-2} + 0.233 R_{X, t-1} \\
- 0.157 R_{X, t-2} - 0.175 S_{X, t-2} - 0.356 S_{X, t-2} - 0.059 S_{X, t-2} \\
+ 1.382 S_{X, t-2} + 0.607 S_{X, t-2} + 0.502 S_{X, t-2} + 0.062 S_{X, t-2} \\
- 0.244 S_{X, t-2} - 0.238 S_{X, t-2} - 0.595 S_{X, t-2} + 0.741
\]

(7.a55)

\[
\Delta S_{X, t} = -0.009 R_{Y, t-1} + 0.013 R_{Y, t-2} + 0.016 R_{Y, t-2} - 0.028 R_{Y, t-2} - 0.0004 R_{Y, t-1} \\
+ 0.007 R_{Y, t-2} - 0.007 R_{Y, t-1} + 0.012 R_{Y, t-2} - 0.0003 R_{X, t-1} \\
- 0.022 R_{X, t-2} - 0.099 S_{X, t-2} + 0.072 S_{X, t-2} - 0.636 S_{X, t-2} \\
+ 0.466 S_{X, t-2} + 0.029 S_{X, t-2} + 0.074 S_{X, t-2} + 0.222 S_{X, t-2} \\
- 0.115 S_{X, t-2} + 0.072 S_{X, t-2} - 0.072 S_{X, t-2} + 0.478
\]

(7.a56)

\[
\Delta S_{X, t} = -0.001 R_{Y, t-1} - 0.0003 R_{Y, t-1} + 0.002 R_{Y, t-2} + 0.001 R_{Y, t-2} - 0.001 R_{Y, t-1} \\
+ 0.002 R_{Y, t-2} - 0.001 R_{Y, t-1} - 0.001 R_{Y, t-2} + 0.0001 R_{X, t-1} \\
- 0.001 R_{X, t-2} - 0.0004 S_{X, t-2} + 0.003 S_{X, t-2} - 0.418 S_{X, t-1} \\
- 0.114 S_{X, t-2} + 0.004 S_{X, t-2} - 0.012 S_{X, t-2} - 0.007 S_{X, t-1} \\
+ 0.015 S_{X, t-2} - 0.010 S_{X, t-2} - 0.002 S_{X, t-2} + 0.005
\]

(7.a57)

\[
S_{X, t} = 0.006 R_{Y, t-1} - 0.008 R_{Y, t-2} - 0.002 R_{Y, t-2} + 0.015 R_{Y, t-2} - 0.002 R_{Y, t-1} \\
+ 0.001 R_{Y, t-2} + 0.008 R_{Y, t-1} - 0.022 R_{Y, t-2} - 0.007 R_{X, t-1} \\
+ 0.003 R_{X, t-2} - 0.037 S_{X, t-1} - 0.018 S_{X, t-2} - 0.157 S_{X, t-2} \\
- 0.702 S_{X, t-2} + 0.452 S_{X, t-2} + 0.252 S_{X, t-2} + 0.032 S_{X, t-2} \\
+ 0.982 S_{X, t-2} + 0.026 S_{X, t-2} - 0.073 S_{X, t-2} + 0.031
\]

(7.a58)
\[ \Delta S_{X_6, t} = -0.001 R_{Y_1, t-1} + 0.002 R_{Y_2, t-2} + 0.002 R_{Y_2, t-2} - 0.003 R_{Y_2, t-2} + 0.003 R_{Y_3, t-1} \\
+ 0.003 R_{Y_3, t-2} - 0.003 R_{Y_4, t-1} + 0.0006 R_{Y_4, t-2} + 0.002 R_{X_1, t-1} \\
- 9.710E-05 R_{X_1, t-2} - 0.012 \Delta S_{X_2, t-1} - 0.003 \Delta S_{X_2, t-2} + 0.086 \Delta S_{X_3, t-1} (7.\text{a59}) \\
+ 0.116 \Delta S_{X_3, t-2} - 0.147 S_{X_4, t-1} - 0.104 S_{X_4, t-2} + 0.483 \Delta S_{X_5, t-1} \\
- 0.019 \Delta S_{X_5, t-2} + 0.088 S_{X_6, t-1} + 0.003 S_{X_6, t-2} + 0.002 \\
S_{X_6, t} = 0.007 R_{Y_1, t-1} + 0.033 R_{Y_1, t-2} - 0.002 R_{Y_2, t-1} - 0.034 R_{Y_2, t-2} + 0.014 R_{Y_3, t-1} \\
- 0.007 R_{Y_3, t-2} - 0.002 R_{Y_4, t-1} + 0.015 R_{Y_4, t-2} + 0.0003 R_{X_1, t-1} \\
+ 0.0001 R_{X_1, t-2} + 0.021 \Delta S_{X_2, t-1} - 0.025 \Delta S_{X_2, t-2} - 0.334 \Delta S_{X_3, t-1} (7.\text{a60}) \\
- 0.305 \Delta S_{X_3, t-2} - 0.428 S_{X_4, t-1} - 0.287 S_{X_4, t-2} + 0.275 \Delta S_{X_5, t-1} \\
- 0.024 \Delta S_{X_5, t-2} + 0.216 S_{X_6, t-1} - 0.502 S_{X_6, t-2} - 0.004 \]

Generally, the VAR equations for the selected time series indicated that the relations of the FF and CC set variables were similar to those of other variables in the same set, as demonstrated by Equations (7.a1) and (7.a30). However, the equations showed a link between FF and CC variables for both lags one and two. The effects of global variables CO₂ and temperature (global and Saudi) were strong to medium in magnitude for the FF set variables in all periods. However, precipitation (global and Saudi) had a medium to strong influence on oil (global and Saudi), NG and coal price of return during Periods 1, 2 and 3. The green energy index return had a strong (positive or negative) effect on the market return of the FF variable set during Period 2. In addition, \( R_{Y_1} \), \( R_{Y_2} \) and \( R_{Y_4} \) (lag one) had strong positive and negative effects on \( R_{X_1} \). Figure 7.2 shows the VAR analysis for the FF, CC and combined variable sets during Periods 1, 2 and 3.
Figure 7.2: Graphical summary of the effectiveness of VAR coefficients.
7.3.6 **Impulse response test results**

Using IRA, we determined the speed and duration of the interactions among the variables of the FF, CC and combined sets. IRA was performed based on the generalised method established by Pesaran and Shin (1998). This technique avoids variations in results due to the ordering of variables, which is a problem that occurs with the Cholesky decomposition method (Eun and Shim, 1989). The results of the generalized IRA are presented as figures showing the impulse responses for Periods 1, 2 and 3, with the responses plotted between $1 \leq t \leq 10$.

![Figure 7.3: Impulse response for FF set.](image-url)
IRA was performed on the FF variables, and the effects are shown in Figure 7.3. During Period 1, as a result of a single shock to global oil return, the other three variables of the FF set were not very responsive; however, Saudi oil return increased initially and became negative ($t = 3$) before recovering, while NG and coal returns stayed more or less positive and did not respond. However, as a result of a shock to $R_Y^2$, the global oil price of return responded markedly, although it quickly decayed within $t = 3$, while the other variables were not affected. Shocks to the other variables did not yield marked responses; thus, it can be concluded that global oil return is highly responsive.

For Period 2, in response to a global oil price of return shock, Saudi oil return did not move markedly in the positive direction, and in fact, moved in the negative direction after $t = 2$, thereafter exhibiting an increasing trend toward zero between $4 \leq t \leq 10$. This different behaviour of $R_Y^2$ indicates that there were noticeable differences between $2 \leq t \leq 3$. In response to an $R_Y^2$ shock, $R_Y^4$ responded more quickly and to a somewhat greater extent than during Period 1, while there was not much difference in the behaviour in the effect of NG. The differences between Periods 1 and 2 occurred in response to a single SD shock to $R_Y^3$, where both $R_Y^1$ and $R_Y^2$ increased rapidly at $t = 2$ before tending toward zero at $t = 7$. In contrast, coal return moved in the negative direction at $t = 2$ before returning to zero at $t = 5$. The $R_Y^4$ shock caused $R_Y^2$ to become negative for a few periods ($1 \leq t \leq 5$) before returning to zero at $t > 5$. For Period 3, the global oil return was the most responsive, where $R_Y^1$ and $R_Y^4$ moved in conjunction in response to a coal price of return shock (Figure 7.3).
For the CC variable set in Period 1, Figure 7.4 shows $R_{X_1}$, $ΔS_{X_2}$ and $ΔS_{X_3}$ (first three panels) were the most responsive, while $S_{X_4}$, $ΔS_{X_5}$ and $S_{X_6}$ were the least responsive. However, relative to the impact of an $S_{X_4}$ shock, $ΔS_{X_5}$ increased quickly for...
the subsequent \(1 \leq t \leq 6\), and then began to decrease and became negative after \(t = 7\). This oscillatory behaviour was more pronounced when Saudi temperature received a single SD shock, in response to which it first increased and then reached zero at \(t = 6\), reached a negative maximum at \(t = 8\) and 9, and then began to move toward zero. The variable \(\Delta S_{X_5}\) also oscillated in response to an \(S_{X_6}\) shock, \(i.e.\ \Delta S_{X_5}\) first increased and then became negative and continually increased from \(t = 5\) onward to be positive. Therefore, during Period 1, \(\Delta S_{X_5}\) appeared to be the most responsive variable, varying in an almost sinusoidal manner, and similar trends were demonstrated during Periods 2 and 3.

The impulse response functions for all variables combined for Periods 1, 2 and 3 are shown in Figure 7.5. For Period 1, a single SD shock to \(R_{Y_1}\) resulted in a \(t = 1\) increase in Saudi oil return and decrease in NG, which subsequently returned to zero at \(t = 4\). The variables in the CC set were not significantly affected by an \(R_{Y_1}\) shock, and this behaviour was also observed for Saudi oil return and NG shocks; however, in case of a coal return of prices shock, the \(CO_2\) variable increased at \(t = 3\) before settling to zero. A \(CO_2\) shock resulted in a sharp increase in NG at \(t = 1\) and an equally sharp decrease, while both global oil and coal price returns reacted after a delay of \(t = 1\) but in opposite directions. As a result of a global temperature shock, NG became negative initially, and then positive. Shocks in precipitation (globally and Saudi) did not strongly affect the FF variables, although a single SD shock to \(\Delta S_{X_5}\) resulted in both \(R_{Y_1}\) and \(R_{Y_2}\) becoming negative at \(t = 5\), which reversed to become positive.
Figure 7.5: Impulse response for FF and CC sets.

Note:
Response of dashed line to one SD innovations.

Quantitative Series Analysis

Multivariate Time Series Analysis
Changes in behaviour were observed in the FF and CC sets of variables during Period 2 (Figure 7.5). In response to an $R_{Y_1}$ shock, the variable Saudi oil return decreased, while Saudi temperature showed approximately sinusoidal behaviour, *i.e.* $S_{X_4}$ increased immediately, while the green energy index return decreased sharply at $t = 1$ before returning to zero. The CC variables also responded to Saudi oil price shock, although the changes in $\Delta S_{X_5}$ were not as pronounced. Here, an $R_{Y_3}$ shock did not markedly affect the CC set of variables.

Figure 7.5 showed that a unit shock to $R_{X_1}$ markedly affected global oil return, while $R_{Y_2}$ became positive and then decreased sharply at $t = 2$ to become negative, and subsequently, returned to zero after $t = 4$. A shock to CO$_2$ resulted in global oil prices becoming negative after $t = 2$, while a shock to $\Delta S_{X_3}$ resulted in $R_{Y_2}$ increasing immediately and $R_{Y_3}$ increasing to a lesser extent. However, the global precipitation shock did not noticeably affect the variables, and the variable $\Delta S_{X_5}$ shock resulted in $R_{Y_2}$ and $R_{Y_3}$ initially moving together to become positive and then gradually becoming negative after $t = 8$. In contrast, $R_{Y_1}$ behaved in almost the opposite manner, becoming negative initially and then reversing to become positive after $t = 8$.

During Period 3, all behaviours shown in Figure 7.5 reinforced the observations made for Periods 1 and 2, *i.e.* the FF variables influenced several CC variables and the CC variable shocks were transmitted to some of the FF variables. In addition, the pronounced sinusoidal response of $\Delta S_{X_3}$ to shocks in many of the variables in the combined set could also be found in the combined period. Taken together, the IRA suggest that events in both oil (global and Saudi) and $R_{Y_4}$ affected the other variables.
the most, while those in $R_{Y3}$ had the least effect. In addition, $\Delta S_{X5}$ was the most responsive variable, and the responses of the variables differed between Periods 1 and 2. This analysis suggested that the integration between variables in the FF and sets increased during the different periods. In addition, a cyclic response pattern was particularly discernible for some of the variables, such as $\Delta S_{X2}$, $\Delta S_{X3}$ and $\Delta S_{X5}$.

### 7.3.7 Variance decomposition test results

VDA were performed for the FF variables for the three periods, and the resulting influence matrix is shown in Table 7.9, where the dependent variables are placed in rows and the independent or input variables are placed in columns. From these results, the extent of openness of the variables can be inferred, i.e. which variables are more or less open or influential compared to the others. The results are shown in terms of the percentage of forecast variance of a variable in response to random shocks provided by other variables in the columns containing those independent variables. The numbers along the diagonal of each matrix show the self-forecast variance for the given variable, while the sum of the percentages for the other three variables is the forecast variance due to the other variables.

Table 7.9: Average variance decomposition matrix for FF variables.

<table>
<thead>
<tr>
<th>Period</th>
<th>$R_{Y1}$</th>
<th>$R_{Y2}$</th>
<th>$R_{Y3}$</th>
<th>$R_{Y4}$</th>
<th>$R_{Y1}$</th>
<th>$R_{Y2}$</th>
<th>$R_{Y3}$</th>
<th>$R_{Y4}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>95.73</td>
<td>3.062</td>
<td>0.559</td>
<td>0.643</td>
<td>95.14</td>
<td>2.299</td>
<td>0.439</td>
<td>1.117</td>
</tr>
<tr>
<td></td>
<td>83.49</td>
<td>15.81</td>
<td>0.385</td>
<td>0.313</td>
<td>91.01</td>
<td>7.967</td>
<td>0.378</td>
<td>0.646</td>
</tr>
<tr>
<td></td>
<td>1.972</td>
<td>0.709</td>
<td>97.16</td>
<td>0.158</td>
<td>8.788</td>
<td>1.754</td>
<td>88.12</td>
<td>1.339</td>
</tr>
<tr>
<td></td>
<td>0.473</td>
<td>1.082</td>
<td>0.776</td>
<td>97.67</td>
<td>0.473</td>
<td>1.082</td>
<td>0.776</td>
<td>97.67</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Period</th>
<th>$R_{Y1}$</th>
<th>$R_{Y2}$</th>
<th>$R_{Y3}$</th>
<th>$R_{Y4}$</th>
<th>$R_{Y1}$</th>
<th>$R_{Y2}$</th>
<th>$R_{Y3}$</th>
<th>$R_{Y4}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>97.92</td>
<td>1.096</td>
<td>0.005</td>
<td>0.970</td>
<td>88.67</td>
<td>10.63</td>
<td>0.020</td>
<td>0.673</td>
</tr>
<tr>
<td></td>
<td>4.711</td>
<td>1.390</td>
<td>93.34</td>
<td>0.558</td>
<td>4.711</td>
<td>1.390</td>
<td>93.34</td>
<td>0.558</td>
</tr>
<tr>
<td></td>
<td>51.53</td>
<td>2.223</td>
<td>1.166</td>
<td>45.08</td>
<td>51.53</td>
<td>2.223</td>
<td>1.166</td>
<td>45.08</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Period</th>
<th>$R_{Y1}$</th>
<th>$R_{Y2}$</th>
<th>$R_{Y3}$</th>
<th>$R_{Y4}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>97.92</td>
<td>1.096</td>
<td>0.005</td>
<td>0.970</td>
</tr>
<tr>
<td></td>
<td>88.67</td>
<td>10.63</td>
<td>0.020</td>
<td>0.673</td>
</tr>
<tr>
<td></td>
<td>4.711</td>
<td>1.390</td>
<td>93.34</td>
<td>0.558</td>
</tr>
<tr>
<td></td>
<td>51.53</td>
<td>2.223</td>
<td>1.166</td>
<td>45.08</td>
</tr>
</tbody>
</table>
As can be seen, all variables in the FF set were affected to a greater or lesser extent by other variables for all periods, with $R_{Y2}$ being the most open to other variables (or most highly influenced) because the total effect from the other three variables drives 84.19% of its forecast variance. Similarly, as can be calculated from Table 7.9, during Period 1, $R_{Y1}$ was the most influential variable because it drove 47.3% of the forecast variance of the other three variables (followed by $R_{Y2}$, with an influence of 23.48%). During Period 2, both $R_{Y2}$ and $R_{Y4}$ were the most open variables, with 92% of their forecast variances being affected by the other variables, respectively. During this period, $R_{Y1}$ again emerged as the most influential variable, driving 62.28% of the forecast variance of the other variables, followed by $R_{Y2}$ at 43.91%. During Period 3, $R_{Y2}$ was the most open variable (89.36% driven) and $R_{Y4}$ was the second-most open variable (54.92% driven), while $R_{Y1}$ was the most influential variable, driving 59.67% of the forecast variances of the other three variables.

Table 7.10: Average variance decomposition matrix for CC variables.

<table>
<thead>
<tr>
<th>Period 1</th>
<th>$R_{X1}$</th>
<th>$\Delta S_{X2}$</th>
<th>$\Delta S_{X3}$</th>
<th>$S_{X4}$</th>
<th>$\Delta S_{X5}$</th>
<th>$S_{X6}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{X1}$</td>
<td>97.49</td>
<td>0.025</td>
<td>0.151</td>
<td>1.094</td>
<td>0.583</td>
<td>0.648</td>
</tr>
<tr>
<td>$\Delta S_{X2}$</td>
<td>0.356</td>
<td>98.74</td>
<td>0.212</td>
<td>0.316</td>
<td>0.090</td>
<td>0.286</td>
</tr>
<tr>
<td>$\Delta S_{X3}$</td>
<td>1.985</td>
<td>0.149</td>
<td>94.82</td>
<td>0.327</td>
<td>1.383</td>
<td>1.335</td>
</tr>
<tr>
<td>$S_{X4}$</td>
<td>0.550</td>
<td>1.079</td>
<td>0.731</td>
<td>77.39</td>
<td>19.38</td>
<td>0.866</td>
</tr>
<tr>
<td>$\Delta S_{X5}$</td>
<td>0.771</td>
<td>0.351</td>
<td>0.351</td>
<td>38.73</td>
<td>56.99</td>
<td>2.797</td>
</tr>
<tr>
<td>$S_{X6}$</td>
<td>0.192</td>
<td>0.489</td>
<td>1.047</td>
<td>26.41</td>
<td>10.22</td>
<td>61.63</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Period 2</th>
<th>$R_{X1}$</th>
<th>$\Delta S_{X2}$</th>
<th>$\Delta S_{X3}$</th>
<th>$S_{X4}$</th>
<th>$\Delta S_{X5}$</th>
<th>$S_{X6}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{X1}$</td>
<td>93.21</td>
<td>0.856</td>
<td>0.143</td>
<td>3.742</td>
<td>0.843</td>
<td>1.202</td>
</tr>
<tr>
<td>$\Delta S_{X2}$</td>
<td>2.084</td>
<td>95.44</td>
<td>1.661</td>
<td>0.192</td>
<td>0.183</td>
<td>0.439</td>
</tr>
<tr>
<td>$\Delta S_{X3}$</td>
<td>0.906</td>
<td>0.501</td>
<td>96.98</td>
<td>0.856</td>
<td>0.168</td>
<td>0.582</td>
</tr>
<tr>
<td>$S_{X4}$</td>
<td>0.226</td>
<td>1.347</td>
<td>1.431</td>
<td>80.34</td>
<td>16.05</td>
<td>0.606</td>
</tr>
<tr>
<td>$\Delta S_{X5}$</td>
<td>0.681</td>
<td>0.822</td>
<td>0.482</td>
<td>37.51</td>
<td>58.78</td>
<td>1.715</td>
</tr>
<tr>
<td>$S_{X6}$</td>
<td>2.308</td>
<td>0.572</td>
<td>2.040</td>
<td>23.72</td>
<td>5.328</td>
<td>66.02</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Period 3</th>
<th>$R_{X1}$</th>
<th>$\Delta S_{X2}$</th>
<th>$\Delta S_{X3}$</th>
<th>$S_{X4}$</th>
<th>$\Delta S_{X5}$</th>
<th>$S_{X6}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{X1}$</td>
<td>94.02</td>
<td>0.497</td>
<td>0.072</td>
<td>3.825</td>
<td>1.279</td>
<td>0.306</td>
</tr>
<tr>
<td>$\Delta S_{X2}$</td>
<td>1.672</td>
<td>96.96</td>
<td>0.845</td>
<td>0.074</td>
<td>0.200</td>
<td>0.241</td>
</tr>
<tr>
<td>$\Delta S_{X3}$</td>
<td>0.502</td>
<td>0.355</td>
<td>97.93</td>
<td>0.419</td>
<td>0.250</td>
<td>0.540</td>
</tr>
<tr>
<td>$S_{X4}$</td>
<td>0.246</td>
<td>0.588</td>
<td>0.337</td>
<td>72.18</td>
<td>25.67</td>
<td>0.979</td>
</tr>
<tr>
<td>$\Delta S_{X5}$</td>
<td>0.506</td>
<td>0.391</td>
<td>0.091</td>
<td>49.55</td>
<td>47.242</td>
<td>2.221</td>
</tr>
<tr>
<td>$S_{X6}$</td>
<td>1.037</td>
<td>0.251</td>
<td>1.273</td>
<td>30.33</td>
<td>11.49</td>
<td>55.63</td>
</tr>
</tbody>
</table>
VDA for the six-time series in the CC set are shown in matrix forms in Table 7.10. It can be calculated from the first matrix (Period 1) that $\Delta S_X$, was the most open variable (43% of its forecast variance was influenced by the other variables) followed by $S_X$, (38.37%), while $S_X$ was the most influential variable (influenced 46.36% of the forecast variances of other variables), followed by $\Delta S_X$ (influenced 35.71%). Period 2 also showed that the most open variable was $\Delta S_X$, with 41.21% of its forecast variance being influenced by the other variables, followed by $S_X$, for which 33.97% of the forecast variance was influenced by other variables. The most influential variable in this period remained $S_X$, which influenced 66% of the forecast variance of other variables. In the combined Period 3, $S_X$ was the most open variable (being influenced to an extent of 44.34%), while $S_X$ was the most influential variable, with a contribution of 53.84% of the forecast variance of other variables.

In Table 7.11, from the first matrix, $R_X$ was the most open variable, with 85.59% of its forecast variance being influenced by all other variables, followed by $\Delta S_X$ (44.19%). For each variable, the percentage influence was calculated as follows. The highest value along the row, not along the diagonal, was found (corresponding to the highest influence by another variable) and converted to a percentage of the sum total of all influences by all variables. During Period 1, the most influential variable was $R_X$, contributing to 48.87% of the forecast variance of all other variables, closely followed by $S_X$, contributing to 46.72% of the variance. During Period 2 (second matrix), variable $R_X$ was the most open, being influenced by up to 92.18%, followed by $R_X$ at 91.91%. Variable $R_X$ was the most influential (81.26%), followed by $R_X$ (71.11%). For Period 3, $R_X$ was the most open variable because it was influenced to an extent of
89.47% by other variables, while $R_{Y_1}$ was the most influential variable because it was influenced to an extent of 65.37% of the forecast variance of all other variables during this period.

Table 7.11: Average variance decomposition matrix for FF and CC set variables.

<table>
<thead>
<tr>
<th>Period 1</th>
<th>$R_{Y_1}$</th>
<th>$R_{Y_2}$</th>
<th>$R_{Y_3}$</th>
<th>$R_{Y_4}$</th>
<th>$R_{S_1}$</th>
<th>$R_{S_2}$</th>
<th>$R_{S_3}$</th>
<th>$R_{S_4}$</th>
<th>$R_{S_5}$</th>
<th>$S_{S_1}$</th>
<th>$S_{S_2}$</th>
<th>$S_{S_3}$</th>
<th>$S_{S_4}$</th>
<th>$S_{S_5}$</th>
<th>$S_{S_6}$</th>
<th>$S_{S_7}$</th>
<th>$S_{S_8}$</th>
<th>$S_{S_9}$</th>
<th>$S_{S_{10}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{Y_1}$</td>
<td>92.94</td>
<td>2.659</td>
<td>0.547</td>
<td>0.565</td>
<td>0.141</td>
<td>0.397</td>
<td>0.121</td>
<td>0.136</td>
<td>1.908</td>
<td>0.578</td>
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</tr>
<tr>
<td>$R_{Y_2}$</td>
<td>80.34</td>
<td>14.40</td>
<td>0.374</td>
<td>0.340</td>
<td>0.223</td>
<td>0.574</td>
<td>0.257</td>
<td>0.370</td>
<td>1.762</td>
<td>1.355</td>
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<tr>
<td>$R_{Y_3}$</td>
<td>1.754</td>
<td>1.103</td>
<td>91.20</td>
<td>0.145</td>
<td>1.290</td>
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<td>1.437</td>
<td>0.708</td>
<td>0.488</td>
<td>1.006</td>
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</tr>
<tr>
<td>$R_{Y_4}$</td>
<td>0.700</td>
<td>0.770</td>
<td>1.071</td>
<td>88.56</td>
<td>2.185</td>
<td>3.792</td>
<td>0.233</td>
<td>1.025</td>
<td>1.571</td>
<td>0.088</td>
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</tr>
<tr>
<td>$R_{S_1}$</td>
<td>1.523</td>
<td>0.155</td>
<td>0.338</td>
<td>1.219</td>
<td>94.28</td>
<td>0.075</td>
<td>0.165</td>
<td>1.066</td>
<td>0.622</td>
<td>0.552</td>
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<tr>
<td>$S_{S_1}$</td>
<td>1.714</td>
<td>0.533</td>
<td>3.900</td>
<td>1.166</td>
<td>0.532</td>
<td>0.913</td>
<td>0.281</td>
<td>0.128</td>
<td>0.136</td>
<td>0.261</td>
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<td>$S_{S_2}$</td>
<td>0.164</td>
<td>1.169</td>
<td>2.302</td>
<td>0.108</td>
<td>1.722</td>
<td>0.206</td>
<td>0.912</td>
<td>0.301</td>
<td>1.444</td>
<td>1.295</td>
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</tr>
<tr>
<td>$S_{S_3}$</td>
<td>0.206</td>
<td>0.746</td>
<td>2.682</td>
<td>0.548</td>
<td>0.581</td>
<td>0.467</td>
<td>0.556</td>
<td>73.75</td>
<td>19.73</td>
<td>0.727</td>
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</tr>
<tr>
<td>$S_{S_4}$</td>
<td>0.676</td>
<td>1.213</td>
<td>1.738</td>
<td>0.943</td>
<td>0.618</td>
<td>0.209</td>
<td>0.299</td>
<td>35.95</td>
<td>55.81</td>
<td>2.538</td>
<td></td>
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</tr>
<tr>
<td>$S_{S_5}$</td>
<td>1.768</td>
<td>0.503</td>
<td>1.016</td>
<td>0.616</td>
<td>0.231</td>
<td>0.381</td>
<td>0.952</td>
<td>24.99</td>
<td>10.71</td>
<td>58.82</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Period 2</th>
<th>$R_{Y_1}$</th>
<th>$R_{Y_2}$</th>
<th>$R_{Y_3}$</th>
<th>$R_{Y_4}$</th>
<th>$R_{S_1}$</th>
<th>$R_{S_2}$</th>
<th>$R_{S_3}$</th>
<th>$R_{S_4}$</th>
<th>$R_{S_5}$</th>
<th>$S_{S_1}$</th>
<th>$S_{S_2}$</th>
<th>$S_{S_3}$</th>
<th>$S_{S_4}$</th>
<th>$S_{S_5}$</th>
<th>$S_{S_{10}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{Y_1}$</td>
<td>87.35</td>
<td>2.354</td>
<td>0.442</td>
<td>0.756</td>
<td>2.460</td>
<td>0.894</td>
<td>0.197</td>
<td>3.357</td>
<td>0.811</td>
<td>1.373</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R_{Y_2}$</td>
<td>83.15</td>
<td>7.824</td>
<td>0.418</td>
<td>0.378</td>
<td>2.825</td>
<td>0.780</td>
<td>0.103</td>
<td>2.901</td>
<td>0.701</td>
<td>0.918</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R_{Y_3}$</td>
<td>8.550</td>
<td>1.355</td>
<td>85.32</td>
<td>0.145</td>
<td>1.543</td>
<td>0.895</td>
<td>0.194</td>
<td>1.083</td>
<td>0.476</td>
<td>0.240</td>
<td>0.335</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R_{Y_4}$</td>
<td>79.21</td>
<td>2.320</td>
<td>0.729</td>
<td>8.087</td>
<td>2.839</td>
<td>0.828</td>
<td>0.118</td>
<td>3.216</td>
<td>0.829</td>
<td>1.819</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R_{S_1}$</td>
<td>86.54</td>
<td>3.732</td>
<td>0.424</td>
<td>0.534</td>
<td>2.758</td>
<td>0.828</td>
<td>0.137</td>
<td>3.148</td>
<td>0.764</td>
<td>1.130</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$S_{S_1}$</td>
<td>1.817</td>
<td>0.667</td>
<td>0.472</td>
<td>0.719</td>
<td>0.424</td>
<td>93.48</td>
<td>1.501</td>
<td>0.148</td>
<td>0.188</td>
<td>0.562</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$S_{S_2}$</td>
<td>0.963</td>
<td>0.982</td>
<td>0.724</td>
<td>2.318</td>
<td>0.074</td>
<td>0.341</td>
<td>92.68</td>
<td>0.982</td>
<td>0.168</td>
<td>0.764</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$S_{S_3}$</td>
<td>0.523</td>
<td>1.321</td>
<td>1.260</td>
<td>0.621</td>
<td>1.074</td>
<td>1.240</td>
<td>1.631</td>
<td>76.65</td>
<td>15.10</td>
<td>0.569</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$S_{S_4}$</td>
<td>0.957</td>
<td>1.264</td>
<td>1.297</td>
<td>0.626</td>
<td>1.145</td>
<td>0.735</td>
<td>0.611</td>
<td>36.14</td>
<td>55.72</td>
<td>1.480</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$S_{S_5}$</td>
<td>1.855</td>
<td>0.792</td>
<td>1.870</td>
<td>0.972</td>
<td>0.226</td>
<td>0.527</td>
<td>1.615</td>
<td>23.31</td>
<td>4.893</td>
<td>63.93</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7.3.8 Granger causality test results

GCA was performed separately for the three periods, and the results for the FF set of variables are shown in Table 7.12. As can be seen, each of the FF market variables ($R_{Y_1}$, $R_{Y_2}$, $R_{Y_3}$ and $R_{Y_4}$) influenced the others at various levels of significance, although not all pairs had statistically significant interactions. For example, during Period 1, Saudi oil influenced the global oil market at a high (1%) significance level, while $R_{Y_1}$ also influenced $R_{Y_2}$ but at a low (10%) significance level. Similarly, global oil and
Saudi price of return influenced $R_{Y_3}$ at a low (10%) significance level; however, the reverse was not true. However, coal return of prices did not have relation/causality with any of the other variables during this period.

Table 7.12: Granger causality tests for FF variables.

<table>
<thead>
<tr>
<th>Period</th>
<th>$R_{Y_1}$</th>
<th>$R_{Y_2}$</th>
<th>$R_{Y_3}$</th>
<th>$R_{Y_4}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-</td>
<td>1.997*</td>
<td>1.909*</td>
<td>0.579</td>
</tr>
<tr>
<td></td>
<td>5.747***</td>
<td>-</td>
<td>1.948*</td>
<td>0.824</td>
</tr>
<tr>
<td></td>
<td>0.859</td>
<td>0.532</td>
<td>-</td>
<td>0.459</td>
</tr>
<tr>
<td></td>
<td>0.819</td>
<td>0.222</td>
<td>0.213</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Period</th>
<th>$R_{Y_1}$</th>
<th>$R_{Y_2}$</th>
<th>$R_{Y_3}$</th>
<th>$R_{Y_4}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>-</td>
<td>-</td>
<td>2.875**</td>
<td>0.078</td>
</tr>
<tr>
<td></td>
<td>3.219***</td>
<td>-</td>
<td>3.739**</td>
<td>0.547</td>
</tr>
<tr>
<td></td>
<td>0.612</td>
<td>0.310</td>
<td>-</td>
<td>1.995*</td>
</tr>
<tr>
<td></td>
<td>0.438</td>
<td>2.554**</td>
<td>2.694**</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Period</th>
<th>$R_{Y_1}$</th>
<th>$R_{Y_2}$</th>
<th>$R_{Y_3}$</th>
<th>$R_{Y_4}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>-</td>
<td>6.039***</td>
<td>5.727***</td>
<td>0.039</td>
</tr>
<tr>
<td></td>
<td>3.966**</td>
<td>-</td>
<td>7.276***</td>
<td>0.151</td>
</tr>
<tr>
<td></td>
<td>0.045</td>
<td>0.008</td>
<td>-</td>
<td>1.986*</td>
</tr>
<tr>
<td></td>
<td>0.513</td>
<td>1.975*</td>
<td>4.522**</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: *** and ** indicate significance at 1%, 5% and 10% levels, respectively.

For Period 2, both $R_{Y_1}$ and $R_{Y_2}$ influenced each other at a 5% significance level, denoted by two asterisks in Table 7.12. The oil market variables ($R_{Y_1}$ and $R_{Y_2}$) affected NG at a 5% significance level; however, the reverse was not true for both variables. Coal return Granger caused both oil market return ($R_{Y_2}$ and $R_{Y_3}$) at a 5% level of significance, but no causality was noted from the market for Saudi oil return to coal return; however, $R_{Y_3}$ influenced $R_{Y_4}$ at a 10% confidence/significance level. For Period 3, oil market return ($R_{Y_1}$ and $R_{Y_2}$) showed Granger causality with NG at a high (1%) significance level. Coal price return influenced NG return at a medium (5%) significance level. The Granger causality was weak to medium at 10% and 5% significance levels from coal price return to $R_{Y_2}$ and $R_{Y_3}$, respectively (Table 7.12).
Table 7.13: Granger causality tests for CC variables.

<table>
<thead>
<tr>
<th>Period 1</th>
<th>R_X1</th>
<th>ΔS_X2</th>
<th>ΔS_X3</th>
<th>S_X4</th>
<th>S_X5</th>
<th>Period 2</th>
<th>R_X1</th>
<th>ΔS_X2</th>
<th>ΔS_X3</th>
<th>S_X4</th>
<th>S_X5</th>
</tr>
</thead>
<tbody>
<tr>
<td>R_X1</td>
<td>-</td>
<td>0.413</td>
<td>0.193</td>
<td>1.504</td>
<td>0.078</td>
<td>0.099</td>
<td>-</td>
<td>1.897&quot;</td>
<td>-1.908&quot;</td>
<td>1.316</td>
<td>1.736</td>
</tr>
<tr>
<td>ΔS_X2</td>
<td>0.034</td>
<td>-1.896&quot;</td>
<td>1.438</td>
<td>0.011</td>
<td>0.648</td>
<td>ΔS_X3</td>
<td>3.753&quot;</td>
<td>-</td>
<td>6.158&quot;</td>
<td>0.422</td>
<td>1.970&quot;</td>
</tr>
<tr>
<td>ΔS_X3</td>
<td>0.301</td>
<td>0.203</td>
<td>-3.173&quot;</td>
<td>0.448</td>
<td>6.243&quot;</td>
<td>ΔS_X4</td>
<td>3.842&quot;</td>
<td>1.440</td>
<td>-</td>
<td>1.899&quot;</td>
<td>5.663&quot;</td>
</tr>
<tr>
<td>S_X4</td>
<td>0.219</td>
<td>0.369</td>
<td>1.036</td>
<td>-</td>
<td>0.426</td>
<td>0.877</td>
<td>S_X5</td>
<td>0.953</td>
<td>0.010</td>
<td>1.108</td>
<td>-</td>
</tr>
<tr>
<td>ΔS_X5</td>
<td>1.252</td>
<td>0.062</td>
<td>3.811&quot;</td>
<td>7.297&quot;</td>
<td>-</td>
<td>8.290&quot;</td>
<td>ΔS_X6</td>
<td>0.158</td>
<td>0.303</td>
<td>5.511&quot;</td>
<td>7.404&quot;</td>
</tr>
<tr>
<td>S_X6</td>
<td>1.405</td>
<td>0.491</td>
<td>1.453</td>
<td>4.337&quot;</td>
<td>1.380</td>
<td>-</td>
<td>S_X1</td>
<td>0.384</td>
<td>0.317</td>
<td>1.312</td>
<td>1.983&quot;</td>
</tr>
</tbody>
</table>

Note: ***,** and * indicate significance at 1%, 5% and 10% levels, respectively.

Table 7.13 indicates that, during Period 1, relatively a number of CC variables had causal relations. ΔS_X2 caused ΔS_X3 at low (10%) significance, while ΔS_X3 caused S_X4 and S_X6 at 5% and 1% significance levels, respectively. The results also showed that causality was at a 1% (high) level of significance from ΔS_X2 to (S_X4 and S_X6), with the S_X6 Granger causing S_X4 at a 5% (medium) significance level and the ΔS_X5 Granger causing ΔS_X3 at a 5% level of significance. However, there was no causality noted from R_Y1 to other variables in the CC set.

Moreover, Period 2, the results indicated that global CO2 and temperature Grangers caused the green energy index return (at 5% significance) and between ΔS_X2 and ΔS_X5 (at 10% significance) (Table 7.13). The causality was bidirectional for global temperature and Saudi temperature at a 1% (high) level of significance from ΔS_X3 to ΔS_X5 and ΔS_X5 to ΔS_X3 and unidirectional between ΔS_X3 and S_X6. The relation between variables S_X4 and S_X6 was significant in both directions at 10% (low) from S_X6 and S_X4.
and 5% (medium) from $S_{X_4}$ to $S_{X_n}$, while Saudi temperature influence $S_{X_4}$ at high (1%) significance levels. There were several differences between Periods 2 and 3, where some variables influenced others at different significance levels, including a direction causality from $S_{X_6}$ to $S_{X_4}$ and $\Delta S_{X_5}$ to $\Delta S_{X_3}$ at 1% and 5% significance levels, respectively. In addition, a two-way Granger causality test indicated no significant causality between $\Delta S_{X_2}$ and $\Delta S_{X_3}$ (Table 7.13).

The results in Table 7.14 show the Granger causalities between the two set of variables (FF and CC) based on the VAR model. As can be seen, each time series affected the other, and these effects were statistically significant. During Period 3, nearly all-time series showed Granger causality with the other time series at 1%, 5% and 10% significance levels, which means that nearly all variables were linked significantly. Specifically, there was two-way Granger causality among oil market return ($R_{Y_1}$, $R_{Y_2}$) and $\Delta S_{X_3}$, i.e. from oil market return to $\Delta S_{X_3}$ and from $\Delta S_{X_3}$ to oil market return at 10% (low) and 5% (medium) significance level, respectively, while $R_{Y_4}$ also caused $\Delta S_{X_3}$ (5% significance level). Note that the reverse causalities were significant at the 1% level. Therefore, the $R_{Y_4}$ Granger caused $\Delta S_{X_2}$ at a 1% (high) level of significance; however, only the $\Delta S_{X_2}$ Granger caused $R_{Y_4}$ at a 10% (low) level of significance. Oil market return (global and Saudi) caused $\Delta S_{X_2}$, both at medium (5%) significance levels, as $R_{Y_2}$ influenced $\Delta S_{X_2}$. In addition, the $R_{Y_3}$ Granger caused $\Delta S_{X_3}$ and $R_{X_1}$ caused $R_{Y_3}$ at low (10%) significance.
In addition, during Period 1, most causalities showed low (10%) significance, except the Granger causalities (5% significance) from $R_{Y_2}$ to $\Delta S_{X_2}$ and $\Delta S_{X_5}$ to $R_{Y_4}$ (Table 7.14).

However, at the low (10%) significance levels: $R_{Y_1}$ cause global (CO$_2$ and temperature), while $R_{Y_2}$ also cause $\Delta S_{X_3}$; and ($R_{X_1}$, $\Delta S_{X_3}$ and $S_{X_4}$) causes $R_{Y_3}$. For Period 2, there were causalities in both directions for most variable pairs, e.g. both oil market ($R_{Y_1}$ and $R_{Y_2}$) and coal return cause $R_{X_1}$ at 5% and 10% significance levels, respectively (Table 7.14). $R_{Y_4}$ caused $\Delta S_{X_3}$ at a high (1%) significance level, and $R_{Y_1}$ and $R_{Y_2}$ caused $\Delta S_{X_2}$ at moderate levels. The FF variable set affected $\Delta S_{X_1}$ (10% significance), and $R_{Y_1}$ and $R_{Y_4}$ caused $\Delta S_{X_4}$ at low and moderate significance (10% and 5%, respectively).
However, there was no significant Granger causality from/to $S_X$ to/from other indices in any period (Table 7.14).

Figure 7.6 visualizes the flow and strength of causality based on the VAR analysis. Here, the null hypothesis is that the row variable does not Granger-cause the column variable. For the attention of exchangeable planetary, we only regressed the full period equations as ($\varepsilon \sim N(0,1)$). Using the full period as an example, the Granger causality equations are as follows.

- **FF GCA Equations (Period 1)**

  \[
  R_Y_1 = R_{Y_1,-2} + 1.997 R_{Y_2,-2} + 1.909 R_{Y_3,-2} + \tau
  \]  
  \[
  R_Y_2 = 5.747 R_{Y_1,-2} + R_{Y_2,-2} + 1.948 R_{Y_3,-2} + \tau
  \]  
  \[
  R_Y_3 = R_{Y_3,-2} + \tau
  \]  
  \[
  R_Y_4 = R_{Y_4,-2} + \tau
  \]

- **FF GCA Equations (Period 2)**

  \[
  R_Y_1 = R_{Y_1,-2} + 3.219 R_{Y_2,-2} + 2.875 R_{Y_3,-2} + \tau
  \]  
  \[
  R_Y_2 = 3.380 R_{Y_1,-2} + R_{Y_2,-2} + 3.739 R_{Y_3,-2} + \tau
  \]  
  \[
  R_Y_3 = R_{Y_3,-2} + 1.995 R_{Y_4,-2} + \tau
  \]  
  \[
  R_Y_4 = 2.554 R_{Y_2,-2} + 2.694 R_{Y_3,-2} + R_{Y_4,-2} + \tau
  \]

- **FF GCA Equations (Period 3)**

  \[
  R_Y_1 = R_{Y_1,-2} + 6.039 R_{Y_2,-2} + 5.727 R_{Y_3,-2} + \tau
  \]  
  \[
  R_Y_2 = 3.966 R_{Y_1,-2} + R_{Y_2,-2} + 7.276 R_{Y_3,-2} + \tau
  \]  
  \[
  R_Y_3 = R_{Y_3,-2} + 1.986 R_{Y_4,-2} + \tau
  \]  
  \[
  R_Y_4 = 1.975 R_{Y_2,-2} + 4.522 R_{Y_3,-2} + R_{Y_4,-2} + \tau
  \]
\[ R_{X_1} = R_{X_1,-2} + \tau \]  
(7.b13)

\[ \Delta S_{X_2} = \Delta S_{X_2,-2} + 1.896 \Delta S_{X_3,-2} + \tau \]  
(7.b14)

\[ \Delta S_{X_3} = \Delta S_{X_3,-2} + 3.173 S_{X_4,-2} + 6.243 S_{X_6,-2} + \tau \]  
(7.b15)

\[ S_{X_4} = S_{X_4,-2} + \tau \]  
(7.b16)

\[ \Delta S_{X_5} = 3.811 \Delta S_{X_3,-2} + 7.297 S_{X_4,-2} + \Delta S_{X_5,-2} + 8.290 S_{X_6,-2} + \tau \]  
(7.b17)

\[ S_{X_6} = 4.337 S_{X_4,-2} + S_{X_6,-2} + \tau \]  
(7.b18)

\[ R_{X_1} = R_{X_1,-2} - 1.897 \Delta S_{X_2,-2} - 1.908 \Delta S_{X_3,-2} + \tau \]  
(7.b19)

\[ \Delta S_{X_2} = 3.753 R_{X_1,-2} + \Delta S_{X_2,-2} + 6.158 \Delta S_{X_3,-2} + 1.970 \Delta S_{X_4,-2} + \tau \]  
(7.b20)

\[ \Delta S_{X_3} = 3.842 R_{X_1,-2} + \Delta S_{X_5,-2} + 1.899 S_{X_4,-2} + 5.663 \Delta S_{X_5,-2} + 11.558 S_{X_6,-2} + \tau \]  
(7.b21)

\[ S_{X_4} = S_{X_4,-2} + 3.865 S_{X_6,-2} + \tau \]  
(7.b22)

\[ \Delta S_{X_5} = 5.511 \Delta S_{X_3,-2} + 7.404 S_{X_4,-2} + \Delta S_{X_5,-2} + \tau \]  
(7.b23)

\[ S_{X_6} = 1.983 S_{X_4,-2} + S_{X_6,-2} + \tau \]  
(7.b24)

\[ R_{X_1} = R_{X_1,-2} + \tau \]  
(7.b25)

\[ \Delta S_{X_2} = 4.098 R_{X_1,-2} + \Delta S_{X_2,-2} + 4.934 \Delta S_{X_3,-2} + \tau \]  
(7.b26)

\[ \Delta S_{X_3} = 3.798 R_{X_1,-2} + \Delta S_{X_3,-2} + 6.150 \Delta S_{X_5,-2} + 5.432 S_{X_6,-2} + \tau \]  
(7.b27)

\[ S_{X_4} = S_{X_4,-2} + 14.893 S_{X_6,-2} + \tau \]  
(7.b28)

\[ \Delta S_{X_5} = 3.933 \Delta S_{X_3,-2} + 12.742 S_{X_4,-2} + \Delta S_{X_5,-2} + 9.766 S_{X_6,-2} + \tau \]  
(7.b29)

\[ S_{X_6} = 6.719 S_{X_4,-2} + S_{X_6,-2} + \tau \]  
(7.b30)

\[ R_{Y_1} = R_{Y_1,-2} + 2.385 \Delta S_{X_2,-2} + 2.232 \Delta S_{X_3,-2} + \tau \]  
(7.b31)

\[ R_{Y_2} = R_{Y_2,-2} + 2.274 \Delta S_{X_2,-2} + 3.024 \Delta S_{X_3,-2} + \tau \]  
(7.b32)

\[ R_{Y_3} = R_{Y_3,-2} + 2.210 \Delta S_{X_3,-2} + \tau \]  
(7.b33)

\[ R_{Y_4} = R_{Y_4,-2} + 1.957 \Delta S_{X_2,-2} + 2.387 \Delta S_{X_3,-2} + 2.199 \Delta S_{X_5,-2} + \tau \]  
(7.b34)

\[ R_{X_1} = 2.166 R_{Y_3,-2} + R_{X_1,-2} + \tau \]  
(7.b35)
\[ \Delta S_{X_2} = \Delta S_{X_2,-2} + \tau \]  
(7.b36)

\[ \Delta S_{X_3} = 2.163 R_{Y_3,-2} + \Delta S_{X_3,-2} + \tau \]  
(7.b37)

\[ S_{X_4} = 2.171 R_{Y_3,-2} + S_{X_4,-2} + \tau \]  
(7.b38)

\[ \Delta S_{X_5} = \Delta S_{X_5,-2} + \tau \]  
(7.b39)

\[ S_{X_5} = S_{X_5,-2} + \tau \]  
(7.b40)

- **FF and CC GCA Equations (Period 2)**

\[ R_{Y_1} = R_{Y_1,-2} + 3.229 R_{X_1,-2} + 3.248 \Delta S_{X_2,-2} + 2.243 \Delta S_{X_3,-2} + 2.148 \Delta S_{X_4,-2} + \tau \]  
(7.b41)

\[ R_{Y_2} = R_{Y_2,-2} + 3.316 R_{X_1,-2} + 3.754 \Delta S_{X_2,-2} + 2.357 \Delta S_{X_3,-2} + \tau \]  
(7.b42)

\[ R_{Y_3} = R_{Y_3,-2} + 2.482 \Delta S_{X_3,-2} + \tau \]  
(7.b43)

\[ R_{Y_4} = R_{Y_4,-2} + 2.435 R_{X_1,-2} + 4.790 \Delta S_{X_2,-2} + 2.458 \Delta S_{X_3,-2} + 2.442 S_{X_4,-2} + 3.237 \Delta S_{X_5,-2} + \tau \]  
(7.b44)

\[ R_{X_1} = 2.395 R_{Y_1,-2} + 2.489 R_{Y_2,-2} + 2.232 R_{Y_3,-2} + 2.238 R_{Y_4,-2} + R_{X_1,-2} + \tau \]  
(7.b45)

\[ \Delta S_{X_2} = 3.328 R_{Y_4,-2} + \Delta S_{X_2,-2} + \tau \]  
(7.b46)

\[ \Delta S_{X_3} = 3.263 R_{Y_1,-2} + 3.123 R_{Y_2,-2} + 8.763 R_{Y_4,-2} + \Delta S_{X_3,-2} + \tau \]  
(7.b47)

\[ S_{X_4} = S_{X_4,-2} + \tau \]  
(7.b48)

\[ \Delta S_{X_5} = 3.098 R_{Y_1,-2} + 3.552 R_{Y_2,-2} + 3.932 R_{Y_4,-2} + \Delta S_{X_5,-2} + \tau \]  
(7.b49)

\[ S_{X_5} = S_{X_5,-2} + \tau \]  
(7.b50)

- **FF and CC GCA Equations (Period 3)**

\[ R_{Y_1} = R_{Y_1,-2} + 3.831 \Delta S_{X_2,-2} + 2.281 \Delta S_{X_3,-2} + \tau \]  
(7.b51)

\[ R_{Y_2} = R_{Y_2,-2} + 3.962 \Delta S_{X_2,-2} + 2.093 \Delta S_{X_3,-2} + 3.565 \Delta S_{X_4,-2} + \tau \]  
(7.b52)

\[ R_{Y_3} = R_{Y_3,-2} + 2.001 \Delta S_{X_3,-2} + \tau \]  
(7.b53)

\[ R_{Y_4} = R_{Y_4,-2} + 5.412 \Delta S_{X_2,-2} + 3.505 \Delta S_{X_3,-2} + 3.805 \Delta S_{X_5,-2} + \tau \]  
(7.b54)

\[ R_{X_1} = 1.991 R_{Y_3,-2} + R_{X_1,-2} + \tau \]  
(7.b55)

\[ \Delta S_{X_2} = 1.967 R_{Y_4,-2} + \Delta S_{X_2,-2} + \tau \]  
(7.b56)

\[ \Delta S_{X_3} = 3.198 R_{Y_1,-2} + 3.048 R_{Y_2,-2} + 8.130 R_{Y_4,-2} + \Delta S_{X_3,-2} + \tau \]  
(7.b57)

\[ S_{X_4} = S_{X_4,-2} + \tau \]  
(7.b58)

\[ \Delta S_{X_5} = 3.198 R_{Y_4,-2} + \Delta S_{X_5,-2} + \tau \]  
(7.b59)

\[ S_{X_5} = S_{X_5,-2} + \tau \]  
(7.b60)
7.4 Summary and conclusion

This study presented a novel approach to address the existing gaps in the national literature, complete with econometrical and environmental research using multivariate analysis. This chapter investigated the extent and manner of the interdependence among four FF set indices, the CC set time series and both variable sets using a VAR method.
before and after the implementation of major CC policies. This study examined interactive influences for the short and long term across three specific periods. In particular, we evaluated the effects of different shocks on the VAR system’s variables under the assumption that each variable is influenced by its own impulse and those of other variables. The examined variables presented features that permit a VAR approach. We attempted to find results for IRA, VDA and GCA for 1 January 1978–30 June 2016 (Period 3). The sample period was divided into two subperiods for a detailed analysis (before the KP, 1 January 1978–28 February 1997 (Period 1) and after the KP, 1 March 1997–30 June 2016 (Period 2)).

In summary, the methods of this chapter provide a better understanding of the overall picture of the relationship between and among the selected variables (FF and CC variable sets), particularly during the analysed periods. The analyses answered the objectives and hypotheses through the following empirical results.

- Correlation matrix tests for the variables suggest that a number of variables in the FF, CC and combined CC and FF sets were highly correlated with each other in Periods 1, 2 and 3 (Tables 7.2, 7.3 and 7.4).
- The VAR result shows that a strong significant relationship (positive/negative) exists among the FF, CC and combined CC and FF sets in short- and long-term periods (Figure 7.2).
- The IRA results indicate increasing integration among the variables during the periods. The results reveal that each variable in the FF or CC variable set responds efficiently to shocks from other variables for Periods 1, 2 and 3. Shocks in the CC variables were transmitted to some of the FF variables (Period 3) (Figures 7.3, 7.4 and 7.5).
- The VDC results show that a number of variables are significantly influenced by movements in other variables given different variables becoming less open to the effects of others (Tables 7.9, 7.10 and 7.11).
• GCA was separately performed for the two sets of variables and in combination to determine the direction of causality between the pairs of variables. Granger causality indicated that one- and two-way causality exist between any pair of FF, CC and combined CC and FF variable sets (Figure 7.6).
• The FF, CC and combined CC and FF sets’ indices have close linkages and respond to each other quite rapidly and within the short (Period 2) and long periods (Period 3).
Chapter 8

Quantitative III: Magnitude of the Canonical Relations
Chapter 8 presents empirical results and discusses the output of a CCA for the FF variables and CC information. CCA is a generalized form of multiple regression analysis that measures the interrelatedness of multiple dependent and independent variables. Keskin and Ozsoy (2004) described CCA as a multivariate statistical method that reveals complex interactions between variables in a dataset. Weiss (1972) considered that CCA examines the correlations, variances and other predictable commonalities between variable sets. In Hotelling’s (1936) model, an association between variable sets can be determined from the minimum number of canonical variates; therefore, CCA enables an in-depth study of variable set correlations (Sharma, 1995).

Since the publication of Hotelling’s (1936) model, CCA has been extended by other researchers. Subsequent developments include generalized solutions for concurrent associations between variable datasets. CCA has become a powerful multivariate method in diverse disciplines, such as social science, psychology, ecology, marketing, education, sociology-communication and political science, and has even been applied in poultry science and zoology (Jaiswal et al., 1995). The evolution of supporting software suites has also accelerated the use of CCA (González et al., 2008). However, CCA has not been applied to relation estimations among FF variables [oil market (global and KSA) and global (NG and coal) returns], CC variables [global (green energy index, CO₂, temperature and precipitation) and KSA (temperature and precipitation)].
Accordingly, this study attempts to estimate the interrelations between the variable sets $R_Y$, $S_X$ and determine variances in the contribution of FF price returns relative to CC issues and various green initiatives. The purpose of this chapter is to study the reciprocal relation between the FF industry and CC, and the consequent effect of this relation on the market value of the FF industry, which could be significantly affected by CC and linear combination between FF and CC variables that maximises the correlation coefficient.

### 8.2 Procedures in canonical correlations analyses

CCA is a multivariate analysis technique used to evaluate complex relations among three or more variables and that between two sets of variables. CCA creates two new variables for each subject, i.e. canonical variates, and computes a canonical variate for both the dependent and predictor sets. The canonical variate is the score predicted from a regression equation based on the variables within a set, and the canonical correlation ($C_j$) is the correlation between the two canonical variates. This multivariate research strategy has two advantages. First, it allows the evaluation of complex relations while controlling statistical errors that arise from relations that occur by chance. Second, it provides information required to evaluate the importance of a predictor variable to explain variability in the criterion variable given the effects of other predictor variables. This allows drawing tentative causal inferences using correlational data. Here, the objective was to employ CCA techniques to determine whether changes in FF prices are related to CC and vice versa. A flowchart of the analysis is shown in Figure 8.1.
8.3 Empirical analyses and discussion

The CCA models were implemented using MATLAB (R2014a). The correlation and eigenvalue ($\lambda$) analysis for the two sets (FF and CC) of variables and three periods are shown in Table 8.1. A canonical function ($\Phi_i^t\Psi_i^t$) or variate is a set of standardized canonical function coefficients obtained from linear equations for the observed predictor and criterion variable sets. Each variable in the smaller variable set corresponds to one function; therefore, there are four canonical functions corresponding to the four variables in the FF set. Each function is orthogonal to every other function; thus, each set of synthetic predictor and criterion variables is perfectly uncorrelated with all other synthetic predictor and criterion variables from other functions. For the predictor variables, a single function is comparable to the set of standardized weights found in multiple regression. This orthogonality is crucial because it allows separate interpretation of each function. The $C_j$ coefficient is the Pearson $r$ relation between the two synthetic variables of a given canonical function. Due to the scaling created by the
standardized weights in the linear equations, this value can only be in the range 0 to 1 and cannot become negative.

The squared canonical correlation \((C_j^2)\) represents the proportion of variance, or the effect size after accounting for the variance, shared by the two synthetic variables. Since the synthetic variables represent the observed predictor and criterion variables, \(C_j^2\) indicates the amount of shared variance between the variable sets and is directly analogous to the \(R^2\) effect in multiple regression. Thus, as can be seen from Table 8.1, the \(C_j\) value measuring the strength of association for the canonical function ranked 1 for Period 1 is 0.440, which is a moderate correlation.

The corresponding \(C_j^2\) value for \(\Phi_1\Psi_1\) was 0.193 and could explain 43.576% of the variance of correlation having a \(\lambda\) value of 0.063. This indicates that the hypothesis, i.e. a positive correlation between standardized FF and CC values exists, can be assumed to be true. Here, \(\lambda\) is actually the product of the model matrix and the inverse of its error matrix. In this case, each eigenvalue is calculated by taking the ratio of the highest squared correlation to the complement one of the highest squared correlation. The \(\Phi_2\Psi_2\) variate value is 0.228, which is weak to moderate and has a \(\lambda\) value of 0.054, which can explain 37.6% of the correlation variance. The first two pairs ranked 1 and 2 can explain 81.173% of the variance, which is a satisfactorily high proportion. This indicates that, for Period 1, examining only the first two pairs of canonical variates should be sufficient.
For Period 2, the canonical correlation value for the function ranked 1 is 0.899, which is a strong correlation (Table 8.1). The $C_1$ value for $\Phi_1\Psi_1$ is 0.808 and can explain up to 99.979% of the correlation variance having a $\lambda$ value of 0.405. The second pair of variates has a canonical correlation value of 0.185, which indicates weak correlation, and has a $\lambda$ value of 0.036 and can explain only 0.011% of the variance in correlations. This indicates that, for Period 2, studying only the first pair of variates would be adequate. The obtained results for the overall Period 3 indicate that the function ranked 1 yielded a canonical correlation value of 0.815, which is a strong correlation, and the corresponding $\lambda$ was 1.978 and the $\Phi_1\Psi_1$ of the variates could explain 98.07% of the correlation variance. The $\Phi_2\Psi_2$ variates had a weak correlation value of 0.166 and could explain only 1.4% of the variance, indicating that the first pair of variates is adequate for the overall Period 3. The $\lambda$ results and canonical correlations indicate the presence of at most two significant canonical correlations between the variates of the dependent and independent variables.

Table 8.1: Canonical correlations and eigenvalues between two variable sets.

<table>
<thead>
<tr>
<th>Period</th>
<th>$C_j$</th>
<th>$C_j^2$</th>
<th>$\lambda$</th>
<th>Percent</th>
<th>Cumulative Percent</th>
<th>Period</th>
<th>$C_j$</th>
<th>$C_j^2$</th>
<th>$\lambda$</th>
<th>Percent</th>
<th>Cumulative Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$\Phi_1\Psi_1$</td>
<td>0.440</td>
<td>0.193</td>
<td>0.063</td>
<td>43.57</td>
<td>0.063</td>
<td>43.57</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Phi_2\Psi_2$</td>
<td>0.228</td>
<td>0.052</td>
<td>0.054</td>
<td>37.60</td>
<td>0.054</td>
<td>37.60</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Phi_3\Psi_3$</td>
<td>0.140</td>
<td>0.019</td>
<td>0.020</td>
<td>13.81</td>
<td>0.020</td>
<td>13.81</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Phi_4\Psi_4$</td>
<td>0.085</td>
<td>0.007</td>
<td>0.007</td>
<td>5.013</td>
<td>0.007</td>
<td>5.013</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>$\Phi_1\Psi_1$</td>
<td>0.899</td>
<td>0.808</td>
<td>0.405</td>
<td>99.979</td>
<td>0.405</td>
<td>99.979</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Phi_2\Psi_2$</td>
<td>0.185</td>
<td>0.034</td>
<td>0.036</td>
<td>0.011</td>
<td>0.036</td>
<td>0.011</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Phi_3\Psi_3$</td>
<td>0.149</td>
<td>0.022</td>
<td>0.023</td>
<td>0.007</td>
<td>0.023</td>
<td>0.007</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Phi_4\Psi_4$</td>
<td>0.104</td>
<td>0.011</td>
<td>0.011</td>
<td>0.003</td>
<td>0.011</td>
<td>0.003</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>$\Phi_1\Psi_1$</td>
<td>0.815</td>
<td>0.664</td>
<td>1.978</td>
<td>98.07</td>
<td>1.978</td>
<td>98.07</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Phi_2\Psi_2$</td>
<td>0.166</td>
<td>0.027</td>
<td>0.028</td>
<td>1.400</td>
<td>0.028</td>
<td>1.400</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Phi_3\Psi_3$</td>
<td>0.091</td>
<td>0.008</td>
<td>0.008</td>
<td>0.410</td>
<td>0.008</td>
<td>0.410</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Phi_4\Psi_4$</td>
<td>0.049</td>
<td>0.002</td>
<td>0.003</td>
<td>0.120</td>
<td>0.003</td>
<td>0.120</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: $\Phi_\Psi_i$: Canonical Function where $i = 1, 2, 3, 4$.

To confirm these findings, a dimension reduction analysis using the Chi-square and an $F$ test was performed to identify the extent to which each canonical function can account...
for shared variance between the datasets and to test the hierarchical arrangements of functions for statistical significance. Table 8.2 presents dimension reduction analysis results. The Chi-square test was used because it is appropriate for non-skewed or non-Gaussian predictors, which was determined to be the case for this analysis. The chi-square test results suggest a statistically meaningful relation between the first pair of canonical variables ($\Phi_1$ and $\Psi_1$) in the three periods. This indicates that only the first root is significant and that the rank of the coefficient matrix for all periods is $C_1$; thus, only one factor is significant in determining whether FF price changes are related to CC. According to the chi-square test results, only the first pair of canonical variables is related in a statistically significant manner, i.e. at 10% (Period 1) and 1% (Periods 2 and 3) significance (Tables 8.1 and 8.2). In addition, there is a 19.3% shared variance between these variates for Period 1, 80.8% shared variance for Period 2 and 66.4% shared variance for Period 3, as shown in Table 8.1.

Table 8.2: Dimension reduction analysis.

<table>
<thead>
<tr>
<th>Period</th>
<th>$\Lambda_{\text{Wilks}}$</th>
<th>Chi-Square</th>
<th>F-value</th>
<th>DF</th>
<th>Error DF</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Φ₁Ψ₁</td>
<td>0.868</td>
<td>31.81</td>
<td>1.334</td>
<td>24</td>
<td>772</td>
<td>(*)</td>
</tr>
<tr>
<td>Φ₂Ψ₂</td>
<td>0.923</td>
<td>18.03</td>
<td>1.207</td>
<td>15</td>
<td>613</td>
<td>0.261</td>
</tr>
<tr>
<td>Φ₃Ψ₃</td>
<td>0.973</td>
<td>6.090</td>
<td>0.761</td>
<td>8</td>
<td>446</td>
<td>0.637</td>
</tr>
<tr>
<td>Φ₄Ψ₄</td>
<td>0.993</td>
<td>1.629</td>
<td>0.544</td>
<td>3</td>
<td>224</td>
<td>0.653</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Period</th>
<th>$\Lambda_{\text{Wilks}}$</th>
<th>Chi-Square</th>
<th>F-value</th>
<th>DF</th>
<th>Error DF</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Φ₁Ψ₁</td>
<td>0.323</td>
<td>514.5</td>
<td>25.14</td>
<td>24</td>
<td>1578</td>
<td>(***)</td>
</tr>
<tr>
<td>Φ₂Ψ₂</td>
<td>0.962</td>
<td>17.52</td>
<td>1.170</td>
<td>15</td>
<td>1250</td>
<td>0.288</td>
</tr>
<tr>
<td>Φ₃Ψ₃</td>
<td>0.989</td>
<td>4.849</td>
<td>0.606</td>
<td>8</td>
<td>908</td>
<td>0.774</td>
</tr>
<tr>
<td>Φ₄Ψ₄</td>
<td>0.998</td>
<td>1.093</td>
<td>0.364</td>
<td>3</td>
<td>455</td>
<td>0.779</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Period</th>
<th>$\Lambda_{\text{Wilks}}$</th>
<th>Chi-Square</th>
<th>F-value</th>
<th>DF</th>
<th>Error DF</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Φ₁Ψ₁</td>
<td>0.300</td>
<td>827.2</td>
<td>29.51</td>
<td>24</td>
<td>772</td>
<td>(***)</td>
</tr>
<tr>
<td>Φ₂Ψ₂</td>
<td>0.934</td>
<td>15.36</td>
<td>1.027</td>
<td>15</td>
<td>613</td>
<td>0.425</td>
</tr>
<tr>
<td>Φ₃Ψ₃</td>
<td>0.967</td>
<td>7.516</td>
<td>0.941</td>
<td>8</td>
<td>446</td>
<td>0.482</td>
</tr>
<tr>
<td>Φ₄Ψ₄</td>
<td>0.989</td>
<td>2.437</td>
<td>0.815</td>
<td>3</td>
<td>224</td>
<td>0.487</td>
</tr>
</tbody>
</table>

Note: ***, ** and * indicate significance at 1%, 5% and 10% levels, respectively.
8.3.1 **Significance of canonical correlation values**

An important part of CCA is to ascertain the significance of each root or function in the analysis. Table 8.3 shows the general fit of the model for Pillai, Hotelling, Wilks and Roy’s multivariate criteria. The first three tests are based on the likelihood ratio. The null hypothesis for each test is that there is no relation between the two sets of FF and CC variables for each of the three periods, *i.e.* for each period $H_0$: all $C_j = 0$; $H_1$: at least one $C_j \neq 0$. According to the multivariate tests, the general fit of the model clearly reveals that all tests yielded significant results ($p < 0.1$ for Period 1 and $p < 0.01$ for Periods 2 and 3).

<table>
<thead>
<tr>
<th>Period 1</th>
<th>Value</th>
<th>F-value</th>
<th>DF</th>
<th>Error DF</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pillai</td>
<td>0.138</td>
<td>1.336</td>
<td>24</td>
<td>896</td>
<td>(*)</td>
</tr>
<tr>
<td>Hotelling</td>
<td>0.145</td>
<td>1.329</td>
<td>24</td>
<td>878</td>
<td>(*)</td>
</tr>
<tr>
<td>Wilks</td>
<td>0.868</td>
<td>1.334</td>
<td>24</td>
<td>772</td>
<td>(*)</td>
</tr>
<tr>
<td>Roy</td>
<td>0.193</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Period 2</th>
<th>Value</th>
<th>F-value</th>
<th>DF</th>
<th>Error DF</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pillai</td>
<td>1.076</td>
<td>13.58</td>
<td>24</td>
<td>896</td>
<td>(***)</td>
</tr>
<tr>
<td>Hotelling</td>
<td>0.474</td>
<td>43.56</td>
<td>24</td>
<td>878</td>
<td>(***)</td>
</tr>
<tr>
<td>Wilks</td>
<td>0.300</td>
<td>29.5</td>
<td>24</td>
<td>772</td>
<td>(***)</td>
</tr>
<tr>
<td>Roy</td>
<td>0.808</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Period 3</th>
<th>Value</th>
<th>F-value</th>
<th>DF</th>
<th>Error DF</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pillai</td>
<td>0.702</td>
<td>16.14</td>
<td>24</td>
<td>1820</td>
<td>(***)</td>
</tr>
<tr>
<td>Hotelling</td>
<td>2.016</td>
<td>37.85</td>
<td>24</td>
<td>1802</td>
<td>(***)</td>
</tr>
<tr>
<td>Wilks</td>
<td>0.323</td>
<td>25.14</td>
<td>24</td>
<td>1578</td>
<td>(***)</td>
</tr>
<tr>
<td>Roy</td>
<td>0.664</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:**
***, ** and * indicate significance at 1%, 5% and 10% levels, respectively.

The findings of the multivariate test of significance indicate that the full model across all functions in the three periods is statistically significant using Wilk’s $\Lambda = 0.868$, 0.300 and 0.323, where $F = (24, 772) = 1.334$ ($p < 0.1$), $F = (24, 772) = 29.506$ ($p < 0.01$) and $F = (24, 1578) = 25.142$ ($p < 0.01$) (Table 8.3). Wilk’s $\Lambda$ represents the unexplained variance by $C_j$; thus, $1-\Lambda$ yields the full $C_j$ effect size, where $1-\Lambda$ represents the total variance shared by the canonical variables. Therefore, for the four
canonical functions, the effect size is 0.193, 0.808 and 0.664 for Periods 1, 2 and 3, respectively. In addition, the scores of the significant canonical ($\Phi_1, \Psi_1$) by Hotelling’s test were plotted for each period (Figure 8.2). As can be seen, the set 1 ($\Phi_1$) vs. set 2 ($\Psi_1$) plot is reasonably linear for Period 1 and distinctly linear for Periods 2 and 3, which confirms the canonical correlation dimension reduction analysis.

![Figure 8.2: Scores of significant canonical first function by Hotelling’s test.](image_url)

### 8.3.2 Raw canonical coefficients of variates

One of the purposes of conducting CCA is to obtain the relation between variables belonging to a given set and the corresponding canonical variates in the form of canonical scores. The raw and standardized coefficients correspond to a linear relation, which can be interpreted as partial regression coefficients in a linear regression if the canonical variates are assumed to be the predicted or outcome variables. The raw canonical coefficients for the variables in the FF set are categorised into three periods in Table 8.4. Moreover, the raw canonical coefficients are equal to the $b$-weights in regression and can be used to compute the predicted data based on the subject’s actual scores. Therefore, the coefficients should be scaled such that the resulting canonical variates have a mean of zero and variance of one.
These coefficients can be interpreted in a manner similar to that of regression coefficients; thus, they can be used to predict variations in the first to fourth variates in terms of changes to the variables (Table 8.4). For example, for Period 1, a single unit rise in $R_{Y_1}$ leads to a decline of 0.061 units to the first variate, an increase of 0.141 to the second variate, an increase of 0.101 units to the third variate and a decline of 0.306 units to the fourth variate. Note that possible differences in the scale of the variables are reflected in the scale of the raw coefficients.

Table 8.4: Raw canonical coefficients for FF set variables.

<table>
<thead>
<tr>
<th>Period 1</th>
<th>$\Phi_1$</th>
<th>$\Phi_2$</th>
<th>$\Phi_3$</th>
<th>$\Phi_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{Y_1}$</td>
<td>-0.061</td>
<td>0.141</td>
<td>0.101</td>
<td>-0.306</td>
</tr>
<tr>
<td>$R_{Y_2}$</td>
<td>-0.075</td>
<td>-0.134</td>
<td>-0.047</td>
<td>0.372</td>
</tr>
<tr>
<td>$R_{Y_3}$</td>
<td>-0.043</td>
<td>0.222</td>
<td>-0.225</td>
<td>0.025</td>
</tr>
<tr>
<td>$R_{Y_4}$</td>
<td>-0.187</td>
<td>-0.279</td>
<td>-0.215</td>
<td>-0.191</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Period 2</th>
<th>$\Phi_1$</th>
<th>$\Phi_2$</th>
<th>$\Phi_3$</th>
<th>$\Phi_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{Y_1}$</td>
<td>-0.054</td>
<td>-0.163</td>
<td>0.281</td>
<td>0.527</td>
</tr>
<tr>
<td>$R_{Y_2}$</td>
<td>-0.059</td>
<td>-0.131</td>
<td>-0.376</td>
<td>-0.261</td>
</tr>
<tr>
<td>$R_{Y_3}$</td>
<td>0.004</td>
<td>0.138</td>
<td>-0.106</td>
<td>0.095</td>
</tr>
<tr>
<td>$R_{Y_4}$</td>
<td>-0.005</td>
<td>0.289</td>
<td>0.104</td>
<td>-0.310</td>
</tr>
</tbody>
</table>

Note: FF variable set: $R_{Y_1}$: Global oil price return, $R_{Y_2}$: Saudi oil price return, $R_{Y_3}$: Global NG prices return, and $R_{Y_4}$: Global coal prices return.

Similarly, during Period 1, a one-unit increase in $R_{Y_2}$ leads to reductions of 0.075, 0.134 and 0.047 units to the first, second and third variates, and an increase of 0.372 units to the fourth variate (Table 8.4). $R_{Y_3}$, one-unit led to decrease in the first and third variate (0.043, 0.225 respectively) and increase in the second and fourth variate (0.222, 0.025 respectively) and for $R_{Y_4}$ decrease in the four variates. During Period 2, a one-unit increase to $R_{Y_1}$ leads to a decrease of 0.054 units in the first variate, a decrease of 0.163 units in the second variate, an increase of 0.281 units in the third variate and an increase of 0.527 units in the fourth variate. One-unit of $R_{Y_2}$ return led to decrease $\Phi_1$ (where
\( i = 1, 2, 3, 4 \), \( R_{Y3} \) led to increase (\( \Phi_1, \Phi_2 \) and \( \Phi_4 \)) and decrease (\( \Phi_4 \)), and \( R_{Y4} \) led to increase in (\( \Phi_2 \) and \( \Phi_3 \)) and decrease (\( \Phi_1 \) and \( \Phi_4 \)).

Table 8.5 shows the coefficients for the variables in the CC set. As can be seen, an increase in \( R_{X1} \) led to an increase of 0.039 units in the first variate, a decrease of 0.073 units in the second variate, a decrease of 0.050 units in the third variate and a decrease of 0.044 units in the fourth variate (Period 1). A one-unit increase in \( \Delta S_{X2} \) and \( \Delta S_{X3} \) during Periods 1 and 2 led to a decrease in first, second and fourth variate, and an increase in the third variate. Similarly, \( S_{X6} \) decreases in (\( \Psi_1 \) and \( \Psi_4 \)) and increases in (\( \Psi_2 \) and \( \Psi_3 \)) in Periods 1 and 3. The other coefficients can be interpreted in a similar manner while noting that differences in the scale of the FF and CC variables are reflected in the scale of the raw coefficients.

<table>
<thead>
<tr>
<th>Period</th>
<th>( \Psi_1 )</th>
<th>( \Psi_2 )</th>
<th>( \Psi_3 )</th>
<th>( \Psi_4 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.039</td>
<td>-0.073</td>
<td>-0.050</td>
<td>-0.044</td>
</tr>
<tr>
<td></td>
<td>-1.900</td>
<td>-4.106</td>
<td>1.343</td>
<td>-2.343</td>
</tr>
<tr>
<td></td>
<td>-0.454</td>
<td>-1.696</td>
<td>3.595</td>
<td>-1.294</td>
</tr>
<tr>
<td></td>
<td>0.039</td>
<td>0.521</td>
<td>0.889</td>
<td>0.173</td>
</tr>
<tr>
<td></td>
<td>-1.117</td>
<td>1.495</td>
<td>-0.811</td>
<td>-0.551</td>
</tr>
<tr>
<td></td>
<td>-1.043</td>
<td>0.182</td>
<td>0.347</td>
<td>-0.079</td>
</tr>
<tr>
<td>2</td>
<td>-0.118</td>
<td>-0.010</td>
<td>-0.027</td>
<td>-0.008</td>
</tr>
<tr>
<td></td>
<td>-0.002</td>
<td>-0.157</td>
<td>0.085</td>
<td>-0.142</td>
</tr>
<tr>
<td></td>
<td>-0.008</td>
<td>-1.890</td>
<td>1.904</td>
<td>-1.664</td>
</tr>
<tr>
<td></td>
<td>0.001</td>
<td>0.852</td>
<td>0.505</td>
<td>-0.290</td>
</tr>
<tr>
<td></td>
<td>0.001</td>
<td>0.097</td>
<td>-1.415</td>
<td>-0.870</td>
</tr>
<tr>
<td></td>
<td>-0.008</td>
<td>0.970</td>
<td>0.134</td>
<td>-0.081</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Period</th>
<th>( \Psi_1 )</th>
<th>( \Psi_2 )</th>
<th>( \Psi_3 )</th>
<th>( \Psi_4 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>-0.142</td>
<td>0.003</td>
<td>-0.031</td>
<td>0.015</td>
</tr>
<tr>
<td></td>
<td>0.042</td>
<td>-0.150</td>
<td>0.035</td>
<td>-0.238</td>
</tr>
<tr>
<td></td>
<td>0.317</td>
<td>-4.459</td>
<td>3.869</td>
<td>0.992</td>
</tr>
<tr>
<td></td>
<td>-0.057</td>
<td>0.316</td>
<td>0.801</td>
<td>0.691</td>
</tr>
<tr>
<td></td>
<td>0.108</td>
<td>0.611</td>
<td>-1.147</td>
<td>1.453</td>
</tr>
<tr>
<td></td>
<td>-0.139</td>
<td>0.773</td>
<td>0.899</td>
<td>-0.409</td>
</tr>
</tbody>
</table>

Note: CC variable set: \( R_{X1} \): Green energy index return, \( \Delta S_{X2} \): Global CO\(_2\), \( \Delta S_{X3} \): Global temperature, \( S_{X4} \): Global precipitation, \( \Delta S_{X5} \): Saudi temperature, and \( S_{X6} \): Saudi precipitation.
8.3.3 Standardized canonical coefficients of variates

To remove the influence of scale, it is effective to use standardized canonical coefficients while determining the influence of dependent variables on the functions. The standardized canonical coefficients play the role of \( b \)-weights in regression and are based on the standard scores of the variables and indicate the relative importance of each variable (Tables 8.6 and 8.7). Their magnitudes represent their relative contributions to the related variate; thus, the canonical variates (\( \Phi_1 \) and \( \Psi_1 \)) representing the optimal linear combinations of the dependent and independent variables can be written in terms of the standardized canonical coefficients for Period 1 as follows.

\[
\Phi_1 = -0.432 R_{Y1} - 0.473 R_{Y2} - 0.134 R_{Y3} - 0.425 R_{Y4} \\
\Psi_1 = 0.197 R_{X1} - 0.263 \Delta S_{X2} - 0.046 \Delta S_{X3} + 0.038 S_{X4} - 0.594 \Delta S_{X5} - 1.039 S_{X6}
\]  

(8.a1)

From this pair of equations, it can be observed that the strongest influence on the first root for Period 1 was from \( R_{Y1}, R_{Y2} \) and \( R_{Y4} \) in the FF set and from \( R_{X1}, \Delta S_{X2}, \Delta S_{X5} \) and \( S_{X6} \) in the CC set. Thus, standardized coefficients indicate how increases to one independent variable produces a greater change in another independent variable. For Period 2, the equations of the optimal linear of \( \Phi_1 \) and \( \Psi_1 \) can be presented in terms of the standardized coefficients as follows.

\[
\Phi_1 = -0.472 R_{Y1} - 0.499 R_{Y2} + 0.002 R_{Y3} - 0.039 R_{Y4} \\
\Psi_1 = -0.998 R_{X1} - 0.247 \Delta S_{X2} - 0.200 \Delta S_{X3} + 0.001 S_{X4} + 0.053 \Delta S_{X5} - 0.009 S_{X6}
\]  

(8.a2)

Equation (8.a2) suggests that the strongest relation factor from the FF set was from the global and Saudi oil markets and \( \Psi_1 \) from \( R_{X1} \) and \( \Delta S_{X2} \). For Period 3, the strongest effect from the FF variables on the first root was from \( R_{Y1}, R_{Y2} \) and \( R_{Y4} \) (Period 1),
while that from the CC variables was from $R_{X_1}$ and $S_{X_6}$. The corresponding equations involving optimal linear combinations are as follows.

$$\Phi_1 = 0.185 R_{Y_1} + 0.384 R_{Y_2} - 0.007 R_{Y_3} + 0.844 R_{Y_4}$$

$$\Psi_1 = -0.985 R_{X_1} + 0.050 \Delta S_{X_2} + 0.033 \Delta S_{X_3} - 0.057 S_{X_4} + 0.058 \Delta S_{X_5} - 0.139 S_{X_6}$$

(8.a3)

Table 8.6: Standardized canonical coefficients for FF set variables.

<table>
<thead>
<tr>
<th>Period</th>
<th>$\Phi_1$</th>
<th>$\Phi_2$</th>
<th>$\Phi_3$</th>
<th>$\Phi_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-0.432</td>
<td>1.004</td>
<td>0.717</td>
<td>-2.183</td>
</tr>
<tr>
<td>2</td>
<td>-0.473</td>
<td>-0.842</td>
<td>-0.298</td>
<td>2.336</td>
</tr>
<tr>
<td>3</td>
<td>-0.134</td>
<td>0.697</td>
<td>-0.707</td>
<td>0.079</td>
</tr>
<tr>
<td>4</td>
<td>-0.425</td>
<td>-0.634</td>
<td>-0.488</td>
<td>-0.435</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Period</th>
<th>$\Phi_1$</th>
<th>$\Phi_2$</th>
<th>$\Phi_3$</th>
<th>$\Phi_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.185</td>
<td>0.715</td>
<td>2.896</td>
<td>1.159</td>
</tr>
<tr>
<td>2</td>
<td>0.384</td>
<td>-0.132</td>
<td>-2.213</td>
<td>-2.316</td>
</tr>
<tr>
<td>3</td>
<td>-0.007</td>
<td>0.912</td>
<td>-0.333</td>
<td>0.323</td>
</tr>
<tr>
<td>4</td>
<td>0.844</td>
<td>-0.647</td>
<td>-0.400</td>
<td>0.928</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Period</th>
<th>$\Psi_1$</th>
<th>$\Psi_2$</th>
<th>$\Psi_3$</th>
<th>$\Psi_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>R_{Y_1}</td>
<td>-0.472</td>
<td>-1.420</td>
<td>2.441</td>
</tr>
<tr>
<td>2</td>
<td>R_{Y_2}</td>
<td>-0.499</td>
<td>-1.098</td>
<td>-3.151</td>
</tr>
<tr>
<td>3</td>
<td>R_{Y_3}</td>
<td>0.002</td>
<td>0.716</td>
<td>-0.553</td>
</tr>
<tr>
<td>4</td>
<td>R_{Y_4}</td>
<td>-0.039</td>
<td>2.430</td>
<td>0.873</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Period</th>
<th>$\Psi_1$</th>
<th>$\Psi_2$</th>
<th>$\Psi_3$</th>
<th>$\Psi_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>R_{X_1}</td>
<td>-0.998</td>
<td>-0.083</td>
<td>-0.231</td>
</tr>
<tr>
<td>2</td>
<td>$\Delta S_{X_2}$</td>
<td>-0.247</td>
<td>-0.003</td>
<td>0.133</td>
</tr>
<tr>
<td>3</td>
<td>$\Delta S_{X_3}$</td>
<td>-0.200</td>
<td>-0.001</td>
<td>0.201</td>
</tr>
<tr>
<td>4</td>
<td>S_{X_4}</td>
<td>0.001</td>
<td>0.875</td>
<td>0.518</td>
</tr>
<tr>
<td>5</td>
<td>$\Delta S_{X_5}$</td>
<td>0.053</td>
<td>0.001</td>
<td>-0.778</td>
</tr>
<tr>
<td>6</td>
<td>S_{X_6}</td>
<td>-0.009</td>
<td>0.976</td>
<td>0.135</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Period</th>
<th>$\Psi_1$</th>
<th>$\Psi_2$</th>
<th>$\Psi_3$</th>
<th>$\Psi_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$\Delta S_{X_2}$</td>
<td>-0.985</td>
<td>0.024</td>
<td>-0.214</td>
</tr>
<tr>
<td>2</td>
<td>$\Delta S_{X_3}$</td>
<td>0.050</td>
<td>-0.180</td>
<td>0.042</td>
</tr>
<tr>
<td>3</td>
<td>$\Delta S_{X_4}$</td>
<td>0.033</td>
<td>-0.463</td>
<td>0.401</td>
</tr>
<tr>
<td>4</td>
<td>S_{X_5}</td>
<td>-0.057</td>
<td>0.316</td>
<td>0.801</td>
</tr>
<tr>
<td>5</td>
<td>$\Delta S_{X_6}$</td>
<td>0.058</td>
<td>0.330</td>
<td>-0.620</td>
</tr>
<tr>
<td>6</td>
<td>S_{X_6}</td>
<td>-0.139</td>
<td>0.773</td>
<td>0.899</td>
</tr>
</tbody>
</table>
8.3.4 Canonical correspondence analysis

A CCA map is a convenient visualization of the matrix of explanatory variables in terms of the explained correspondence. It is applied when the explained variables have unimodal distributions. In addition, it preserves the chi-square distances between objects. In this case, the analysis was performed using the FF set as the explanatory variables and the CC set as the response variables. Figure 8.3 shows the three period plots of canonical correspondence. The distances in the three panels between points representing the FF and CC variable sets are the chi-square distances, and type of scaling (rows of the data are at the centroids of the columns) is used to produce meaningful relations.

In Period 1, NG price of return was more likely to influence the $R_{X_1}$ and $S_{X_6}$ variables, and $R_{Y_1}$ and $R_{Y_2}$ were somewhat less likely to influence $S_{X_4}$ (Figure 8.3). In addition, the price of coal return was, to a small extent, likely to influence the $\Delta S_{X_2}$ variable. The likelihood of influence was estimated visually based on the orthogonal distance of the lines of the explanatory variables from the points of the explained variables. For Period 2, all variables from the FF set were likely to influence, to a greater or lesser extent, the $R_{X_1}$ variable from the CC set. For the overall Period 3, the $R_{Y_4}$ variable was most likely to influence the $\Delta S_{X_5}$ variable, followed by $\Delta S_{X_2}$ and $\Delta S_{X_3}$ to lesser extents, while variables $R_{Y_1}$, $R_{Y_2}$ and $R_{Y_3}$ were expected to influence $R_{X_1}$ to some extent.

In Figure 8.3, the most important similarity that the result showed that the global oil market move in the same direction as $R_{Y_2}$ (second quadrant in Period 1, 2 and 3) as well as coal return (second quadrant in Period 2 and third quadrant in Period 1 and 3). The
second most important result is between \((R_{Y_1}, R_{Y_2}, R_{Y_4})\) and \((\Delta S_{X_2}, \Delta S_{X_3}, \Delta S_{X_5})\), which move in the same direction but in different quadrants. Although the distances between the categories of the FF and CC sets are not defined scientifically, their degree of closeness of points on the graphical depiction relative to their angle from the origin and points in the same quadrant can be used as guidelines to demonstrate the relation between the FF and CC variables.

![Graphical depiction of canonical correspondence analysis](image)

**Figure 8.3:** Graphical depiction of canonical correspondence analysis.

### 8.3.5 Canonical and cross loadings

The calculated canonical coefficients may become unstable if the data have multicollinearity, because canonical loading or canonical structural correlations are obtained as measures of the simple linear correlation between the independent variables and their respective canonical variates. This also serves an important purpose, *i.e.* the contribution of the underlying variables in the dependent and independent sets to the canonical variates can be measured by their correlations, which are also known as canonical loadings.

However, canonical loadings may exhibit substantial variability between different samples such that the relations implied by them may become sample-specific, *e.g.* they
may have occurred purely by chance or due to other extraneous factors. Therefore, some caution is required when interpreting canonical relations between variables using loading values, especially within the context of the external validity of research results. The canonical coefficients are destabilized by multicollinearity or minute sample sizes, and to avoid this problem, the significance of each canonical covariate was increased by considering the loadings, which refer to the correlations between $\Phi_i$ and $\Psi_i$ and the primary dataset. Variables with greater absolute values for their canonical loadings contribute more to the multivariate relations between FF and CC.

Table 8.8: Canonical loadings for FF set variables.

<table>
<thead>
<tr>
<th>Period 1</th>
<th>$\phi_1$</th>
<th>$\phi_2$</th>
<th>$\phi_3$</th>
<th>$\phi_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{Y_1}$</td>
<td>-0.880</td>
<td>0.268</td>
<td>0.426</td>
<td>-0.024</td>
</tr>
<tr>
<td>$R_{Y_2}$</td>
<td>-0.864</td>
<td>0.116</td>
<td>0.319</td>
<td>0.332</td>
</tr>
<tr>
<td>$R_{Y_3}$</td>
<td>-0.210</td>
<td>0.640</td>
<td>-0.734</td>
<td>0.095</td>
</tr>
<tr>
<td>$R_{Y_4}$</td>
<td>-0.929</td>
<td>-0.604</td>
<td>-0.556</td>
<td>-0.376</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Period 2</th>
<th>$\phi_1$</th>
<th>$\phi_2$</th>
<th>$\phi_3$</th>
<th>$\phi_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{Y_1}$</td>
<td>-0.992</td>
<td>0.026</td>
<td>0.098</td>
<td>0.072</td>
</tr>
<tr>
<td>$R_{Y_2}$</td>
<td>-0.982</td>
<td>-0.041</td>
<td>-0.106</td>
<td>-0.059</td>
</tr>
<tr>
<td>$R_{Y_3}$</td>
<td>-0.241</td>
<td>0.678</td>
<td>-0.519</td>
<td>0.461</td>
</tr>
<tr>
<td>$R_{Y_4}$</td>
<td>-0.957</td>
<td>0.208</td>
<td>0.162</td>
<td>-0.120</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Period 3</th>
<th>$\phi_1$</th>
<th>$\phi_2$</th>
<th>$\phi_3$</th>
<th>$\phi_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{Y_1}$</td>
<td>-0.816</td>
<td>0.284</td>
<td>0.453</td>
<td>-0.319</td>
</tr>
<tr>
<td>$R_{Y_2}$</td>
<td>-0.783</td>
<td>0.247</td>
<td>0.187</td>
<td>-0.489</td>
</tr>
<tr>
<td>$R_{Y_3}$</td>
<td>-0.204</td>
<td>0.879</td>
<td>-0.320</td>
<td>0.289</td>
</tr>
<tr>
<td>$R_{Y_4}$</td>
<td>-0.987</td>
<td>-0.043</td>
<td>0.012</td>
<td>0.155</td>
</tr>
</tbody>
</table>

Generally, Table 8.8 shows that variables $R_{Y_1}$, $R_{Y_2}$ and $R_{Y_4}$ have a strong inverse relation with the first variate and $R_{Y_3}$ has weak relations with $\Phi_1$ lodging. For example, in Period 2, all four variables of the FF set show negative correlation with the first variate, and the $R_{Y_1}$, $R_{Y_2}$ and $R_{Y_4}$ variables show very strong influence loading (–0.992, –0.982 and –0.957, respectively), whereas $R_{Y_3}$ has weak relation loading and less influential variable in figuration of the first canonical variable.
In addition, as shown in Table 8.9, $R_{X_1}$ has a weak relation (0.174) with $\Psi_1$, $\Delta S_{X_2}$ has a moderate negative effect (−0.448), $\Delta S_{X_3}$ has a moderate influence (0.305), $S_{X_4}$ has a weak negative relation (−0.128), $\Delta S_{X_5}$ has a weak positive link (0.233) and $S_{X_6}$ has a very weak negative effect (−0.03). For Periods 2 and 3, the strengths of the loading relations are overall greater than those in Period 1, for $\Delta S_{X_2}$ (negative strong), $R_{X_1}$ (negative moderate), $\Delta S_{X_3}$ and $\Delta S_{X_5}$ (positive moderate), and $S_{X_4}$ (negative weak), while $S_{X_6}$ – positive weak (in Period 2) and negative weak (in Period 3).

The shared variances of the variables across the two sets, or the cross loadings, are shown in Tables 8.10 and 8.11 for the three periods. For Period 1, the FF variable set has low shared variances in the first canonical variate ($R_{Y_1}$, $R_{Y_2}$, $R_{Y_3}$ and $R_{Y_4}$ have 4.62%, 4.45%, 0.26% and 5.5% of the variance explained by $\Phi_1$, respectively) (Tables 8.10). Similarly, the CC variable set has low shared variances in the corresponding first
canonical variate ($R_{X_1}$, $\Delta S_{X_2}$, $\Delta S_{X_3}$, $S_{X_4}$, $\Delta S_{X_5}$ and $S_{X_6}$ have 0.06%, 1.19%, 0.55%, 0.10%, 0.11% and 0.01% of the variance explained by $\Psi_1$, respectively).

Moreover, for Period 2, the behaviour of the variables in the FF set changed remarkably, i.e. the $R_{Y_1}$, $R_{Y_2}$ and $R_{Y_4}$ variables imply that variate $\Phi_1$ would be able to predict 76.21%, 72.59% and 70.56% of the variations, respectively, while $R_{Y_3}$
continued to have a low cross-loading value. For the CC variable set, \( R_{X_1} \), \( \Delta S_{X_2} \) and \( \Delta S_{X_3} \) show a high to medium effect (–0.478, 0.723 and 0.402 predicted by \( \Psi_1 \)), and the other cross-loading values for this period are lower (Table 8.11). Furthermore, for Period 3, Table 8.10 indicates that \( R_{Y_4} \) has high shared variance with the first canonical variate, which explains 64.64% of the variances, followed by \( R_{Y_1} \) and \( R_{Y_2} \) with 40.70% and 44.22%, respectively.

The CC variable set cross loading shows that \( \Delta S_{X_2} \) had a moderate negative cross loading of –0.58, while \( R_{X_1} \) had a cross loading value of –0.389. The remaining variables indicate a low shared variance among \( \Delta S_{X_3}, S_{X_4}, \Delta S_{X_5} \) and \( S_{X_6} \), with the first canonical variate (\( \Psi_1 \)) explaining 9.18%, 1.74%, 7.95% and 0.02% of the variations of these variables, respectively (Table 8.11). Therefore, the different results relative to correlation between bivariate (Tables 7.1 and 7.2) and canonical correlations (Tables 8.6 to Table 8.11) may clarify the fact that understanding canonical variates in a significant function is based on the premise that the variables in each set that contribute weightily to shared variances for these functions are considered correlated (Hair et al., 2014).

### 8.3.6 Canonical redundancy analysis

An important aspect of CCA is that high canonical correlation values do not necessarily indicate strong relations between corresponding sets of variables because the correlations only maximize the linear combination correlation in the two sets rather than variances between the sets. Therefore, prior to making inferences about the relations, redundancy analysis must be performed such that the amount of variance in the dependent variable that is shared with the independent variable can be truly ascertained.
Redundancy in CCA is calculated as the extent of variance in the actual variables belonging to one set that can be explained by the canonical variates of the other set that have the same $C_j$ measuring the relation. The variables provide explanations about their own variances, as well as the variance of the opposite sets. Thus, higher coefficient values produce greater variance information (Huixuan Gao, 2002).

The redundancy resembles the multiple regression $R^2$ statistics, which represent the amount of variance in the dependent variables explained by the independent variables within the model. Analogously, in CCA, redundancy is the amount of variance in the original variables of one set of variables in a canonical function that is explained by the canonical variate of the other set of variables in that canonical function. The first canonical loadings of the CV1-1 and CV2-1 models are shown in Figure 8.4.

For Period 1, the canonical variable CV1-1 explains 0.337 of the overall variance in the FF set (or its own set of variables) and 0.23 of the overall variance in the CC set (the other set of variables) (Figure 8.4). The $R_{Y_i}$ set explains a much lower percentage of variances in the canonical variates for the ($R_{X_i}$ and $S_{X_i}$) set. For example, the canonical variate CV1-4 from the $R_{Y_i}$ set can explain only 0.01 of the variance in the corresponding CV2-4 variate from the ($R_{X_i}$ and $S_{X_i}$) set, CV1-3 from the $R_{Y_i}$ set explains only 0.04 of the variance in CV2-3 from the ($R_{X_i}$ and $S_{X_i}$) set and CV1-2 from $R_{Y_i}$ explains 0.09 of the variance in CV2-2 from ($R_{X_i}$ and $S_{X_i}$). Similarly, the canonical variate CV2-4 from the ($R_{X_i}$ and $S_{X_i}$) set can explain none of the variation in the canonical variate CV1-4 from the FF variable set, CV2-3 explains 0.06 of the variance.
in CV1-3 and CV2-2 explains 0.11 of the variance in CV1-2 from the CC variable set (Figure 8.4).

Figure 8.4: Canonical redundancy analysis.

From Figure 8.4, for Period 2, CV1-4 can explain only 2% of the variance in the corresponding variate CV2-4, CV1-3 explains only 5% of the variance in CV2-3 and CV1-2 from $R_Y$ can explain 4% of the variance in CV2-2. Likewise, the canonical variate CV2-4 explains 1% of the variation in the canonical variate CV1-4, CV2-3 can explain 2% of the variance in CV1-3 and CV2-2 can explain 4% of the variance in CV1-2. Therefore, compared to Period 1, the proportion of variance of one CV that can be explained by the opposite set’s CV decreased to some extent. In Period 3, the canonical variates CV1-1 and CV2-1 explain 57.3% and 37.35% and 27.3% and 16.5% of the total variance in sets $R_Y$ and the variables ($R_X$ and $S_X$), respectively.

The redundancy analysis suggests that the canonical variates for set $R_Y$, especially the third CV (CV1-3 and CV1-4), explain little of the variance in the corresponding variate (CV2-3, CV2-4) for the ($R_X$ and $S_X$) set. Similarly, (CV2-3, CV2-4) of set ($R_X$ and
SXi) explains little of the corresponding variate (CV1-3, CV1-4) in set RYi. The graphical results of the significant loading function and redundancy are shown in Figure 8.5.

8.3.7 Cluster canonical correlation analysis

A common shortcoming of CCA is that, although it can be used to perform dimensional reduction analysis using datasets with two paired modalities, it is not suitable when multiple point clusters in one modality are associated with multiple clusters of points in another modality. To address this issue, the CCA technique has been expanded to cases
where each variable set contains several clusters or classes using cluster CCA in which all data points from one modality belonging to a particular class are paired with all points from the other modality that belong to the same class.

Hierarchical clustering is an approach to clustering \( n \) units (or objects), each described by \( p \) features, into a number of groups by creating a hierarchy of clusters that can be represented in a tree-like diagram, \( i.e. \) a dendrogram. In the dendrogram, units in the same cluster are joined by a horizontal line, where the scale on the \( y \)-axis of the dendrogram reflects the distances of the units within the cluster. The leaves at the bottom of the dendrogram represent the individual units. Here, leaves are combined to form small branches, and small branches are combined into larger branches until one reaches the trunk or root of the tree that represents a single cluster containing all units. Elements joined at lower levels are considered more tightly clustered than those joined at higher levels.

Figure 8.6 shows a CCA cluster dendrogram created using both the FF and CC set variables for the three periods. The dendrogram can be used to find emerging structures with respect to groups of variables by observing its different levels. The horizontal scale can be used to visually ‘cut’ the tree structure at different distances and identify more compact groups that are closely connected to each other, as well as distant groups that are not well connected. For example, at a horizontal distance of 0.5 for Period 1, three clusters may be identified: variables \( R_{Y_1}, R_{Y_2} \) and \( R_{Y_4} \) forming the first cluster, variables \( \Delta S_{X_2} \) and \( \Delta S_{X_3} \) forming the second cluster and variables \( S_{X_4}, \Delta S_{X_5} \) and \( S_{X_6} \) forming the third cluster.
At a lesser horizontal distance, the oil market (global and Saudi) variables are closely related. Similarly, the global (CO\textsubscript{2} and temperature) variables are closely related, and \(\Delta S_{X_5}\) and \(S_{X_6}\) form another pair of variables. In addition, according to the horizontal scale, during Period 1, \(\Delta S_{X_2}\) and \(\Delta S_{X_3}\) are most closely related to each other, followed by the pairs \(\Delta S_{X_5}\) and \(S_{X_6}\) and \(R_{Y_1}\) and \(R_{Y_2}\) (Figure 8.6).

During Period 2, the behaviour of the variables changed markedly (Figure 8.6). As a result, the dendrogram can be ‘cut’ horizontally into three clusters of variables, \textit{i.e.} \(\Delta S_{X_5}\) and \(S_{X_6}\) forming the first cluster; the FF variable set, \(S_{X_4}\) and green energy index return forming the second cluster and the variables \(\Delta S_{X_2}\) and \(\Delta S_{X_3}\) forming the third cluster. At a lower horizontal distance, \(\Delta S_{X_3}\) and \(S_{X_6}\) form one pair of variables, \(R_{Y_1}\) and \(R_{Y_4}\) form another pair, \(R_{Y_2}\) and \(R_{X_1}\) form a third pair and global variables (CO\textsubscript{2} and temperature) form a fourth close pair. Based on the horizontal distance, \(R_{Y_1}\) and \(R_{Y_4}\) are most closely related, followed by the pair \(R_{Y_2}\) and \(R_{X_1}\), then by \(\Delta S_{X_5}\) and \(S_{X_6}\) and then by \(\Delta S_{X_2}\) and \(\Delta S_{X_3}\). Therefore, while global variables (CO\textsubscript{2} and temperature) were most closely related during Period 1, the extent of their similar behaviour lessened during Period 2 when two other pairs of variables became much more closely related (Figure 8.6).

For the overall Period 3, the dendrogram can be visually ‘cut’ at a horizontal distance of 0.5 to identify three clusters: \(\Delta S_{X_2}\), \(S_{X_4}\) and \(R_{Y_3}\) forming the first; \(\Delta S_{X_5}\), \(\Delta S_{X_5}\) and \(S_{X_6}\) forming the second and \(R_{Y_1}\), \(R_{Y_2}\), \(R_{Y_4}\) and green energy index return forming the third cluster (Figure 8.6). Based on the horizontal scale, the pair \(\Delta S_{X_5}\) and \(S_{X_6}\) was the most closely related during Period 3, followed by \(R_{Y_3}\) and \(\Delta S_{X_2}\) and \(R_{Y_2}\) and \(R_{X_1}\).
addition, according to the horizontal scale, during Period 3, global variables (CO₂ and temperature) were the most closely related, followed by the pair ΔSₓ₅ and Sₓ₆ and the (global and Saudi) oil market pair.

**Figure 8.6**: Cluster canonical correlation analysis.

### 8.4 Summary and conclusion

This chapter investigates the correlations between the use of FF and CC. CCA revealed a significant relationship between the variables in the Rᵧᵢ and (Rₓᵢ, Sₓᵢ) sets. Chapter 8 calculates three Cⱼ coefficients between the variable sets, and statistical tests confirm that only the first coefficient is sufficient for interpretation in the three observed periods. The highest coefficients obtained are 0.440, 0.899 and 0.815. Analogous to the R² statistics in the regression analysis, 19.3%, 80.8% and 66.4% are interpreted as explanatory powers in CCA. The selected CC variables can play a significant role in the business activities of the FF sector, and global CC can affect the price and volume of the FF variable set. Moreover, FF consumption fluctuates with changes in temperature and precipitation. Business and customer reactions to climate influence their use of energy, affecting energy demand in the short-, medium- and long-terms. Therefore, FF
firms are subject to a greater degree of CC risk and significant variances in earnings, making it necessary for investors to integrate CC information into a stock’s market assessment.

In this chapter, the result shows in general that the first root receives the strongest influence for the FF set from three markets ($R_{Y_1}$, $R_{Y_2}$ and $R_{Y_4}$), CC set from four variables ($R_{X_1}$, $\Delta S_{X_2}$, $\Delta S_{X_3}$ and $S_{X_6}$) and two variables across the FF and CC sets ($R_{X_1}$, $\Delta S_{X_2}$). This chapter’s empirical results support its aims and the prediction that FF variable information is value-relevant and that rational investors appropriately price CC information. The results also confirm the existence of a significant relationship between returns on investments and CC. This chapter estimates the weight between the FF and CC variable sets in the linear combination. However, CCA shows that the relationships are significant on short- and long-term bases and confirms the results discussed in Chapter 7.
Chapter 9

Conclusion and Recommendation
9.1 Introduction

In this chapter, the problems and related existent results are briefly explained and summarised, and the aims of this study are introduced, assisting the reader to capture a sense of the importance and goals of the study. The key findings of this study and their contribution to the literature are reported. These findings could be the foundation for future work, as recommended. This research evaluates empirically the relationships between real oil (global and Saudi), NG, and coal (both global) returns on the one hand and CC [green energy index, global CO$_2$ and temperature and precipitation (global and Saudi)] on the other hand. This empirical research is founded on the theoretical tenets delineated in the previous chapters. In addition, this research provides a basis for future studies by examining the influence of real FF prices, CC policies and renewable energy on the economies of FF-producing countries.

The greatest contemporary concerns are how FF prices relate to CC policies, CC extreme events, and the general shift in public opinion towards environmental issues witnessed particularly over the last decade. Due to its CO$_2$ intensive products and the nature and scope of its short- and long-term capital investments, the FF industry is exposed significantly to economic and physical risks developing from CC. Sub-national, national and international CC policy interventions, including those orchestrated through the UN, could affect finance, competition and growth, and effect the ability of companies to create shareholder wealth. Moreover, CC could affect significantly shareholders’ wealth and the market value of FF governments/companies due to adverse climate events which are attributed to anthropogenic CC. In a sense, these intertwining issues are encouraging as they indicate that the economic impacts of
CC are becoming internalised indirectly by markets to the extent that they could prevail as the most significant factors affecting investment decisions. Governments, companies, and investors should take action to militate against dangerous CC with the main objective of reducing GHG emissions from economic activities (their own and those of the users of their products).

The global concerns are supported by the influence of the CC on both the environment and the global economy, and recognised in the survey of the literature, the need for the present study. The relationship between the FF industry and CC, and consequent influence on the market return of the FF industry, has been this investigation’s key focus. Reaction of the FF prices to CC and green energy arising from this relationship has been the key drive of this research especially for KSA. The main study question, ‘To what extent are FF prices a function of CC policies and/or FF stock valuation processes, globally and in the KSA?’ was addressed by investigating empirically the value relevance of CC in the FF industry.

### 9.2 Main findings of this thesis

The FF industry produces harmful hydrocarbons which contribute to CC, resulting in serious consequences, not least from the perspective of increasing the severity of environmental hazards such as hurricanes, floods, droughts and desertification. But there is an important circularity, or endogeneity, here as well whereby, in turn, CC policies and public preferences for environmental goods and services affect the supply and demand of FF and thus incomes, shareholders’ wealth, market prices and macroeconomic stability.
First, this study finds that CC and green energy are value relevant for the KSA’s oil equity returns. CC policies cause changes in FF stock prices. Moreover, extreme climate events have particularly significant effects on stock equity returns. Furthermore, the stock prices of KSA equity returns are affected differently by CC policies, global oil production/pricing, and public environmental preferences. Second, this study also suggests that CC variable set are value relevant for the FF industry. The exponentially increasing concentrations of CO\textsubscript{2} in the atmosphere shows starkly that CC has been accelerating at an alarming rate since 1978. The dynamics of temperature, precipitation and extreme climate events are inextricable functions of atmospheric GHG concentrations.

Significantly, this study concludes that CC, including extreme CC-induced events, is value related for the KSA petroleum industry, and that investors incorporate these data in their stock valuation methodologies. CC policies and actions including the increasing proliferation of renewable energy sources are more important for investors in the KSA oil industry. Unusually high temperatures influence generally the local demand for gasoline and petroleum, and are important in defining demand for petroleum production and products. Likewise, this research finds that an increase in CO\textsubscript{2} emissions is associated with an increase in FF stock returns. Thus, an increase in production is associated with an increase in share prices.

In addition, after the adoption of the UNFCCC KP, CC and GHG emissions are value related and have become an important consideration for investors. Moreover, a low to moderate significant relationship between CO\textsubscript{2} emissions and temperature and FF companies’ stock returns between 1 January 1978 and 28 February 1997 shifted to a
highly insignificant relationship between 1 March 1997 and 30 June 2016. Finally, expanding further by the inclusion of behavioural and CC variables, confirms the value relevance of CC for FF companies’ returns: there is a low to moderate significant relationship between green energy index return and FF return on investments between 1 January 1978–28 February 1997; a low significant relationship for NG between 1 January 1978–28 February 1997 and 1 January 1978–30 June 2016; and a highly significant relationship between FF returns and CC between 1 January 1978–30 June 2016 (80.8%) and 1 January 1978–30 June 2016 (66.4%). This leads to the conclusions that FF production/prices have increased since 1978 and exacerbated CC; the world is not moving fast enough on green energy; and extant CC policy frameworks are insufficient in terms of their requirements (i.e. GHG mitigation) and enforcement mechanisms (e.g. pecuniary penalties in the event of defaulting on commitments). Furthermore, KSA domestic oil production has increased, and sales have increased significantly also.

In summary, this research concludes that:

1. Management structures and policies of KSA’s FF industry influence stock price dynamics, and FF affect public environmental preferences;

2. KSA should work to transform its vast oil wealth into a modern, sustainable economy fit 21st century and establishing green energy programs;

3. Policy responses have been led by global negotiation, but have been indecisive or qualified at the national level (KSA) and so far largely ineffective, despite strong global agreement on CC;

4. Green energy is mainly driven by CC policies (not by FF price) such as financial incentives for green energy investment;
5. A significant relationship exists between CC variable set and the market-value of the FF industry;

6. A significant relationship exists between global CC variables (CO₂, temperature and precipitation) and KSA CC variables (temperature and precipitation) and green energy index returns;

7. A highly significant relationship exists between FF share prices and CC after the adoption of the KP in 1997; and

8. A significant lodging association exists between FF and green energy return, global CO₂ and global/Saudi temperature after the adoption of the KP in 1997.

As this investigation predicted, in an active efficient market, comprised primarily of rational investors, the shares of FF governments/companies are priced appropriately and reflect the most updated weather, CC and green energy information. Moreover, the capital market is efficient and rational investors focused on maximising their risk adjusted returns on investments before the KP was adopted in 1997. Furthermore, and again since 1997, rational investors are concerned about the environmental impacts of their investments and about the effects of CC and GHG emissions. Based on the evidence from this study, it is concluded that 1) CC and green energy index return are value relevant and influence FF industry equity returns. 2) CC and green energy index returns following the adoption of the KP in 1997 are value related and an important consideration for investors in the FF industry. 3) Environmental variables, as a function of returns, provide further theoretical insights for optimally configuring financial models.
The research finds that the KSA government/investors are starting to become concerned about the overall effects of GHG emissions on CC and green energy, and they could view a clean energy future as preferable. In addition, the impacts of CC and green energy index return on FF production are changing through their impact on global supply and demand. Moreover, CC and peak oil production could become associated when further expansion of oil production becomes difficult (Dunlop, 2007). Therefore, oil demand could drop as a result of CC and green energy index return and its myriad impacts on the environment and the global economy.

The effect of world FF prices is a major influence on FF production and profitability. FF prices are no longer defined by simple supply and demand, but are influenced by geopolitics, diminishing oil reserves, derivatives and a global push towards regulating CO₂ emissions and green energy. Geologic constraints on production, combined with rising CC risks and new environmental regulations on the FF industry, are expected to have profound implications for the FF industry, and to apply pressure on the oil market amongst others.

Mitigating CC and increasing green energy are complex long-term objectives, but immediate, sustained and informed action is required in order to stabilise atmospheric GHG concentrations and curtail emissions. As global investors in the energy business, the KSA petroleum companies recognise that one of their key environmental responsibilities is to pursue strategies that are sensitive to CC and green energy (Saudi Arabia Vision 2030). While major FF companies are employing different strategies, they all share a self-imposed vigilance vis-à-vis their environmental and social responsibilities. At present, FF companies in KSA are beginning to address CC and
invest capital in new and renewable technologies. However, currently, investors continue to view FF companies as the most profitable investment domain. Governments, companies, and investors should take action with the principal objective of reducing CO$_2$ emissions from economic activities, and lessening the influence of avoidable CC.

9.3 Research contributions

This study is timely and contributes to the emerging field of environmental finance in a number of ways. This study advances academic knowledge by examining the extent to which the investment market incorporates CC and green energy information in stock valuation processes of the FF industry. Correspondingly, this study adds empirical evidence to academic knowledge of efficient capital markets and behavioural finance in terms of IRA, VDA, GCA and CCA of CC and green energy index returns on FF stock equity returns. The comparative analysis conducted herein suggests that investors are rational and that returns on investments in the oil (global and Saudi), NG, and coal (both global) sectors reflect CC information as configured and operationalised in this research.

Additionally, this study contributes by providing a long-term comparative examination of the KSA’s FF industry. This research compares the share prices of stocks in the global oil index (which includes multinational companies that operate worldwide and, hence, are affected by CC and green energy) with the share price of a KSA petroleum company, located and operating solely in the KSA over the last 84 years. This study observes a fluctuation in the share prices of the KSA oil industry and climate-related data over 38 years from 1978 to 2016. Moreover, the KSA oil industry is compared with
a global reference via benchmarking oil, NG, and coal metrics (oil: Brent, Fateh and WTI; NG: Europe, Japan (LNG), UK and US; coal: Australia, Colombia and South Africa).

In methodological terms this research has endeavoured to apply advanced time-series models, including volatility modelling. Importantly, the analyses and empirical results contribute to our understanding of how financial markets may be encouraged to channel more resources into environmental concerns. The results provide additional insights into the importance of environmental variables in finance models. The contributions to academic research could be summarised as follows:

1. Confirmed the direct influence of CC and green energy on stock equity returns for FF-producing countries’ stock indices through application of IRA, VDA, GCA and CCA. The research contributes empirical findings on the Granger causality of CC and green energy on stock returns and discusses this causality from neoclassical and behavioural finance perspectives.

2. Determined the impact of CC and green energy conditions on the market value of FF stock returns and the KSA oil industry’s returns by applying conditional variance family approaches. The results suggest that stock prices are affected differently by CC and green energy.

3. Determined the effects of CC and green energy on stock equity returns of the FF sector, by applying VAR approaches. The results suggest that investors are rational and integrate CC-related information into their stock valuations of the FF variable set.

4. Supported the value relevance of CC and green energy index return by using the CCA models. This research contributes empirical findings on the value
relevance of CC arising from a reciprocal relationship between CC and the FF industry. The results suggest that investors are rational and seek to maximise returns on their investments.

5. Examined the value relevance of CC by applying the ‘association’ approach and incorporating economic and financial variables.

6. Supported the value relevance of CC by including environmental variables in financial models.

7. Improved on extant understanding as to how CC and green energy affect share prices of the FF return (especially KSA) following the adoption of the KP in 1997, and how governments/companies respond to CC.

The main benefits of this research:

1. Revealing the relationship between global oil, NG and coal and KSA oil return price;

2. Revealing the relationship between global CC variables (CO2, temperature and precipitation) and KSA CC variables (temperature and precipitation) using finance modelling;

3. Explore structures and management in KSA and how CC and green energy index return could affect the country;

4. Contributes to the emerging field of environmental finance by modelling FF and CC;

5. Determines the current stage of investors’ integration of CC and environmental information;

6. Provides insights into how CC and green energy influence stock share prices and capital allocation;
7. Provides insights into the capital market’s capability to incentivise sound environmental management;

8. Improves our understanding of how the capital market could channel more resources into environmental concerns and could be encouraged to do so; and

9. Offers insights into the role of FF price of return in CC and green energy index return.

9.4 Future research

This study, together with the existing body of literature on environmental finance, contributes to critical debates and questions concerning the FF-CC nexus. The aim herein has been to better understand the salient dynamics, relationships and uncertainties with a view to informing and optimising future economic strategies. This research has opened paths for new study opportunities arising from the results presented. Future studies could be extended to:

1. Investigate whether a relationship exists between CC and share prices following the introduction of the KSA Emission Trading Scheme;

2. Investigate the financial market’s responses to specific events such as the establishment of the UNFCCC (1992), the European Emission Trading Scheme (2005), and the 15th session of the Conference of the Parties to the UNFCCC held in Copenhagen (2009). VAR modelling could capture the evolution of interdependencies between multiple variables;

3. Investigate whether a relationship exists between CC and share prices in India and China (the biggest importer of FF) following the adoption of the KP in 1997; and
4. Investigate the causal relationship between CC and the FF industry by using a variant of Granger causality which is robust to non-normality (Hacker and Hatemi-J, 2006).

The contemporary vision of a low carbon economy is likely to affect dramatically the way companies conduct their business. Moreover, risks and opportunities are bringing great uncertainty to FF governments/companies, prompting innovative responses in terms of management and operations which concomitantly give rise to many and varied possibilities for future academic research.
Appendix I
## Green energy index

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Company</th>
<th>Country</th>
<th>Sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABY</td>
<td>Abengoa Yield PLC</td>
<td>United Kingdom</td>
<td>Energy Utilities</td>
</tr>
<tr>
<td>ADM</td>
<td>Archer Daniels Midland Co.</td>
<td>United States</td>
<td>Energy and Agricultural</td>
</tr>
<tr>
<td>AEIS</td>
<td>Advanced Energy Industries, Inc.</td>
<td>United States</td>
<td>Energy Technology</td>
</tr>
<tr>
<td>AMRC</td>
<td>Ameresco, Inc.</td>
<td>United States</td>
<td>Energy Services</td>
</tr>
<tr>
<td>AMRS</td>
<td>Amyris, Inc.</td>
<td>United States</td>
<td>Renewable Energy and products</td>
</tr>
<tr>
<td>ASTI</td>
<td>Ascent Solar Technologies, Inc.</td>
<td>United States</td>
<td>Energy Services</td>
</tr>
<tr>
<td>AVX</td>
<td>AVX Corp.</td>
<td>United States</td>
<td>Energy Technology</td>
</tr>
<tr>
<td>AWNE</td>
<td>Americas Wind Energy Corp.</td>
<td>Canada</td>
<td>Energy Services</td>
</tr>
<tr>
<td>BEP</td>
<td>Brookfield Renewable Energy Partners LP</td>
<td>Canada</td>
<td>Energy Utilities</td>
</tr>
<tr>
<td>BLDP</td>
<td>Ballard Power Systems, Inc.</td>
<td>Canada</td>
<td>Energy Services</td>
</tr>
<tr>
<td>BSRC</td>
<td>BioSolar, Inc.</td>
<td>United States</td>
<td>Energy Services</td>
</tr>
<tr>
<td>BWEN</td>
<td>Broadwind Energy, Inc.</td>
<td>United States</td>
<td>Energy Services</td>
</tr>
<tr>
<td>CCC</td>
<td>Calgon Carbon Corp.</td>
<td>United States</td>
<td>Energy Services</td>
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Appendix II
Human Ethics Protocol 2017/006

Your Human Ethics Protocol 2017/006 has been Fully approved

rims@griffith.edu.au <rims@griffith.edu.au> 17 February 2017 at 10:25
To: a.tularam@griffith.edu.au
Cc: research-ethics@griffith.edu.au, k.madison@griffith.edu.au

GRIFFITH UNIVERSITY HUMAN RESEARCH ETHICS COMMITTEE

Dear Dr Gurudeo Tularam

I write in relation to your application for ethical clearance for your project "The Effects of "Greening of World" and Climate Change variables on Production and Pricing of Fossil Fuels: A Case Study of Kingdom of Saudi Arabia" (GU Ref No: 2017/006). The research ethics reviewers resolved to grant your application a clearance status of "Fully Approved".

This is to confirm receipt of the remaining required information, assurances or amendments to this protocol.

Consequently, I reconfirm my earlier advice that you are authorised to immediately commence this research on this basis.

The standard conditions of approval attached to our previous correspondence about this protocol continue to apply.

Regards

Kim Madison | Human Research Ethics

Office for Research
Griffith University  | Nathan  | QLD 4111  | Level 0, Bray Centre (N54)
T +61 7 373 58043 | email k.madison@griffith.edu.au
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