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A sustainable supply chain study of the Indian bioenergy sector

Vimal Eswarlal

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Thesis Summary

In India, more than one third of the population do not currently have access to modern energy services. Biomass to energy, known as bioenergy, has immense potential for addressing India's energy poverty. Small scale decentralised bioenergy systems require low investment compared to other renewable technologies and have environmental and social benefits over fossil fuels. Though they have historically been promoted in India through favourable policies, many studies argue that the sector's potential is underutilised due to sustainable supply chain barriers. Moreover, a significant research gap exists. This research addresses the gap by analysing the potential sustainable supply chain risks of decentralised small scale bioenergy projects. This was achieved through four research objectives, using various research methods along with multiple data collection techniques. Firstly, a conceptual framework was developed to identify and analyse these risks. The framework is founded on existing literature and gathered inputs from practitioners and experts. Following this, sustainability and supply chain issues within the sector were explored. Sustainability issues were collated into 27 objectives, and supply chain issues were categorised according to related processes. Finally, the framework was validated against an actual bioenergy development in Jodhpur, India. Applying the framework to the action research project had some significant impacts upon the project's design. These include the development of water conservation arrangements, the insertion of auxiliary arrangements, measures to increase upstream supply chain resilience, and the development of a first aid action plan. More widely, the developed framework and identified issues will help practitioners to take necessary precautionary measures and address them quickly and cost effectively. The framework contributes to the bioenergy decision support system literature and the sustainable supply chain management field by incorporating risk analysis and introducing the concept of global and organisational sustainability in supply chains. The sustainability issues identified contribute to existing knowledge through the exploration of a small scale and developing country context. The analysis gives new insights into potential risks affecting the whole bioenergy supply chain.

Keywords: Biomass, Decision Support System, Framework, Sustainability Issues, Supply Chain Issues

Dedication

I dedicate this work to my dear family and friends.

Acknowledgment

It would not have been possible to write this doctoral thesis without the help and support of the kind people around me, to only some of whom it is possible to give particular mention here.

First and foremost I would like to thank my parents and whole family for their love, support and encouragement throughout, for which my mere expression of thanks does not suffice.

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List of Abbreviations

Abbreviation	Meaning
AHP	Analytic Hierarchy Process
ARC	Action Research Case Study
BET	Bioenergy Technologies
CC	Conversion Constant
CF	Expert Contribution Factor
CHP	Combined Heat and Power plant
CI	Consistency Index
CII	Confederation of Indian Industries
CR	Consistency Ratio
CSCMP	Council of Supply Chain Management Professionals
CSR	Corporate Social Responsibility
DTI	Department of Trade and Investment, UK.
DSI	Down Stream Industry
DSS	Decision Support Systems
EC	European Commission
EG	Expert Group
ELECTRE	Elimination and Choice Expressing Reality
EPSRC	Engineering and Physical Sciences Research Council
Et	Expert
FAHP	Fuzzy Analytic Hierarchy Process
FAO	Food and Agriculture Organisation of the United Nations
FG	Focus Groups
FICCI	Federation of Indian Chambers of Commerce and Industry
GBEP	Global Bioenergy Partnership
GDP	Gross Domestic Product
GHG	Green House Gas
GW	Giga Watt
G20	Group of Twenty Finance Ministers and Central Bank Governors (major economies)
IEA	International Energy Agency
IN	Interviews
INF OBJ	Influence on the Objective
INR	Indian Rupees
IRM	Institute of Risk Management
KW	Kilo Watt

MAUT	Multi-Attribute Utility Theory
MCDA	Multiple Criteria Decision Analysis
MCDM	Multiple Criteria Decision Making
MNRE	Ministry of New and Renewable Energy, Government of India
MHA	Million Hectare
MT	Million Tonne
MTOE	Million Tonnes of Oil Equivalent
MW	Mega Watt
NGO	Nongovernmental Organisations
OBJ IMP	Objective’s Impact
OECD	Organisation for Economic Co-operation and Development
OI	Objective Index
PISCES	Policy Innovation Systems for Clean Energy Security
PCS	Primary Case Study
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluations
QSR	Qualitative Survey Research
REN21	Renewable Energy Policy Network for the 21st Century
RL	Risk Likelihood
RM	Risk Magnitude
RO	Research Objective
RS	Risk Severity
SCM	Supply Chain Management
SCR	Organizational Sustainability Risks
SCRM	Supply Chain Risk Management
SCS	Secondary Case Study
SME	Small and Medium Enterprises
SRM	Sustainability Risk Management
SSBS	Small Scale Bioenergy Systems
SSCM	Sustainable Supply Chain Management
SSCRA	Sustainable Supply Chain Risk Analysis
SSCRM	Sustainable Supply Chain Risk Management
STFN	Standardized Trapezoidal Fuzzy Number
SUSR	Global Sustainability Risks
TERI	The Energy and Resources Institute
UK	United Kingdom
UN	United Nations
UNDP	United Nations Development Programme
UNIDO	United Nations Industrial Development Organisation

VESP	Village Energy Security Program
WBSC	Waste Biomass Supply Chains
WHO	World Health Organization

List of Definitions

Term	Definition
Bioenergy	"All energy derived from biofuels" (FAO, 2004).
Biofuels	"Fuel[s] produced directly or indirectly from biomass" (FAO, 2004).
Biomass	"Material of biological origin excluding material embedded in geological formations and transformed to fossil" (FAO, 2004).
Corporate Sustainability	"Corporate sustainability is a multi-faceted concept that recognizes the importance of corporate growth and profitability on one hand, and also requires the corporation to pursue societal goals on the other hand, specifically those relating to sustainable development" (Cheung, 2011, p. 162).
Global Sustainability	A sustainable development process that can improve the globe / world (system) in a sustainable manner.
Global Sustainability Issues	These issues are the positive or negative impact on global sustainability expected as a result of the system.
Objectives	Objectives are "basic rules of sustainable development, typically formulated as a commandment" and allow for the assessment of sustainability (Madlener et al., 2006, p. 247). Organisational sustainability objectives are linked to the business's mission and vision. The global sustainability objectives will depend on the kind and level of social responsibility embraced by the business.
Organisational Sustainability	The sustainable development of the business.
Organisational Sustainability Issues	These issues are the positive or negative impact on organisational sustainability expected as a result of the system. In this thesis these issues are considered across the supply chain (also termed as Supply Chain Issues).
Risk	"Any event which may prevent or impair the achievement of objectives" (Cowan, 2006, p.3).
Small Scale Bioenergy Systems (In India)	The bioenergy systems up to 2 MW (electric power or equivalent).
Supply Chain	"All the activities involved in delivering a product [or service] from raw material through to the customer" (Lummus & Vokurka, 1999, p. 12).
Supply Chain Management	"Supply chain management is defined as the systemic,

	strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole" (Mentzer et al., 2001, p. 18).
Supply chain risk	Any risks for the information, material and product flows from original supplier to the delivery of the final product for the end user (Jüttner et al., 2003, p. 7).
Sustainable Development	Sustainable development means change and it is not a state like sustainability instead it is a process of change that can improve the system in a sustainable manner.
Sustainability	"Sustainability is a property of a system open to interactions with its external world. It is not a fixed state of constancy, but a dynamic preservation of the essential identity of the system amidst permanent change. A small number of generic attributes may provide the foundations of sustainability" (Gallopín, 2003, p. 35).
Sustainable Supply Chain Management	"The management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements" (Seuring & Müller, 2008, p. 1700).
Sustainable Supply Chain Risks	It include any risks for the organisational sustainability (organisations own development) and global sustainability (sustainable development of the society) across the supply chain.
Sustainable Supply Chain Risk Management	It aims to identify and manage the potential sources of risk for the organisational and global sustainability across the supply chain.
Traditional Biomass	"Wood fuels, agricultural by-products and dung burned for cooking and heating purposes. In developing countries, traditional biomass is still widely harvested and used in an unsustainable and unsafe way. It is mostly traded informally and non-commercially" (FAO, 2004).

Chapter One: Introduction

1.1 Research Background

As energy is a fundamental driver for sustainable development (IEA & OECD, 2009), interest in issues related to energy access and availability are on the rise. However, despite this increasing focus large parts of the developing world lack proper electricity access. In India, where this study is carried out, more than one third of its population does not have access to electricity (IEA & OECD, 2009). Moreover there is a significant gap between demand and supply of energy in developing countries. This is revealed by the constant energy shortages during both normal and peak loads in many countries (Banerjee, 2006; Mathy & Guivarch, 2010). Furthermore as economic growth is coupled with energy demand (Solow, 1956), there is an increasing energy demand in developing countries, such as India on their path to economic development. This issue can be clearly seen when India's per capita energy consumption is compared against China, the United Kingdom and the United States of America who are 3, 5 and 12 times greater respectively (World Bank, 2012). From the above arguments it can be concluded that there is a huge energy supply deficit in India which needs to be addressed immediately in order to cater the enormous energy poverty and growing energy requirements.

Renewable energy is more suitable to address the energy demand of India, in light of fossil fuel price volatility in the international market and its dependence on imported fossil fuel (Arora et al., 2010; Buragohain et al., 2010). Renewable energy technologies such as bioenergy (energy from biomass) have enormous potential to cater to energy demand in India due to biomass availability (Arora et al., 2010; MNRE, 2012b). It can also contribute towards climate change mitigation and sustainable development (Openshaw, 2009). On top of that, investment required for bioenergy is low when compared to other renewable energy technologies such as solar energy (Ravindranath & Balachandra, 2009).

The existing, centralised large scale energy production systems in India have challenges such as huge transmission losses (Mathy & Guivarch, 2010), rural electrification complications (Ravindranath & Balachandra, 2009), external debt and environmental degradation (Kumar et al., 2009). Due to this, small scale decentralised energy systems are preferred as they can minimise distribution losses, appropriate for rural electrification and improve system reliability (Hiremath et al., 2009; Mathy & Guivarch, 2010).

Due to the above mentioned reasons, small scale bioenergy systems are preferred as a practical solution to cater to the energy needs in India. Furthermore they can be more efficient (Hiremath et al., 2009), reliable (Hiremath et al., 2010a), cost effective (Hiremath et al., 2010a; Hiremath et al., 2009; Mathy & Guivarch, 2010; South Centre, 2008) and reduce long distance transportation of biomass (South Centre, 2008). Moreover, they can bring multiple environmental benefits such as emission reduction (Hiremath et al., 2010a; South

Centre, 2008) and socio-economic benefits such as job creation (Hiremath et al., 2010a; Hiremath et al., 2009; Kumar et al., 2009; South Centre, 2008) in the local region. Due to this small scale bioenergy systems are preferred and promoted in India through government policies and supporting mechanisms (Jain et al., 2011; Shweta, 2012).

1.1.1 Science Bridge Project:

This thesis has been funded by the UK's Engineering and Physical Science Research Council (EPSRC) within the ambit of a 'Science Bridge' project. The Science Bridge project aim was to "implement, in the UK and India, efficient decentralised bio-energy systems and to carry out research needed to assist widespread adoption of these systems" (Science Bridge Project, 2010). The project had five work packages, where first 4 work packages studied the bioenergy sector from technological perspective and work package 5 investigated it from management perspective. The Science Bridge project objectives (especially that of work package 5) and collaboration with this research project, helped to inform the research aims and objectives. However, author of this thesis asserts his moral right and ownership of this work and condition of the funding and collaboration with the science bridge project do not have any conflict with this intellectual property right claim.

1.2 Problem Statement

In spite of the Government incentives and support (Camerata & Bansal, 2011; Ravindranath & Rao, 2011) and potential of bioenergy (Arora et al., 2010; Buragohain et al., 2010; MNRE, 2012b), the actual implementation of small scale bioenergy projects falls short of expectations in India (Camerata & Bansal, 2011; CII, 2012; Ravindranath & Rao, 2011). Furthermore, the existing small scale bioenergy systems also perform poorly (Central Electricity Authority, 2012a), impacting the profitability of these systems (Ravindranath & Rao, 2011; Shukla, 2000). These shortfalls can be attributed to the barriers affecting small scale bioenergy projects (Ravindranath & Rao, 2011; Shukla, 2000; TERI, 2010), while sustainability and supply chain are identified as the two prime areas of concern for the bioenergy sector (OECD & IEA, 2012).

If properly managed, bioenergy supply chains can contribute to sustainable development (Cushion et al., 2010; Elghali et al., 2007; Escobar et al., 2009; IEA, 2007a). However, the inefficient management of bioenergy supply chains can lead to severe negative impacts and deteriorate the situation further (OECD & IEA, 2012; Rossi, 2012; TERI, 2010; UNIDO, 2009). These negative impacts can in turn lead into regulatory risks and poor public perception affecting the organisational sustainability of bioenergy industry (Harrison et al., 2011; Rösch & Kaltschmitt, 1999). Therefore, sustainability issues are recognised as a significant challenge for the bioenergy industry that need to be accounted for (IEA Bioenergy, 2011; UNIDO, 2009). A difficulty with sustainability issues is that they are context dependent

(Cushion et al., 2010). However, the sustainability impacts identified are incomplete and mostly relate to the biodiesel sector. These are some of the major drawbacks among various other shortcomings of the studies that have currently looked at the Indian bioenergy sector from a sustainability perspective (Gonsalves, 2006; Harrison et al., 2009; Harrison et al., 2011; Kumar et al., 2012; Ravindranath et al., 2004; Somashekhar et al., 2000; Tiwari et al., 2009).

Bioenergy supply chains are complex (Elghali et al., 2007) and are recognised as a 'tough challenge' (Kundra, 2010). This increases the importance of correctly managing the supply chain for the organisational sustainability of the bioenergy industry (George & Nicholas, 2012; Ikonen, 2012; Kundra, 2010; OECD & IEA, 2012; Sobhanbabu et al., 2010; World Bank, 2011). In order to effectively manage the supply chain, issues throughout the entire supply chain need to be addressed (CII, 2012; Elghali et al., 2007). Studies such as Palit et al. (2013), Ravindranath and Rao (2011), Ravindranath and Balachandra (2009), Ravindranath et al. (2004), Jagadish (2003); Rao and Ravindranath (2002) and Somashekhar et al. (2000) have analysed the Indian bioenergy sector barriers from technical, policy or an economic perspective. However, none of the studies assess the bioenergy sector in India from a supply chain perspective. There is also a lack of research in the bioenergy supply chain more generally (Iakovou et al., 2010) and more specifically, any investigation into the complete supply chain risks of the small scale bioenergy sector in India.

In addition to the above mentioned problems, it is also recognised that in order to achieve a sustainable bioenergy supply chain, considering the supply chain and sustainability issues in decision making is a necessity (IEA Bioenergy Task 43, 2012; MAKE-IT-BE, 2011; OECD & IEA, 2012). However, identifying, analysing and mitigating the sustainable supply chain risks of the bioenergy sector is a challenging task (IEA Bioenergy Task 43, 2012; Smith, 2012). The systems or frameworks supporting practitioners in taking such decisions in the bioenergy sector is scarce (Awudu & Zhang, 2012; Baños et al., 2011; Gold & Seuring, 2011; Iakovou et al., 2010; Scott et al., 2012; Shabani et al., 2013). Also, in the sustainable supply chain management field, there is a lack of frameworks to systematically analyse and manage the risks (Ashby et al., 2012; Carter & Easton, 2011; Carter & Rogers, 2008; Seuring, 2012).

1.3 Research Aims and Objectives

This research aims to identify and analyse sustainable supply chain risks of the small scale bioenergy sector within Indian context. The intention to increase adoption of small scale bioenergy systems, by supporting practitioners in addressing the main challenges recognised in the problem statement (Section 1.2) is the motivation behind this research. Therefore, this research focuses on the sustainable supply chain of small scale bioenergy schemes from a risk management perspective. The four specific research objectives, to ensure the aim is achieved, are:

- Research Objective 1 (RO1): To develop a sustainable supply chain risk analysis framework;
- Research Objective 2 (RO2): To identify sustainability issues of the small scale bioenergy projects in India;
- Research Objective 3 (RO3): To identify supply chain issues of the small scale bioenergy projects in India;
- Research Objective 4 (RO4): To apply and evaluate the sustainable supply chain risk analysis framework.

1.4 Thesis Structure

The literature related to the individual research objectives is diverse. Therefore, in this thesis the literature review component is split into different chapters that correspond to research objectives. This ensures the logical flow of information. The thesis structure is shown in Figure 1.1 and discussed below.

Chapter 2 provides detailed description of the research context, synopsis of bioenergy technology and scope of this study. **Chapter 3** discusses the research problem in detail and develops aims and objectives of this research by exploring concerns of the practitioners and challenges of the sector. **Chapter 4** discusses the logical reasoning behind the research and provides details and justification of research methodologies and methods used in this study.

Chapter 5 addresses the first research objective (RO1). It presents the research gap and provides a guide to develop the framework. It then introduces and discusses the conceptual framework. **Chapter 6** responds to the objective, to identify sustainability issues of the small scale bioenergy in India (RO2). Initially it presents the literature review, followed by the findings and discussion of the findings. **Chapter 7** provides a detailed investigation of the supply chain issues of the small scale bioenergy sector in India (RO3). It starts with the literature review and then presents findings and discussion section. The framework is applied and evaluated (RO4) in **Chapter 8**, with regard to an upcoming bioenergy plant in India. It presents and justifies the mathematical model adopted, then provides details of framework application, validation of results, and evaluation of the framework. **Chapter 9** presents the overall research conclusions with a summary of contributions.

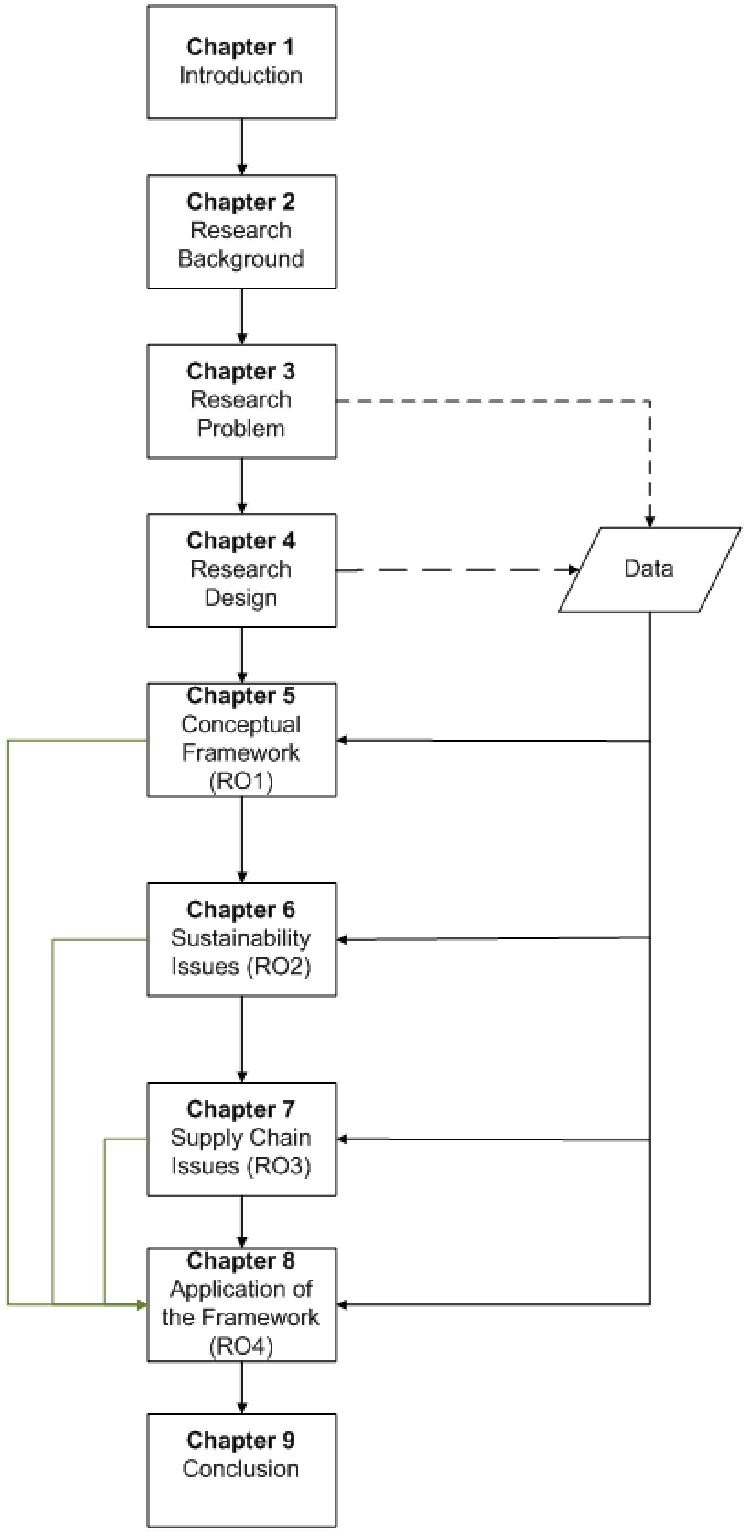

Figure 1.1: Thesis Structure

Chapter Two: Study Context

2.1 Introduction

This chapter provides background information relating to the socio-economic context of the study, significance of the topic and scope of this research. This chapter starts with a short description of general facts about India. It is then followed with the significance of energy sector and small scale bioenergy systems (SSBS) in India, an overview of bioenergy systems and the scope of this project.

2.2 Country Profile - India

As this study is mainly carried out in India, this section provides information relating to the geography, demography and economy of India. In addition to this, details about the energy scenario in India have been discussed in section 2.4.

India, the world's largest democracy is a country in South Asia. It consists of 28 states and 7 union territories. It is 7th largest country in the world, with an area of 32,87,263 square kilometre (National Portal of India, 2012). India is the second most populous country with a population of 1.24 billion in 2011 (World Bank, 2012), of this 30% of the people are in the age group of 0 to 14as shown in the Figure 2.1 (Data from: World Bank, 2012), in 2011.

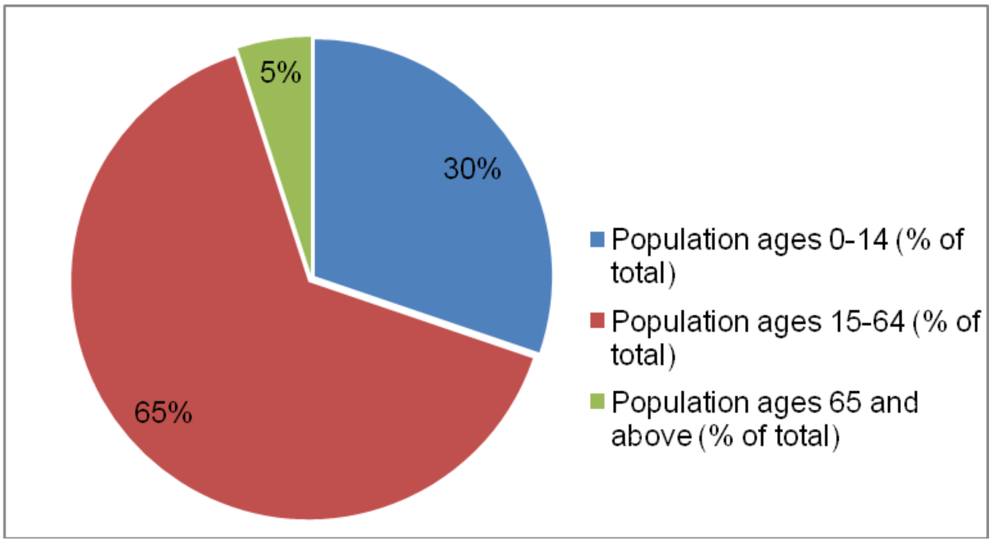

Figure 2.1: Population Age Group

Indian economy has been on the rise with a minimum 4% growth rate of gross domestic product (GDP) in last decade as shown in Figure 2.2 (Data from: World Bank, 2012). While on the one hand, the total nominal GDP of India in 2011 was calculated at $1.848 trillion by the World Bank (2012), making it one of the major economic players in the globe, on the other hand, 69 percentage of the population in 2010, were living on less than

$2.00 a day (World Bank, 2012), making poverty and inequality important issues for the nation.

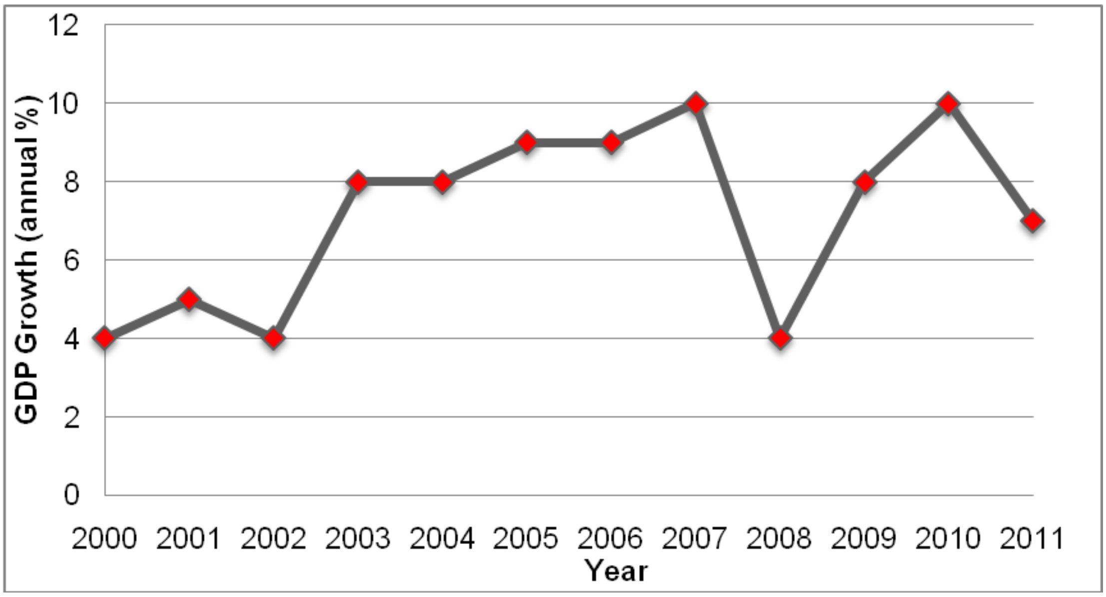

Figure 2.2: Annual Percentage of GDP Growth of India

While the young population and rising economy provides a great opportunity for India, poverty is an enormous challenge. Energy is an important stimulant to utilise the opportunities for growth, to alleviate poverty and to attain an inclusive growth, which is discussed in the section below.

2.3 Energy for Development

Energy is an indispensable part of the current society, facilitating better life style through modern technology. United Nations (UN) report states that1.3 billion people globally still lack access to electricity and "without access to sustainable energy, there can be no sustainable development" (UN, 2012). In order to emphasize and promote importance of the sustainable energy, the UN has announced 2012 as the 'International Year of Sustainable Energy for All'.

Lack of energy supply is a major barrier for growth of both developing and developed countries because "lack of electricity exacerbates poverty and contributes to its perpetuation, as it precludes most industrial activities and the jobs they create" (IEA, 2002, p.365). According to Kanagawa and Nakata (2007), fundamental socio-economic aspects of development, such as education, health, environment and income have a strong bonding with energy. Hence, they state that energy is an influential mechanism for poverty reduction.

The European Commission states that "energy is at the heart of everybody's quality of life" (EC, 2010), because dependence on low quality and inefficient energy supply leads to low quality of life for large proportions of rural population and urban poor (Kumar et al., 2009). In summary, in order to achieve development and to address the problem of poverty, access to sustainable energy is fundamental (Central Electricity Authority, 2012b; Srivastava & Rehman, 2006).

2.4 Energy Scenario

Energy being one of the essential components for growth, its global consumption has increased from 8816MTOE (Million Tonnes of Oil Equivalent) in 1990 to 13078 MTOE in 2011 (Enerdata, 2012). The major contributors for the increase in the consumption from 2000 to 2011 have been Middle East, Asia, Africa and Latin American regions with 5.5%, 5.1%, 2.9% and 2.5% raise per year in that period respectively (Enerdata, 2012). This clearly shows the energy demand increase across the globe and its prospects of expansion for the future.

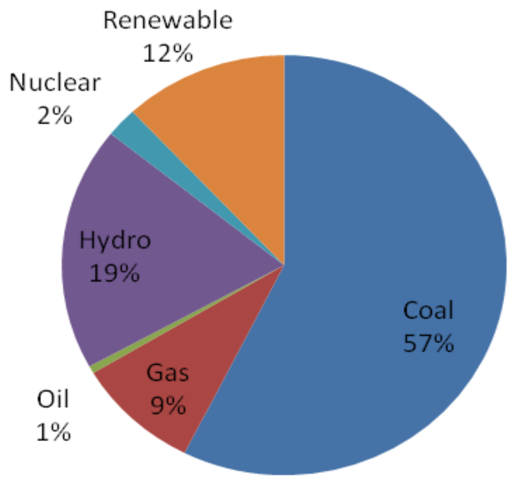

Figure 2.3: India's energy blend - 2012

India being one of the developing nations, its consumption has increased by 6.2% from 2010 to 2011 (Enerdata, 2012). The total installed capacity as of 31/10/2012 is 209.27GW (Ministry of Power - Government of India, 2012) and its electricity production mix based on the installed capacity as of 31/10/2012 is as shown in the Figure 2.3 (Data from: Ministry of Power - Government of India, 2012). India plans to add another 80GW and 79.2GW to its generation capacity during its 12th (2012-2017) and 13th (2017-2022) planning periods to address its growing demand (Central Electricity Authority, 2012b).

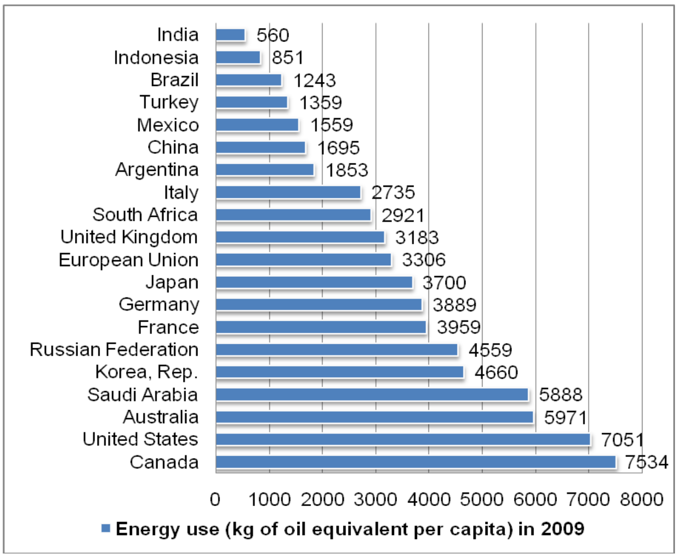

Figure 2.4: Energy usage by G20 Major Economies

In spite of India's plans to increase its electricity generation capacity, the energy consumption per capita of the country is still the lowest amongst G20 major economies as shown in the Figure 2.4 (Data from: World Bank, 2012). In India, during the accounting year 2009-10, the official electricity requirement shortage in normal and peak loads were 10% and 13% respectively (Central Electricity Authority, 2012c). During 2008,28% of people without access to electricity across developing regions of the world where living in India (Legros et al., 2009). As of 2008, the 35.5% of the population in India did not had access to electricity, with a huge variation between rural and urban areas as shown in Figure 2.5 (Data from: IEA & OECD, 2009).

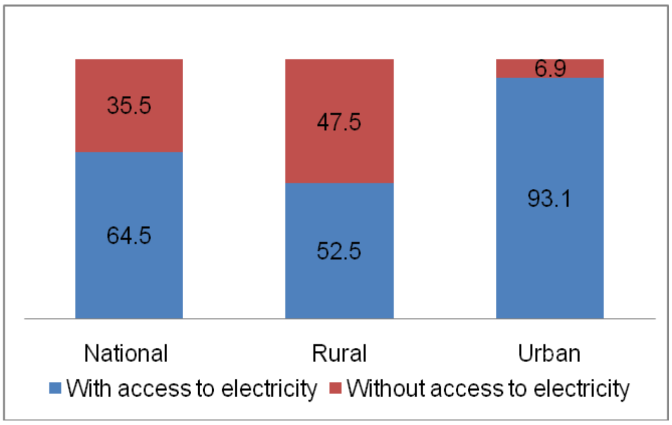

Figure 2.5: Access to electricity in India - 2008

Based on the above discussion, it is evident that there is a massive demand to increase the energy production in India, in order for the objective to achieve socio-economic development and provide electricity access to all the people can be fulfilled.

2.5 Role of Renewable Energy

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Figure 2.6: Global Final Energy Consumption - 2010

(Source: REN21, 2012)

In 2010, the share of renewable energy in global final energy consumption has been estimated at16.7%, where modern renewable technologies contributing for 8.2% as shown in Figure 2.6 (Source: REN21, 2012). There is an increasing promotion for the renewable energy sector across the globe (REN21, 2012). India is also on its way to increase its renewable energy share in its energy mix. Some of the important reasons for India to accelerate utilization of renewable energy resources are as follows.

Natural resource availability: India has rich, untapped renewable energy sources that have enormous potential for solar, wind, biomass and hydro power (Arora et al., 2010).

Energy security: During 2010-11, the total primary energy supply was 679.7Mtoe in which more than 35% (241.7Mtoe) of it was imported (Central Statistics Office, 2012), making it heavily dependent on other countries for its domestic needs. This trend seems to continue in the near future as well, as the expected shortfall (which will be imported) during 2016-17 of coal alone is 238MT, 28.2% of the overall requirement 842MT (Central Electricity Authority, 2012b). Hence, renewable energy can be a solution to address the problem of domestic fuel shortage and high dependency on imported fuel by developing domestic resources for energy security (Arora et al., 2010; Buragohain et al., 2010).

Price volatility: There has been a continuous increase and fluctuation in the fossil fuel prices. The prices have been projected to grow further (Arora et al., 2010; Buragohain et al., 2010). For example, it is estimated that crude oil prices will be 46 % more in 2030 from 2010 (Arora et al., 2010). Increased deployment of renewable energy technologies can be an option to minimise the effect of price volatility.

Climate change concern: India's per head Carbon dioxide emissions are only one-fourth of the global average level. However it emits roughly 4% of the worldwide emissions (Arora et al., 2010) and it has been on a continuous rise in the last two decades as show in Figure 2.7 (Data from: Enerdata, 2012). India is committed to reduce its increasing emission intensity. Renewable energy can play a significant role in supporting India's realization of its emission reduction plans (Arora et al., 2010; Buragohain et al., 2010).

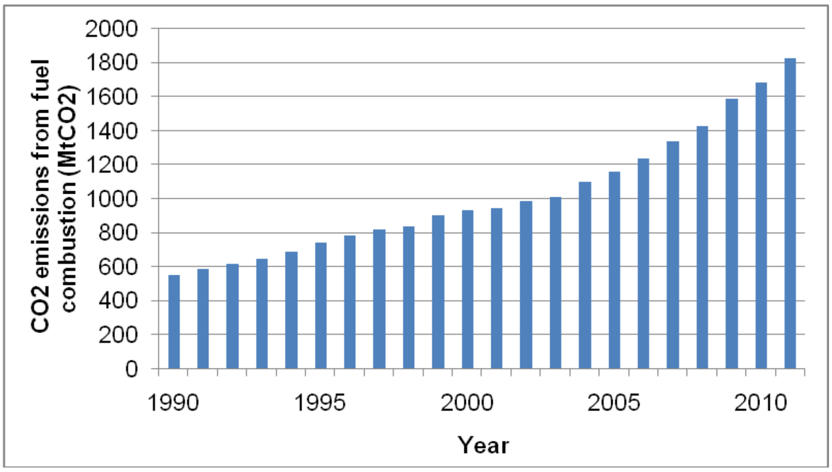

Figure 2.7: CO² Emissions from Fuel Combustion in India

Renewable energy has great potential in India because of the increasing energy demand, natural resource availability, concerns about climate change, increasing price of fossil fuels and high dependence on imported energy. Wind, solar, bioenergy and hydropower are the major renewable energy sources used in India, already as of 31/10/2012 renewable has over 24.9 GW of installed capacity of electricity generation, which is approximately 12% of total installed capacity in India as shown in Figure 2.3 (Ministry of Power - Government of India, 2012). Moreover, India plans to add another 18.5GW and 30.5GW to its renewable energy generation capacity during its 12th (2012-2017) and 13th (2017-2022) planning periods respectively (Central Electricity Authority, 2012b). This shows huge prospects for renewable energy in India.

2.6 Contribution of Bioenergy

Bioenergy is one of the oldest and very reliable renewable energy options. Bioenergy is the main source of fuel for most of rural people in developing countries, where the traditional use of biomass accounted for 8.5% of global energy consumption in 2010 as shown in Figure 2.6 (Source: REN21, 2012). Traditional and modern use of biomass together contributed for more than 10% of global energy consumption in 2010 making it the fourth major energy resource (REN21, 2012).

Table 2.1: Bioenergy Generation Capacity in India - 30/09/2012

Renewable Energy System	***Cumulative Capacity (MW / MW_{eq})***
Grid Connected	
Biomass Power	1226.60
Bagasse Cogeneration	2132.73
Waste to Power - Urban	93.68
Off-Grid/ Captive Power	
Waste to Energy - Urban	108.94
Biomass(non-bagasse) Cogeneration	412.61
Biomass Gasifiers - Rural	16.25
Biomass Gasifiers - Industrial	138.05
Total	**4128.86**

In India, it has been estimated that during 2007, 58% and 11% of population relied on wood and dung as cooking fuel respectively (IEA & OECD, 2009). The website of ministry of new and renewable energy, India (MNRE) states that as of 30/09/2012 there are 4.54 million family bio-gas plants in India and total installed capacity of bioenergy plants to produce electricity or combined heat and power is 4128.86 MW, further details of this is provided in Table 2.1 (Data from: MNRE, 2012a). However, this statistics does not include the vast number of biomass based heat plants mostly utilised in small scale industrial process heating applications. Huge biomass based power generation potential is estimated for India, under various scenarios such as 17000 MW from surplus agro residues, additional 5000 MW from switching over to modern techniques of cogeneration (MNRE, 2012b).Another scenario estimates a total potential of 45000 MW by using surplus agro residues and utilising marginal and degraded lands (Buragohain et al., 2010). This indicates that in spite of the major role of bioenergy in India, it is still underutilised and there is vast potential for the bioenergy sector to grow further.

Bioenergy has been given great importance in recent years, because of the following important motivations. Bioenergy can be a vital approach to make most out of forest, crop and livestock residues and to support domestic and industrial waste management (Wright, 2006). Bioenergy can provide higher quantity as well as quality of energy services in different forms such as gas, oil, heat and electricity for a greater number of people (Ravindranath & Balachandra, 2009). It offers an opportunity to optimize power grid by providing variable load services under real life conditions such as oscillating demand in contrast to current solar and wind energy technologies (Gold & Seuring, 2011). It is environmentally friendly (Ravindranath & Balachandra, 2009) and distributed almost evenly in most parts of the country (Buragohain et al., 2010). It can be a means to support sustainable growth and poverty alleviation by creating local job opportunities (Openshaw, 2009; Voivontas et al., 2001). Bioenergy can help to achieve higher climate change benefits with less overall economic cost (Ravindranath & Balachandra, 2009). It can address India's energy security concerns while upholding ecologically sustainable development (Shweta, 2012). Keeping these motivations in mind, Indian government (MNRE) is in the process of initiating "National Bioenergy Mission", which will further support the uptake of the Bioenergy in India (Shweta, 2012).

2.7 Demand for Small Scale Bioenergy

In India, the bioenergy systems up to 2 MW (electric power or equivalent), 2-10 MW, and above 10 MW are categorised as small, medium and large scale plants respectively (Jain et al., 2011). Small scale bioenergy systems can be further classified as shown in Table 2.2, in order to recognise different spectrums within small scale category. Small scale decentralised systems can be differentiated from large scale centralized systems, by generation of power nearer to demand centres. While it can operate as a stand-alone isolated system or with a connection to grid to compensate supply and demand variations (Kaundinya et al., 2009).

Table 2.2: Small Scale Bioenergy Systems Classification

Classification	***Size (electric or equivalent)***
Pico	Less than 1 KW
Nano	From 1KW to less than 10KW
Micro	From 10KW to less than 100KW
Mini	From 100KW to less than 1MW
Intermediate	From 1 MW to less than 2 MW

Small scale decentralized systems were the earliest electric power systems intended to cater to the requirements of local population but developments of large centralized systems are driven by view of economies of scale and technology developments (Mathy & Guivarch, 2010). However, there has been a renewed interest in small scale energy systems due to various reasons discussed below.

The quality and quantity of energy dictates how societies will evolve (Rajvanshi, 1993). The rural electrification through centralized grid systems is still a great challenge. Even in villages that are already electrified, power cuts and load shedding are very common (Ravindranath & Balachandra, 2009).This is revealed by constant shortages in energy on normal and peak demand, in India (Banerjee, 2006; Mathy & Guivarch, 2010). The centralized grid systems capacity addition has not been able to keep in pace with the ever-increasing need for electricity in most developing countries. The huge transmission and distribution losses from grid in India (during 2001, losses were as high as 35% of total power production)makes centralised power systems further unattractive (Mathy & Guivarch, 2010). In addition to that centralised systems can also lead to huge external debt and environmental degradation (Kumar et al., 2009).SSBS can be one of the solutions. Because it has the “advantage of improving tail-end voltages, reducing distribution losses and improving system reliability” (Mathy & Guivarch, 2010, p.102). Furthermore it has other benefits such as “substantially lower capital outlay, lower risks, shorter gestation periods and proximity to load centers” (Hiremath et al., 2009, p.4).

SSBS can offer a viable solution for meeting electricity needs of the local population. Studies have shown that decentralized biomass power generation systems can contribute to a considerable share of electricity needs in rural areas of developing world (Hiremath et al., 2010b; Hiremath et al., 2009; Mathy & Guivarch, 2010). SSBS when compared to centralised large scale bioenergy systems can reduce biomass transportation to long distances, which will incur high financial costs and diminish total energy gain. In addition to this, it decreases pressure on the demographic resources such as natural forests (South Centre, 2008).

The economies of scale argument, put forward against small scale bioenergy plant are also not true always. On the contrary studies show that it can be an efficient (Hiremath et al., 2009), reliable (Hiremath et al., 2010a) and cost effective (Hiremath et al., 2010a; Hiremath et al., 2009; Mathy & Guivarch, 2010; South Centre, 2008) system. For example, the unit cost of energy (INR / KWh) of biomass gasifier and grid electricity (mostly coal based) is 4.17 and 3.25 respectively and life cycle cost (INR / KW) of the same systems are 141950 and 174310 respectively (Ravindranath & Balachandra, 2009). Even if the cost of unit electricity is slightly higher for biomass based gasifier systems compared to grid in Indian context it has still created local livelihood opportunities and it is an environment friendly system(Ravindranath & Balachandra, 2009). Furthermore it can consistently supply energy for agriculture, industry, commercial and household sector in both rural and urban areas (Hiremath et al., 2009), which gives it a unique advantage.

Figure 2.8: Annual Deaths Worldwide by Cause

(Source: IEA & OECD, 2006)

IEA based on the World Health Organisation (WHO) figures estimated that each year 1.3 million premature deaths occur worldwide (southeast Asia including India is the region with the highest casualty)because of indoor air pollution by using biomass, as shown in Figure 2.8 (Source: IEA & OECD, 2006) .It is responsible for more deaths than Malaria and nearly half as many as caused due to AIDS /HIV (IEA & OECD, 2006). Adoption of SSBS with proper technology can reduce (through creating a higher monetary value for biomass resources and by providing alternative energy availability) the exposure to indoor pollution and toxic by-products of combustion due to traditional biomass use in households, which particularly affects the health of women and children (South Centre, 2008).

Figure 2.9: Small Scale Bioenergy Systems Impact on the Livelihoods

(Source: Practical Action Consulting, 2009)

SSBS can replace fossil fuel and other non-renewable sources used in large percentage of villages in developing countries which in turn can contribute to the reduction in greenhouse gas emissions (Hiremath et al., 2010b; South Centre, 2008). SSBS when properly managed can bring environmental (such as biodiversity management, land reclamation and emission reduction) as well as socio-economic benefits (such as job creations, increase in the local business and self-reliance) (Hiremath et al., 2010a; Hiremath et al., 2009; Kumar et al., 2009; South Centre, 2008).

Based on their research on a decentralized small scale biomass-based power generation system implemented in Hosahalli village of India, Ravindranath et al. (2004, p.939) have stated that, the SSBS "has provided multiple social, economic and environmental benefits". The report published jointly by Food and Agriculture Organisation of the United Nations (FAO) and Policy Innovation Systems for Clean Energy Security (PISCES) based on case studies in Asia, Latin America and Africa region, have also recognized multiple impacts that SSBS can have on rural livelihoods (Practical Action Consulting, 2009). These sustainable benefits are understood as the development of different types of capitals such as natural, financial, human, social and physical capitals as shown in Figure 2.9 (Source: Practical Action Consulting, 2009).

SSBS has great potential to support rural and social developments by creating livelihoods in developing nations along with energy production. MNRE, Government of India is also promoting this sector through special capital subsidy and other initiatives because of its merits discussed above (Jain et al., 2011).

2.8 Overview of bioenergy

Figure 2.10: Bioenergy routes

(Source: IEA, 2007b)

In bioenergy there are different types of resources, processes, technologies and products which make this a vast and diverse sector. Hence, there is a need for understanding the different classifications of the system (which is addressed in this section) in order for a better elucidation and prediction (Khan et al., 2009). Figure 2.10 (Source: IEA, 2007b) show some of the important categories.

FAO defines bioenergy as “all energy derived from biofuels”; biofuels as “fuel[s] produced directly or indirectly from biomass” and biomass as “material of biological origin excluding material embedded in geological formations and transformed to fossil” (2004).

There are different classification systems for biomass; mainly it’s classified based on its origin and / or properties. The biomass resources based on its origin can be mainly divided into four categories primary residues (generated as a by-product from agriculture or forest), secondary residues (generated as a by-product from industries processing biomass for production of food products or biomass materials), tertiary residues (generated as a by-product of used biomass based products) and energy crops (generated from crops and trees dedicated to energy production). Based on the properties, biomass can be classified as woody fuel (ex: wood), herbaceous fuels (ex: straw), wastes (ex: sewage sludge), derivatives (ex: waste from food process industries), aquatic (ex: Kelp) and energy crops (ex: Willow) (Khan et al., 2009).

Biomass can be converted into three main forms of energy products namely heat, power or transport fuels. These products can be formed by different conversion processes from biomass to energy. Three main categories of conversion processes are thermo-chemical, bio-chemical or biological and mechanical. Thermo-chemical conversion of biomass to energy can be carried out by any of the four combustion, pyrolysis, gasification and liquefaction processes. Bio-chemical conversion consists of two main processes namely digestion and fermentation. Extraction is mechanical process used for conversion (McKendry, 2002b). As discussed above bioenergy is a huge sector with highly diverse system components; therefore there is need for defining the reach of this project for transparency. Hence, based on summary of the bioenergy sector given here the next section will describe scope of this project.

2.9 Scope of the Project

This study investigates the small scale bioenergy sector because of its energy production capability, growing demand, significant benefits to community and it is emerging role in Indian context. The study is designed to consider community or industrial level application of bioenergy systems rather than individual house hold level applications. Hence the systems above 10KW and up to 2MW (electric power or equivalent)generation capacities, namely micro, mini and intermediate range systems (based on Table 2.2) are studied.

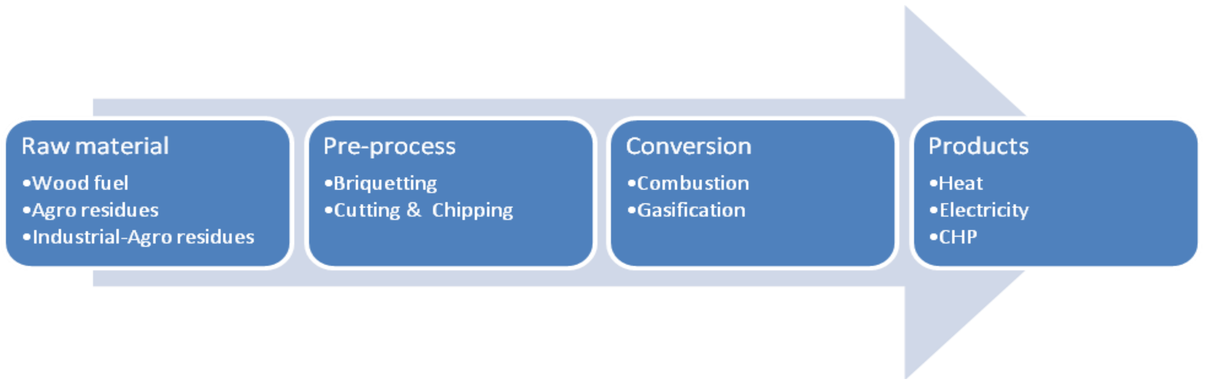

Figure2.11: Project Coverage

Main products of SSBS which are considered for this study are heat and electricity. So it covered systems which produced heat only, power only and combined heat and power (CHP) plants. Based on the information from MNRE's(2012a) website (summary given in Table 2.1) it can be drawn that there are two important streams for SSBS in India, namely (municipal waste) waste to energy and energy from primary and secondary residues. Interest of this project is on the second stream, which produces heat and / or electricity using woody, herbaceous and derivative fuels (primary and secondary residues) because of its huge potential and unique advantages, discussed above. In India, mostly these resources are converted into final product through combustion and gasification technologies (Ravindranath & Rao, 2011). Hence this study has focused on those technologies. In this work pre-processing methods considered are also limited to processes prominently used in India namely, briquetting and 'cutting & chipping' processes. The Figure2.11 explains extent of the project and the different resources, technologies, processes and end products under consideration in this study.

2.10 Conclusion

This chapter has provided an overview about research context, small scale bioenergy systems, its importance and implication for the sustainable development in India and characterization of system under study in this project. Given the significance and background details of SSBS in this chapter, it becomes obvious that there are significant reasons to undertake a study that can reduce the challenges and enhance practical application of SSBS, which is further discussed in next chapter.

Chapter Three: Research Definition

3.1 Introduction

This chapter defines this study by providing crucial information such as motivation, research problem and research objectives. The research aims and objectives are defined below by exploring the practitioner's concerns and challenges of the sector. Review of existing studies and relevant research gaps relating to the individual research objectives are discussed in relevant chapters of this thesis (Chapter 5, 6, 7& 8) for better readability.

3.2 Approach

In applied research, after establishing context the study goes through two stages before execution, namely, 'definition' and design' stages. The *definition* stage should enlighten and refine study aspirations before investigation in order to effectively execute the research. The two important aspects of the research definition stage are to be aware of problems underlying the research area and to identify specific researchable objectives (Hedrick et al., 1993). This study is an applied research in bioenergy sector. In this chapter, research problem and the relevant research objectives related to the 'research definition' stage are presented.

One of the fundamental principles of applied research is that it should have emphasis on both relevance and rigorousness (Bhana, 2007; Rapoport, 1970). The relevance in the applied research setting intends that study contributes towards practical concerns of the people in that problematic situation (Rapoport, 1970). Therefore, in order to carry out relevant research in this work, not only the academic literature but also the practitioner perspective should be considered to define the problem. Hedrick et al. (1993) suggests some strategies for gathering information about the 'real' (practically relevant) problems. These are discussions with research clients, reviewing relevant practitioner literature, gathering current information from relevant parties and conducting information gathering at site visits. In this study, a wide range of information from various related players have been collected to identify the research problem from various sources and forums using different but relevant data gathering techniques. Some of the information gathering strategies used in this research are mentioned below.

Discussions with research clients: The researcher was associated with the 'Science Bridge' project (Chapter 1) as a research team member for 3 years. This provided the opportunity to have continuous formal (including monthly project meetings) and informal discussions with action research case with ARC (described in Chapter 4) project members as they were also part of the Science Bridge project team.

Reviewing relevant practitioner literature: In order to identify the research problem, relevant practitioner literature were examined such as newspaper articles, industry magazines, research calls, reports and websites from the research bodies, government bodies, international organisations, industrial associations and non-governmental organisations (NGO).

Gathering current information from related parties: Different forums such as practitioner conferences, academic and practitioner combined conferences in the bioenergy sector, industrial exhibitions, workshops and seminars were used to collect current information of the field, from related parties such as policy makers, industrialists, managers, bankers, experts, researchers, representatives of international organisations, industrial associations and NGO. Some of those forums the researcher attended were as below:

- Doing Business in India, UK (27-28 May 2010)
- World Renewable Energy Congress, Sweden (08-13 May 2011)
- 13th Renewable Energy Finance Forum, UK (20-21 September 2011)
- European Bioenergy Expo and Conference, UK (05-06 October 2011)
- Interdisciplinary Workshop on Sustainable Management, India (19-20 January 2012)
- Renergy 2012, International Conference and Expo on Renewable Energy, India (12-13 March 2012)
- 20th European Biomass Conference and Exhibition (EUBCE), Italy (18-21 June 2012)
- International Workshop on Bioenergy, Solar Energy and Water Treatment: Technology & Business Solutions, UK (3-4 July 2012)
- EREBUS &AIFAR - Practical Implications of Biomass & Bioenergy Research, UK (9 November 2012)

Site visits: Pilot visits have been made to the company's PCS1 (a captive heat unit, further details in chapter 4) and PCS7 (a bio-brick producer, further details in Chapter 4), where the researcher had informal discussions with related parties and observed their operations, to collect information about practically relevant issues.

Academic literature review: In parallel with all these information gathering strategies mentioned above, academic literature was also reviewed continuously to monitor any developments in the research problem area.

The research problem was formulated by using the information gathered from above mentioned strategies. However, the importance of problem area was highlighted frequently in many occasions during data collection and continued engagement with practitioners.

3.3 Challenges for the Bioenergy Sector

In India, bioenergy systems have been in use for more than two decades now. These systems still have huge prospects for growth and potential to further contribute towards energy demand of the developing nations. The MNRE accredits this potential of bioenergy systems and along with other stakeholders have promoted this sector through a number of policy instruments (for example tariff support), financial incentives(for example capital subsidy) and significant technological support (for example local availability of technology and advancement of technology) to support the sector's growth (Camerata & Bansal, 2011; Ravindranath & Rao, 2011).

In spite of this, bioenergy systems adoption is rather low, which is evident from the recent study conducted by United Nations Development Programme (UNDP) in association with MNRE. It reveals that:

> *Despite the enormous potential for BETs [Bioenergy Technologies] to tap into in a country such as India, and taking into consideration the renewable energy policies and programmes set out by the government, actual on field implementation of BET's is falling short. (Ravindranath & Rao, 2011, p. 7)*

This is acknowledged by the Pramod Chaudhari (Co-Chairman, National Committee on Renewable Energy, Confederation of Indian Industries (CII)) during his speech in 'Bio-Energy Summit 2012 - Enabling Sustainable Energy Access for India' on 05th September 2012 in Delhi (CII, 2012). This issue is also recognised in an article, written by the consultants of South Pole Carbon, an international company operating in Indian renewable energy sector (Camerata & Bansal, 2011). This underachievement of bioenergy technologies are due to "several challenges in the areas of policy development, feedstock supply chain, availability of appropriate technologies, financing and market linkages" (Pramod Chaudhari in CII, 2012).

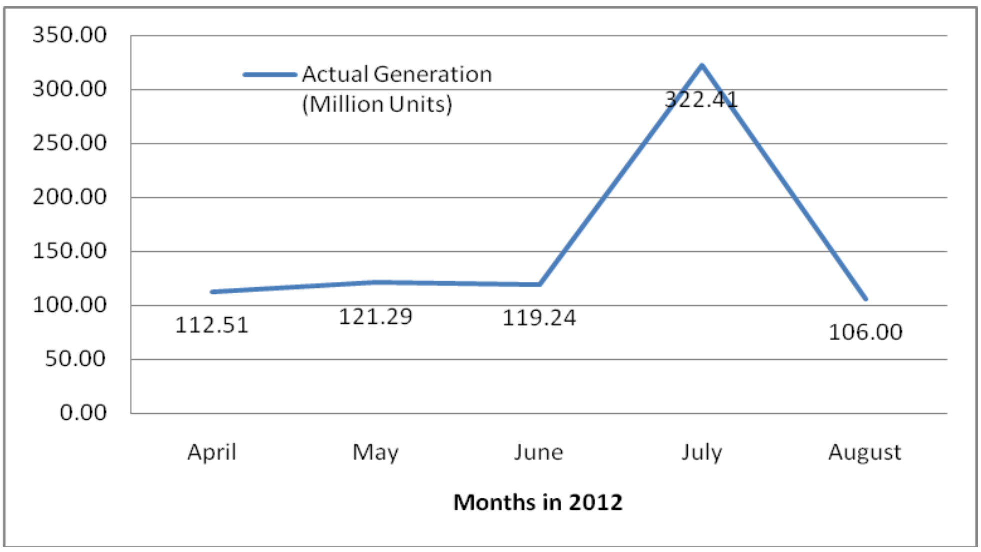

Figure 3.1: Bioenergy Plants Electricity Generation in India

Mr GB Pradhan, Secretary, MNRE, stated that sustainable business model is a very important requirement, for encouraging bioenergy projects in India (FICCI, 2011).Whereas the above mentioned barriers affects successful operation of the systems (Ravindranath & Rao, 2011; Shukla, 2000). Similar conclusion can be drawn from the Figure 3.1 (Data from:Central Electricity Authority, 2012a). The figure shows the electricity generation data of the 707.25 MW (installed capacity) bioenergy plants in India. In which during most of the month's electricity generated was approximately less than 25 % of its full capacity due to various constraints.

The various challenges also have led “financial institutions in developing countries [to] have [a]less favourable risk rating for small scale BETs compared to better established energy technologies like grid access and solar power” (TERI, 2010, p. 24). This in turn influences the financial availability for these technologies. Therefore, in order to increase the commercialisation of small scale bioenergy systems in India there is an urgent need to study the barriers and provide the required support to overcome them (Dong et al., 2009; Ravindranath & Rao, 2011). In order to effectively study and address challenges of the bioenergy sector,Peck et al. (2011, p. i) based on their study:

> *…concludes that many of the constraints or ‘barriers’ being experienced by the sector can be anticipated by examination of on-going events through management and policy assessment lenses.*

The core of this argument, i.e. ‘the need to study the bioenergy sector from a management perspective’ is further supported by recent research calls and projects in this area across the world by some of the major international organisations and research councils such as EPSRC (2012), OECD and IEA (2012) and IEA Bioenergy Task 43 (2012). Keeping in line with this need, the report by OECD and IEA (2012) have identified the supply chain and ‘sustainability & public acceptance’ as the two major non-economic barriers from the management perspective, which need to be addressed immediately. These issues are also identified as important challenges to advance bioenergy technologies towards deployment by the EPSRC (2012), in its recent research call based on the scoping workshop by experts conducted on 24th April 2012.

With an intention to support further deployment and successful operation of bioenergy plants, this work studies the supply chain and sustainability of the small scale bioenergy plants, given its importance for the success of the bioenergy sector. The sections below scope the research problem further and frame the research objectives based on the detailed discussion of bioenergy supply chain and sustainability.

3.4 Bioenergy Supply Chain

Ballou (1992) states that supply chain is one of the important reason for the success or failure of any industry and there is enough evidence that this is also true for the bioenergy sector. As acknowledged by BK Chaturvedi, (Member (Energy) of the Planning Commission, India (05/09/2012)), in his recent speech to the 'Bio-Energy Summit 2012 - Enabling Sustainable Energy Access for India' that, "for the success of bioenergy it is critical to address the supply chain issues" (CII, 2012). This is echoed in various related stakeholders claims that supply chain is a key component for a sustainable bioenergy (George & Nicholas, 2012; Ikonen, 2012; Kundra, 2010; OECD & IEA, 2012; Sobhanbabu et al., 2010; World Bank, 2011). Furthermore it is more widely recognised in the academic literature as an important issue for the bioenergy sector, as shown in Table 3.1. Even other important issues such as size, location, technology used and financial situation of the conversion plant are linked to the decisions about the bioenergy supply chain (Ikonen, 2012; TERI, 2010).

Table 3.1: Some of the important issues of the bioenergy sector

Issues	***References***
Supply chain	(Allen et al., 1998; Escobar et al., 2009; Gmünder et al., 2010; Gold & Seuring, 2011; Hooper & Li, 1996; Iakovou et al., 2010; Kapur et al., 1996; Lewandowski & Faaij, 2006; McKendry, 2002a; Raven et al., 2009; Athanasios A. Rentizelas et al., 2009; Voivontas et al., 2001)
Size	(Allen et al., 1998; Hooper & Li, 1996; Roos et al., 1999; Voivontas et al., 2001)
Location	(Allen et al., 1998; Escobar et al., 2009; Raven et al., 2009; Roos et al., 1999; Voivontas et al., 2001; Wright, 2006)
Technology used	(Allen et al., 1998; Dell & Rand, 2004; Escobar et al., 2009; Gmünder et al., 2010; Hooper & Li, 1996; Jackson, 1992; McKendry, 2002a; Mitchell, 1995; Mitchell et al., 1995; Thornley et al., 2009a)
Finance	(Jackson, 1992; Mitchell, 1995; Rösch & Kaltschmitt, 1999; Wright, 2006)

However, in spite of this importance it has been recognised that "supply chain is a tough challenge for the biomass based energy industries" in India by Kundra (2010), Director of Capital Markets and Energy Portfolio of the Acumen Fund (an investment company which has also invested in Indian small scale bioenergy projects) in his company's annual investor gathering at New York. The researcher observed the same phenomena during the pilot visits to Case study companies PCS1 and PCS7. Furthermore it was acknowledged by all the five speakers (practitioners) of the session 'Biomass Supply Chain' in one of the largest renewable energy industries conference Renergy 2012, in India (12-13 March 2012).

Across the supply chain variety of issues have been identified as significant challenge for the industry such as the availability of biomass (Camerata & Bansal, 2011; Kundra, 2010; World Bank, 2011), the difficulty in collection and procurement of biomass (European Business and Technology Centre, 2011; Kundra, 2010), the raw material and procurement cost (European Business and Technology Centre, 2011; Ikonen, 2012; Kumar & Bernwal, 2010), the seasonality of the raw materials (European Business and Technology Centre, 2011), favourable load conditions (Bürgi, 2003), power purchasing arrangements (Bürgi, 2003), competition for resources (Camerata & Bansal, 2011) and biomass logistics (Athanasios A. Rentizelas et al., 2009).

The bioenergy supply chain, depending on the technology and other circumstances, consists of different activities such as ground preparation and planting, cultivation, harvesting, handling, storage, in-field / forest transport, road transport and use of the fuel at the power station, energy supply to the customers as shown in Figure 3.2. Furthermore, the supply chain involves different parties such as farmers, forest owners, agricultural and forestry contractors, transport and distribution companies, fuel suppliers, house hold customers, business customers and power station operators (Allen et al., 1998). The complex nature of the bioenergy supply chain is due to high numbers of stake holders, supply chain partners and various market segments with inherent issues. The complexity is one of the important reasons for the difficulty in properly managing the bioenergy systems (Elghali et al., 2007).

Figure 3.2: Bioenergy Processes

(Source: Iakovou et al., 2010)

Paying enough attention to practical drivers and constraints across the supply chain is important for the effective supply chain management and it is obviously a vital task for the success of complex supply chain such as of the bioenergy sector (Clements & Sense, 2010; Elghali et al., 2007). Therefore, it is required to identify and understand the issues across the supply chain of the bioenergy industry in order “to strengthen the knowledge base on which decisions are made” (Buchholz et al., 2005, p. 4). This can subsequently lead to the successful operation of bioenergy systems over the life span and increase its replication (Iakovou et al., 2010; Practical Action Consulting, 2009; Ravindranath & Rao, 2011; Roos et al., 1999). Even the recent study conducted by UNDP in association with MNRE to identify the barriers for bioenergy sector in India calls for further research in this area by stating that:

> *These barriers need to be explored in more detail, so that policies and programmes targeting BETs in the future will have a more bespoke role to play in closing the gap between existing and potential capacity(Ravindranath & Rao, 2011, p. 7).*

After careful consideration of the arguments presented above, about the practitioners need and the importance and the challenges of the bio-energy supply-chain, one of the main research objectives developed is, as follows:

- To identify supply chain issues of the small scale bioenergy projects in India. (RO3)

3.5 Sustainable Bioenergy

As discussed in Chapter 2, biomass based power generation can contribute in addressing the energy demand in India along with great sustainable development benefits such as reduction in greenhouse gas emissions, employment generation and income generation (Cushion et al., 2010; Elghali et al., 2007; Escobar et al., 2009; IEA, 2007a). Therefore for bioenergy projects, “it will be necessary to determine the contribution of the supply chain towards sustainable development policy objectives” (Elghali et al., 2007, p. 6076).

Bioenergy can have a greater prospect for positive sustainable impact as stated above, however:

> *A variety of different environmental, social and economic issues need to be addressed to ensure the overall impact of bioenergy is positive compared to that of fossil fuels. (OECD & IEA, 2012)*

Poor bioenergy systems management can possibly create huge negative impacts especially when compared to the benefits it can offer. In some cases it can worsen the situation (OECD & IEA, 2012; Rossi, 2012; TERI, 2010; UNIDO, 2009) with potential negative impacts such as inefficient use of natural resources (Rovere et al., 2010), impacts on food production (Escobar et al., 2009; UNIDO, 2009), affecting local demand for biomass (Bürgi, 2003), land use change (Evans et al., 2010; UNIDO, 2009), land rights (Cushion et al., 2010), water level depletion (Evans et al., 2010), water pollution (Allen et al., 1998), energy crops grown using high amounts of fertilisers (Evans et al., 2010), high fossil fuel use in the supply chain (Allen et al., 1998), high emissions (Allen et al., 1998), traffic generation (Allen et al., 1998), inappropriate working conditions (Escobar et al., 2009), health and safety issues (Allen et al., 1998), noise and visual intrusions (Allen et al., 1998), and low wages (Escobar et al., 2009).These sustainability issues, if not addressed properly, can create a bad perception and insufficient social acceptance (Eswarlal et al., 2013; Harrison et al., 2011; Rösch & Kaltschmitt, 1999). Whereas public perception can impact the success of the bioenergy industry and it has been one of the important challenges for the bioenergy industry (Buchholz et al., 2009b; Cherni et al., 2007; Eswarlal et al., 2011a; Eswarlal et al., 2011b; Eswarlal et al., 2013; Roos et al., 1999; Rösch & Kaltschmitt, 1999; Thornley et al., 2009a; Wegener & Kelly, 2008; Wright, 2006).

These sustainability concerns are also echoed by various experts in various forums (for example Renergy 2012 and EUBCE) attended by the researcher. Moreover, it was identified that sustainable development is one of their primary objectives of the action research case study project ARC. Due to the inherent nature of the Case ARC, which is led by researchers, there was a high emphasis on avoiding any negative sustainability impacts and achieving rural development (such as employment and income generation, supporting rural electrification and rural business) during the project implementation and operation. During the pilot visits to CasePCS1 and PCS7, even though there was not much emphasis on the sustainable development opportunities or potential negative impacts of bioenergy systems, they were viewing them as important promoters for bioenergy. Avoiding fossil fuels and effective utilisation of agro-residues are seen as some of the positive contribution of bioenergy by them.

Table 3.2: The important factors determining the supply potential of biomass

(Source: IEA Bioenergy, 2011)

Bioenergy systems can also be directly influenced by the various sustainability factors as stated below,

> *Bioenergy systems are complex because their three components feedstock supply, conversion technology and energy allocation are influenced by environmental, economic and social factors. (Buchholz et al., 2005, p. 1)*

For example, Table 3.2 (number of * indicates the importance of the factor) clearly shows the influence of sustainability factors on determining the supply potential of biomass.

The sustainability issues are identified as important challenge for the bioenergy systems (IEA Bioenergy, 2011; UNIDO, 2009) and it can limit the potential of bioenergy systems (Camerata & Bansal, 2011). Attributable to the bioenergy systems ability to impact and get influenced by the global sustainability issues (sustainable development). It becomes highly pertinent to consider the sustainability issues when the study conducted by the Smeets and Faaij (2010) reveals that it is feasible to produce bioenergy meeting sustainability criteria at reasonable cost, which is one of the main reservations by the companies about meeting the sustainability criteria. Therefore, it becomes important to take not only technical, but also environmental, economic and social parameters into account while assessing bioenergy systems for successful accomplishment of the projects (Buchholz et al., 2005; TERI, 2010; Thornley et al., 2009a).

The impact of sustainability issues can vary based on the supply chain, scale and technology used. For instance, a study comparing the various technologies and sizes of the bioenergy systems concluded that there is a substantial variation in land-use efficiency and cost for different systems (Thornley et al., 2009a). Whereas another study carried out by Gmünder et al. (2010) found that small scale bioenergy systems reduce greenhouse gas emissions significantly when compared to a diesel generator or grid connection, but the environmental performance is only slightly improved mainly due to the poor pre-processing techniques. Therefore it is important that while making decisions “the whole life-cycle impact of bioenergy production needs to be carefully considered” (OECD & IEA, 2012).

Depending on the country and the rationale behind the use of bioenergy systems in that country, the sustainability issues and objectives can be different (Cushion et al., 2010) because:

> *In the context of developing countries such as India, bio-energy development must be viewed within the context of existing poverty and prevalent resource management systems i.e. the economic, social and environmental conditions and their interrelationship.(Tiwari et al., 2009, p. 4)*

The sustainability issues also depend on the place or location of the plant because the impact on sustainability issues can vary based on that (Cushion et al., 2010). Therefore it is important to recognise the specific sustainable issues relevant to the Indian bioenergy sector in order to effectively manage bioenergy systems.

Taking into account the bioenergy system's potential to bring benefits and/or negative impacts to the society and influence of the sustainability issues across the supply chain and on the success of the bioenergy system, it becomes important to consider the sustainability issues from the very beginning of the bioenergy projects.

Considering the variation of sustainability issues based on the country and system specifications in conjunction with its importance for the success of bioenergy systems discussed above, this research intends to address the following research objective:

- To identify sustainability issues of the small scale bioenergy projects in India. (RO2)

3.6 Bioenergy Decision Support Systems

From the above discussions it is clear that for a successful bioenergy project, it is important to have a supply chain which achieves both organisational (internal supply chain) and global (external) sustainability. The priority to address these issues are also echoed in the recent report of OECD and IEA (2012) and the recent workshop (21/02/2012) conducted by the IEA Bioenergy Task 43 (2012), with a theme of 'Mobilizing sustainable bioenergy supply chain'. Some of the major challenges identified in the workshop, which need to be addressed in order to mobilize the sustainable bioenergy supply chain are as follows:

- *Assessment of the benefits and possible negative impacts of bioenergy supply chains at local, regional, national and global scales;*
- *Assessment of the viability of different bioenergy supply chains, and;*
- *considering market impacts and social impacts (IEA Bioenergy Task 43, 2012)*

The above mentioned issues are also recognised by Smith (2012) as important challenges for achieving sustainable supply chain in bioenergy. Furthermore, Smith (2012) recognise that, identifying the risks for sustainability (such as risks to business, soils, water, biodiversity, GHG balances etc.) and mitigating those risks are important requirements for bioenergy systems, which need to be resolved to fully utilise its potential.

From the above mentioned challenges, it can be said that in order to achieve a sustainable supply chain the decisions based on the information about the risks and impacts is a key requirement. This can be addressed by a risk based decision support system (now on mentioned as framework), which can help the business to take well informed decisions. The analysed information can support business in taking effective management decisions, which in turn can promote bioenergy sector (IEA Bioenergy Task 43, 2012; MAKE-IT-BE, 2011; OECD & IEA, 2012). Moreover, the need for a system to support their decision making process and to avoid any potential pitfalls in achieving a sustainable bioenergy system was highly emphasised by the various participants of the ARC project in various meetings.

In addition to that, "as the amount and complexity of information relating to the development of bio-energy systems increases so does the problem of how to *handle the information in a manner which is helpful for decision making" (Mitchell, 2000, p. 265).*

This can be made worse if this complex decision making processes has to be handled by the small scale bioenergy companies because of their resource constraints. Decision support systems can be a solution to this problem as it can assist in handling the information about the multifaceted interactions in bioenergy systems through a systematic approach (Buchholz et al., 2005; Wright et al., 2013).

For a successful bioenergy project, realizing a sustainable supply chain is a key factor. Therefore with an intention to attain sustainable supply chain for bioenergy projects, in this research the following objectives will be addressed:

- To develop a sustainable supply chain risk analysis framework (RO1) and,
- To apply and evaluate the sustainable supply chain risk analysis framework (RO4).

3.7 Importance of Stakeholder Engagement

As discussed above some of the key issues for the development of the bioenergy sector include supply chain risks, sustainability impact and public acceptance of bioenergy systems. In order to address these issues it is essential that all the relevant stakeholders' views are taken into account in all stages of bioenergy system development. This is because:

recorded views of stakeholders illustrate that diverging priorities exist for different stakeholder groups and this will influence appropriate choice of bioenergy systems for different applications (Thornley et al., 2009a, p.890).

The significance of engaging with stakeholders for a sustainable bioenergy system are well acknowledged (Joudre, 2012; MAKE-IT-BE, 2011; Painuly, 2001; Peck et al., 2011; Tiwari et al., 2009). As lack of involvement of stakeholders can increase the risk caused by objections and the cost of delay associated with it (DTI, 2004) and misplace the priorities in decision making (Painuly, 2001). This can hamper the success (Ravindranath & Balachandra, 2009) and practical application of the system (Mitchell, 2000). An effective stakeholder partnership can result in innovative mechanisms related to the implementation of systems (Ravindranath & Balachandra, 2009) and earlier identification of barriers and measures to overcome those (Painuly, 2001). Also, it is important to have "continued collaboration among all actors to ensure that biomass supply chains are sustainably optimized" (Joudre, 2012, p. 2).

Nevertheless, currently most of the decisions in bioenergy industry are taken based on the cost effective optimal solution by technical experts, without getting support from all the stake holders and considering all the related sustainable issues (Cherni et al., 2007).One of the reasons behind it is the challenge to communicate with huge of number of stakeholders associated with bioenergy sector who possess different perspectives (Buchholz et al., 2009b).

Therefore, given its importance for the success of bioenergy projects and the current short comings, in this research the views of all the relevant stakeholders will be taken into account while addressing the research objectives.

3.8 Chapter Summary

The bioenergy sector has huge prospects for growth in India. However, it faces a lot of challenges which need to be addressed for it to achieve its potential. Due to the nature of the problem, providing business supportive solutions are one of the vital responses to deal with this. The literature covered confirms that sustainability issues and supply chain issues are the two major concerns of bioenergy projects.

Taking all the above discussions into account, this research intends to identify and analyse sustainable supply chain risks of the small scale bioenergy sector in Indian context, which can help the entrepreneurs in the decision making process.

- Research Objective 1 (RO1): To develop a sustainable supply chain risk analysis framework;
- Research Objective 2 (RO2): To identify sustainability issues of the small scale bioenergy projects in India;
- Research Objective 3 (RO3): To identify supply chain issues of the small scale bioenergy projects in India;
- Research Objective 4 (RO4): To apply and evaluate the sustainable supply chain risk analysis framework.

The overall aim of the research will be achieved by meeting the above objectives (which are already discussed in section 3.4, 3.5, and 3.6). Furthermore, given the importance of different stakeholders in the bioenergy sector, the relevant stakeholders' perspectives will be duly considered while fulfilling these research objectives. These objectives are addressed in the individual chapters (Chapter 5, 6, 7 and 8 respectively) following the research design chapter after this.

Chapter Four: Research Design

4.1 Introduction

In the field of applied research, after having identified the research questions, it is imperative to develop a suitable research design to execute the research effectively (Hedrick et al., 1993). “Research is about generating knowledge about what you believe the world is” (Lee & Lings, 2008, p. 6). The knowledge generated should be scientifically valid (Singleton Jr et al., 1993), and in order to generate such scientific knowledge in the management field, it is important that the information is gathered and analysed systematically (Brown, 2006). Therefore, in this work a systematic investigation process backed by a logical reasoning has been adopted. To describe the logical reasoning and components of this research process the sequence proposed by Saunders et al. (2007) shown in the Figure 4.1 is used. This is followed by the research process description; data sources, research execution and analysis techniques; and methodological and ethical considerations.

Figure 4.1: Research Onion

(Source:Saunders et al., 2007)

4.2 Research Philosophy

Philosophical perspective held by the researcher will influence all the stages of research as shown in Figure 4.2 (Source: Lee & Lings, 2008). The philosophical perspective adopted will influence the way in which we relate theory to the reality and transfer the knowledge from reality to theory. It steers the selection of an appropriate research design, data collection methods and data interpretation techniques. It can also direct the way the research design may be adjusted under different situational constraints in order to maintain feasibility of the research plan (Easterby-Smith et al., 2008).

Aston University

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Figure 4.2: Influence of the Philosophy on Research

(Source: Lee & Lings, 2008)

According toMorgan (1979) the term ‘paradigm’, which means a set of ideas and interlinked concepts, is used at the philosophical level to reflect the basic beliefs about the world. There are three main concepts which together describe a research (philosophical) paradigm - ontology (what is real), epistemology (what is knowledge or knowable) and axiology (what values underpin research). These three concepts influence the research objectives and then the research methodology (tools and techniques) surges from objectives (Lee & Lings, 2008). These terms are further explained as follows.

- **Ontology:** Ontology is the belief about the nature of reality. It is about the researcher’s belief whether they consider the world as objective and external or socially constructed (Collis & Hussey, 2003).

- **Epistemology:** “Epistemology is concerned with the study of knowledge and what we accept as being valid knowledge” (Collis & Hussey, 2003, p. 111). It informs whether the reality is broad-spectrum and can be generalised or if it is specific and appropriate for the definite.
- **Axiology:** As per Collis and Hussey (2003), axiology is concerned with the values of research. The researcher’s belief on the aim of the science is axiology. The researcher’s principle on the aim of the science can be to clarify and forecast or to recognize and understand the system.

From the above argument it is evident that research paradigm and its concepts are the important elements which influence the choice of methodology to solve the research problem and have a strong hold on the application of the research outputs. There are various types of research paradigms used in science some of them are shown in Figure 4.1.

Positivist, realist and interpretive are the three most commonly held philosophical positions in the social science research. The basic idea of the interpretive view is that it is necessary for the researcher to understand the world from the view of member in the world rather than as an outsider (Saunders et al., 2007). In the interpretive view, concepts such as ontology will be socially-constructed, the epistemology will be specific and the axiology will be to understand (Lee & Lings, 2008). The theory of realism states that objects have an existence independent of the mind and can be imperfectly and probabilistically apprehensible (Saunders et al., 2007). In the realist view, the concepts such as ontology will be objective and external, the epistemology will be abstract and generalisable and the axiology will be explainable and predictable. Realist philosophy shares same positivist belief on objective world observation and measurement, but it also contends with positivist belief on existence of unobservable things and accepting the fact that there may be an error in observing the objective world. This allows hypothesizing the unobservable entities in our theories, which can be related to empirically observable effects. (Lee & Lings, 2008)

While the research paradigms discussed above are widely accepted as scientific for any social science research but as all the investigators the researcher too found himself in the dilemma as Barker, (1988, p.126) describes,

> *Was I myself to remain objective, scientific and uninvolved or did I need to immerse myself in the ‘world view’ of Mooniedom and share the subjective feeling and experiences of a ‘Moonie trip’? Would I adopt a philosophical anthropology that assumed we are complicated but nonetheless determined, reacting robots; or are we free, initiating creators, capable of self determination?*

Therefore, after a careful thought process the researcher identified that he personally holds a realist view. The researcher believes that reality is objective and external, research will be appropriate for the broad spectrum studied, and intention of this research is to understand, clarify and envisage the system.

4.3 Research Approach

Deduction and induction are the two fundamental concepts of 'elementary logic' and they are very important for any research consideration (Lee & Lings, 2008). This logical reasoning influences the research approach, be it in shaping the process steps, moving from theory to collect data for verification or moving data to create a theory. This is shown in Figure 4.2. The deduction approach can be seen as "generating some kind of evidence with which to support your theory" (Lee & Lings, 2008, p. 13). Induction is the approach of research process "generating information with which to form some kind of theory" (Lee & Lings, 2008, p. 13). The different research paradigms influence towards any one particular approach. However in real world both the approaches are alternated.

In this applied research the researcher begins with the induction approach of gathering information about the practically relevant problems and from that goes on to infer research objectives as discussed in chapter 3. Then the research took a 'spiral' (Lee & Lings, 2008) structure of continuous alternate approaches starting either from induction or deduction phase for different research questions depending on the type of research question and the level of existing relevant knowledge.

4.4 Research Methods

> *Research methods will cultivate your scepticism about research evidence. But it is a healthy scepticism, because enhancing your ability to understand and evaluate how research findings are arrived at will enable you to identify whether they are based on more or less sound methods of inquiry and whether they warrant strong or weak conclusions (Singleton Jr & Straits, 2005, p. 11).*

The above statement highlights the role of research methods in scientific enterprise and its significance as a framework to develop strong conclusion in the research. Singleton Jr and Straits (2005) list the important factors that influence the selection of suitable methods for a research. This includes research aim and objectives, philosophical paradigm, discipline, resource availability and researcher's training.

Research methods are mainly classified into two types namely qualitative and quantitative based on the type of data collected and used to study a phenomenon. The research studies also made a distinction using this classification if the studies are qualitative or quantitative (data) studies. Qualitative research methods provide a detailed, rich and extensive data which helps to understand and describe a complex, dynamic and multi-dimensional nature of the phenomena, and to generate ideas and concepts (Ritchie & Lewis, 2003; Snape & Spencer, 2003). Quantitative methods provides data of the sample which is more representative of the wider population so that some inferences can be made about the characteristics, attitude, and behaviour of the population studied (Creswell, 2003). Multiple (more than one of same type) or mixed (more than one method of different types) methods can be used in research for the better delivery of the purpose based on the research objectives and world view of the author (Lee & Lings, 2008).

Quantitative techniques are mostly used by the positivists. The interpretivists tend to lean more towards the qualitative methods (Brown, 2006). However, Lee and Lings (2008) argue that both qualitative and quantitative methods can be used under the realist paradigm. Having an inherent realist perspective, this researcher decided to use qualitative methods mainly. This is due to the nature of data required to address the research objectives while the existing information is limited.

Bouchard (1976, p. 402) states that to do a good research, “asking the right question and picking the most powerful method for answering that particular question” is very important. Therefore, in this research, multiple research strategies and multiple data collection techniques (or methods) are selected to gather required information. These strategies and methods are selected after carefully considering all the three axioms of a sound methodology namely reliability, validity and representativeness or generalizability (Lee & Lings, 2008), which is discussed below.

4.5 Research Strategies

Different research strategies are used in the social science research and some of them are shown in the Figure 4.1. These research strategies describe the research setting with emphasis on the context of research, role of the researcher (in the process of research), role of the participants and perspective of the phenomenon interested. The selection of these strategies is influenced by factors like the research question, philosophical paradigm and the research approach. Whether a single or a multi strategy can be useful in answering the research questions effectively depends on the research project, available resource and research question itself. In this research after careful consideration the researcher has opted to use multiple research strategies namely case study, action research, qualitative survey research and secondary research. All of these strategies are discussed below.

4.5.1 Case study

> *Case study is defined as “an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident”(Yin, 1994, p. 13).*

Gummesson (2000), says that the access to reality, understandability, and the quality of information makes case studies more favourable. Scapens et al. (2002), states that case studies give us the opportunity to understand the nature of subject studied in practice; in terms of the techniques, procedures and systems, used and the way in which they are used.

Because of these advantages the researcher decided to adopt the case study strategy as one of the research strategy to address the research objectives RO2 and RO3.

Case studies can be used for variety of research types such as descriptive, illustrative, experimental, exploratory, and explanatory. In this particular research, the researcher decides to use the case study approach in an exploratory way as it allows exploring the phenomena under investigation and providing valuable insights about the practice. This type of research tries to identify a pattern in the case and uses theories to categorise or explain the observed phenomena or relations. But through the empirical evidence it may established that the theory needs to be refined, modified or even rejected, which will generate a suitable theory for the subject studied (Scapens et al., 2002).

Multiple case studies are used in this research as they are more powerful means of creating and validating the findings because they permit replication and extension among individual cases (Eisenhardt, 1989).

Case studies also have a huge flexibility in the type of evidences they depend on such as quantitative data or qualitative data or even mixed data types (Richardson & Montanheiro, 1995). The case studies can also be differentiated based on the data collection, if the data is directly collected by the researcher or using a secondary source of information (for example documentary evidence) namely primary cases and secondary cases respectively. In this study, researcher has adopted both types of case studies in addressing research objective RO3, in order to increase the reliability and generalizability of the research findings.

In primary cases it is important to consider the role of the researcher with the subject(s) of the research, before selecting a case study, as it can influence the rigour of the research process. There are different possible roles of the researcher namely outsider, visitor, facilitator, participant and actor. Of these the most commonly adopted is that of the visitor, which has been adopted in this research. In this role the researcher visits the case sites, observes and interviews the subject(s) of the research (Scapens et al., 2002).

Purposive sampling approach has been used to select the cases based on a set of criteria (Voss et al., 2002; Yin, 1994). Scapens et al. (2002) states that for an exploratory case study the selection of case for study is less important and it just needs to be a relevant and representative case of the study area. Therefore, cases were selected taking the variety of purpose (captive, grid connected, direct distribution), outputs (heat, electricity and CHP), processes (raw material supply, pre-processing, conversion, consumer),feedstock type and size of the bioenergy plants into account. The list of selected cases and details about the cases are given in the section 4.8.

4.5.2 Action research

Research is termed as using action research strategy when researchers get involved in the case study as an active participant in the process being researched (Scapens et al., 2002).

> *Action research aims to contribute both to the practical concerns of people in an immediate problematic situation and to the goals of social science by joint collaboration within a mutually acceptable ethical framework (Rapoport, 1970, p. 499).*

There are few concerns about action research strategy such as whether it is an acceptable research approach, potential ethical dilemma of whose interest is being served and possible complications of a significant difference between goals of the researcher and the client (Clark, 1972; Myers, 2008). Towers and Chen (2008) argue that participative method is a valid and relevant scientific research approach. They state that, it has an extended epistemology of experiential, presentational, propositional, and practical ways of knowing that can contribute as a rigorous and justifiable research methodology supporting academic progress of knowledge and understanding. McNiff (2009) adds that action research is an approach to create knowledge of the practice, which can find the ways to improve the practice. In order to address the issue of potential ethical dilemma and possible complications of a significant difference between goals, Hult and Lennung (2007) suggest that the action researcher should clearly state the values founding the work, disclose his role in the collaborative work during the research process.

As this is an applied research carried out under the umbrella of the Science Bridge Project (2010), while one of the work packages of the project was to setup a bioenergy plant. That particular work package element was considered for this study in an action research setting, where the researcher was a participant of that project and his role was to develop business supportive solutions which are very much in line with this thesis intentions. This action research project was an important resource in addressing the research objectives RO1 and RO4 of this study and provided support to carry out this research successfully. Researcher addressed the ethical concerns about the action research project, by providing information to the team members. The information was well received and understood due to the research culture of the team, as Science Bridge Project (2010) was a research project and most of the participants have been involved in active research for a long time. The details of the action research case and the relevant participants' details are given in the section 4.8 below.

4.5.3 Qualitative Survey Research

The description of term ‘survey’ methodology is used by many authors (for example: Groves et al., 2009) to generally cover the quantitative studies only (Jansen, 2010). Whereas the survey research is used,

> *“to answer questions that have been raised, to solve problems that have been posed or observed, to assess needs and set goals, to determine whether or not specific objectives have been met, to establish baselines against which future comparisons can be made, to analyze trends across time, and generally, to describe what exists, in what amount, and in what context” (Issac & Michael, 1997, p. 136).*

Therefore given its applicability as stated above, the survey research as a methodology (not referring to the data collection instrument here) can be used in qualitative studies as well. However, for long time the studies using semi structured interviews or other data collection tools are in use in research but they are simply termed as “qualitative studies” and providing weak methodological justifications (Jansen, 2010). In addressing this issue Jansen (2010) provides the justifications of this basic type of empirical research and terms it as ‘qualitative survey research’.

> *Jansen (2010, sec. 2.1) states that, “a survey is a qualitative survey if it does not count the frequencies of categories (or values), but searches for the empirical diversity in the properties of members, even if these properties are expressed in numbers.”*

The main difference between statistical survey and qualitative survey is that, first one analyse the frequencies and the second one studies the diversity of member characteristics in a population respectively (Jansen, 2010).

Given its easiness to adopt, the research question being addressed and methodological background in this research from the stage of framing the research objectives till the final stage of application and validation of the framework, qualitative survey research strategy was used as one of the research strategies. Information from experts and other relevant stakeholders is collected using this strategy to make sure the practical relevance of the findings, to capture the different perspectives, given the significance of stakeholders in the bioenergy sector mentioned in Chapter 3. The stakeholder groups consulted in this project are government agencies, banks, component suppliers, NGO’s, workers, consultants and researchers, which is used to answer the research objectives (RO2 and RO3). The different groups of experts used in this research constituted researchers from diverse relevant fields including NGO representatives, government officials, consultants and practitioners. In this study a purposive sampling (Oliver, 2006) method was used to select the suitable participants, as Jansen (2010, sec. 3.2) states that,

> *It is both logical and more efficient to purposively select diversity sample with the aim to cover all existing relevant varieties of the phenomenon.*

The details of the stakeholders and expert groups used in this research are given in the data sources section below.

4.5.4 Secondary Research

In this research in order to attain comprehensive understanding of the research problem and background and to respond to the research objectives effectively secondary research strategy (Stewart & Kamins, 1992) is used in addition to the strategies discussed above. The main difference between the other strategies and secondary research strategy is that the researcher does not collect the information from the sources directly and instead used the data collected by others (Stewart & Kamins, 1992). This strategy provided an opportunity to look at the important relevant documents of the sector (Emerald, 2013) and to include the views of other important participants in the sector, whom researcher could not directly contact and collect information from, due to the limitation on the resources such as time and finance. Secondary data can be either raw data or interpreted data, where the interpreted data has been collected and analysed for a particular purpose (Emerald, 2013). In this work interpreted data has been used, however the data that has been used was carefully selected based on reliability, suitability and validity and its use was limited as additional information only in this research rather than solely depending on it in order to avoid any influence of issue of deliberation in those data (Emerald, 2013). In this work both academic literature (Journal papers, Books and Conference papers) and grey literature (Newspapers, practitioner magazines and publications from governments, NGO, companies, industrial associations and international organisations) was used to identify the current state of knowledge and to support the findings of this research. Saunders et al. (2007) have classified the secondary data into three categories namely documentary, multiple source and survey. In this research documentary and multiple source type data have been used.

4.6 Research Data Collection Tools:

In order to collect the information from different sources and participants about the subject matter under enquiry in a range of research settings discussed above, there is a need for an open and flexible approach for data collection. At the same time it is important to have a systematic approach to ensure the rigour in the data collection process and the information collected is valid. Keeping this in mind, it was decided to adopt the tools such as interviews, focus groups, field work, observation (direct and participative) and documentary evidence to collect data in this investigation, all of which are discussed below.

4.6.1 Interviews

Rubin and Rubin (2005), state that interviews are like night-time spectacles, which allow us to see the things which cannot be seen ordinarily. Interviews are one of the important data collection techniques, to provide rich data from different assortment of participants. Interviews help to centre on the subject's world, in which the role of interviewer is to only listen, prompt, encourage and direct (Myers, 2008). Semi structured interviews are the best way to provide the balance between openness and structure. These interviews are based on the issues to be discussed decided before hand, but they only act as topic guides in the interview, which identify the data need to be collected to address the research objectives. In this the order of questions can also be changed in order to maintain the flow of the conversation and also more probing can be done to find any interesting issues rose during the interview. This allows the interviewer to capture any additional perspectives which were not thought in the design stage, so providing the openness, flexibility and structure for the research at the same time (Bryman, 2012; King, 2004). Therefore, in this research semi structured interview technique was chosen as one of the important data collection tool because of the reasons discussed above.

4.6.2 Focus Groups

Focus group was chosen as one of the data collection techniques in this research because of its ability to gather collective views about the topic from a group of people who have knowledge on that particular subject (Myers, 2008).This technique provided more room for the participants where researcher has less control over the data collected when compared to the interview and more control than in an observation process (Kleiber, 2004). In this process the researcher along with the role of a recipient of information; has played a role of moderator persuading participants to convey their opinions and facilitating the interaction process within a mutually respectable environment (Myers, 2008).

This technique also allows the participants to involve in a thoughtful discussion process as Kleiber (2004, p. 91) argues that focus group as a data collection technique,

> *...depends on the interaction of the group to stimulate participants to think beyond their own private thoughts and to articulate their opinions. It is in having to formulate, represent, give evidence, receive feedback, and then respond that individuals beyond the private.*

Through the process stated above focus group provided rich data including the reason for the participant's opinion on the subject matter.

4.6.3 Fieldwork

> *Fieldwork is a form of inquiry in which one is immersed in the on-going social activities of some individual or group for the purpose of research. Fieldwork is*

characterized by personal involvement to achieve some level of understanding that will be shared with others. (Wolcott, 2005, p. 44)

Fieldwork refers to the research conducted outside the laboratory in real life situations with the people belonging to the specific context (Fiedler, 1978). Myers (2008) argues that fieldwork is very useful and can provide additional dimension of the phenomenon under study, which will be difficult to be obtained by interview alone. During fieldwork the researcher makes observations about the real life activities. In simple terms Myers (2008, p. 138) defines, "observation is when you are watching other people from outside." In this research observations were made during the fieldwork and recorded in the field notebooks to provide more enriched data. In any social situation there are nine dimensions which can be observed namely space, actor, activity, object, act, event, time, goal, and feeling (Spradley, 1980). In this research all the relevant dimensions, which help answer the research objectives were observed. The two types of observation process were carried out during the fieldwork in this research namely direct and participative observation, which is discussed below.

4.6.3.1 Direct Observation

In this research, within the primary case study strategy, the direct observation technique is used for data collection in which the role of the researcher was just of a spectator and does not had any direct influence over the processes (or subjects) observed. This type of observation during cases is also known as "passive participation" (Spradley, 1980, p. 59). In differentiating this category of observation from the other Baker (2006, p. 116) states that,

... [It] differs from participant observation in that the researcher does not actually perform the tasks himself, but simply documents the ways in which these tasks are performed.

4.6.3.2 Participant Observation

As the researcher was part of the research team of Science Bridge Project (2010), during that project he used participant observation technique as one of the data collection technique within the action research strategy. Myers (2008, p. 139) defines that:

Participant observation is when you not only observe people doing things, but participate to some extent in these activities as well.

During this process the objective was to interact with the people of team and understand their viewpoint and their activities related to the processes being studied (Myers, 2008). Accordingly the researcher constantly engaged with the team members as an inside member, and recorded the observations related to the research objectives in the field notes all through the project. Nonetheless all the team members were informed and aware of the dual roles (PhD student and team member) of the researcher within the project.

4.6.4 Documentary Evidence

According to Esterberg (2002, p. 121) documents are “any written materials that people leave behind.” Myers (2008), states that the term documents in research during the contemporary period include variety of data forms such as text, audio, pictures and video. As the documents are not prepared or modified for the research, it does address the concerns of researcher bias up to certain extent (Atkinson & Shaffir, 1998). Hence documents such as emails, blogs, web pages, corporate records, magazine articles, newspapers, photographs and videos were used in this research.

> *However, “documents are quick and easy source of information but it does have difficulties such as accessibility and assurance of lack of bias because they are prepared for specific audience” (Myers, 2008, p. 138).*

The issue of accessibility was addressed by negotiating the access for private documents from the case study companies, though most of the documents used in this research are publicly available. In order to address the issue of bias, Scott (1990) put forward four assessment criteria for the documents. They are *authenticity*, *credibility*, *representativeness* and *meaning*. Baker (2006) adds that if the context of the document is taken into account and if it is used as a supplement to other forms of evidence, then the issue of bias can be minimised to a greater extent. Therefore in this research the above mentioned conditions were applied to select the appropriate documents and they were just used as supplementary evidence.

4.7 Research Process

This section answers how the different strategies and methods stated above are employed in this research and how the different components of the research are interlinked. The use of the above discussed research strategies in the different stages of the research are shown in the Figure 4.3. Taking the purpose, resource availability and the need for a sound methodology into account, these various strategies were employed in this research.

As stated above this research is an applied research, where the research problem was developed using the inputs from practice and literature concurrently. Therefore, multiple research strategies employed during the identification of research problem as well (discussed in Chapter3). The first three research objectives (RO1, RO2 & RO3) are derived from the research problem. The research objective RO1 was addressed using the strategies such as action research, qualitative survey research (QSR) and secondary research. Action research and QSR facilitated the collection of requirements by the stakeholders for such a sustainable supply chain risk analysis framework. Secondary research was used to identify the challenges of SME's for adopting sustainability principles and theories and concepts that can underpin the framework.

In addressing the research objective RO2, the secondary research strategy was used to identify the themes from the literature. Followed by that empirical data was collected from primary case studies and QSR. Primary case studies helped to identify the relevant sustainability issues and objectives for the practitioners directly involved in bioenergy supply chain, while QSR strategy was used to collect the information from the external stakeholders. Research objective RO3 was addressed in a similar manner to that of RO2, where the input from secondary case studies were also used in addition to that of primary case studies to strengthen the evidence about the claims of practitioners involved in bioenergy supply chain.

The fourth objective (RO4) was the empirical testing of the framework designed in RO1. The output of RO2 and RO3 were used as input in this experiment. This is depicted in Figure 4.4. Action research strategy was adopted during the application of the framework in a real life project, while the researcher is a research team member of that project. In order to accomplish the objective RO4, analytical tools that process quantitative data have also been applied in this research, which is discussed in Chapter 8. These mathematical techniques were identified through literature review (secondary research). Following the application of the framework, it was evaluated for its future application potential through a focus group with other relevant practitioners in UK (qualitative survey research strategy).

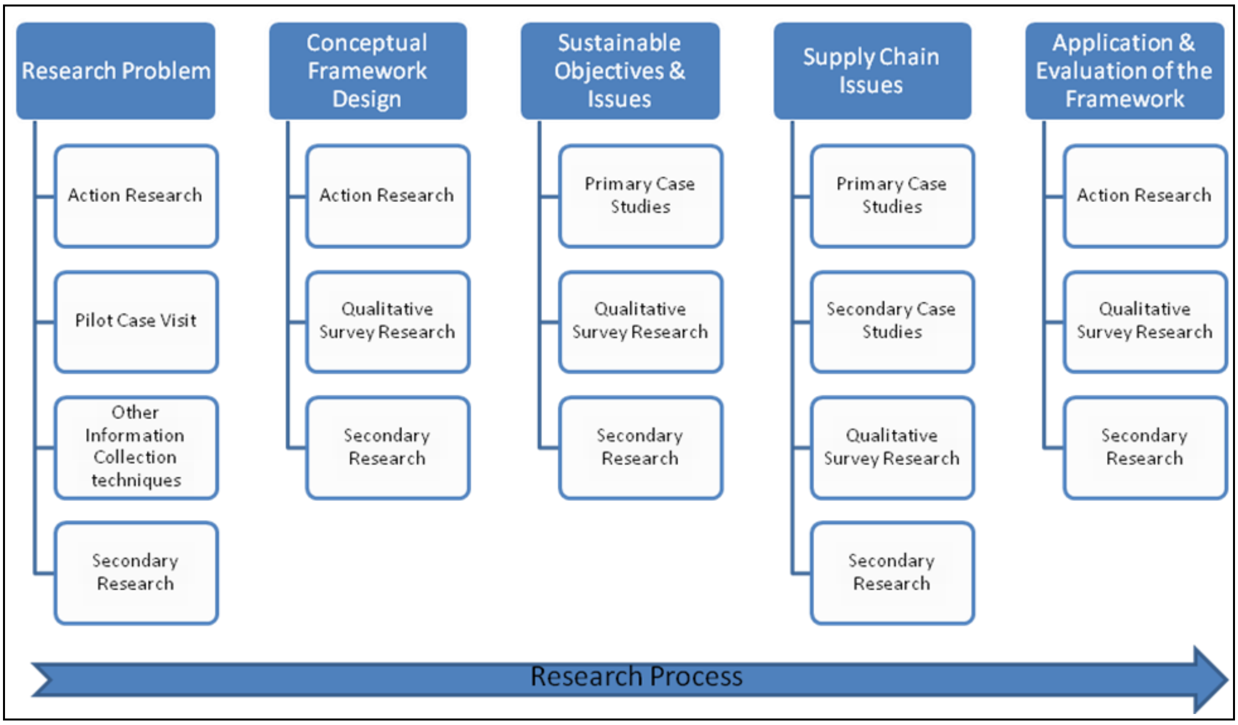

Figure 4.3: Use of the Research Strategies

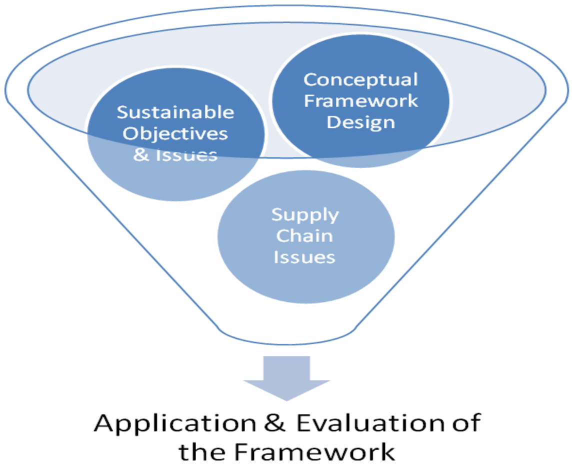

Figure 4.4: Link between the Research Objectives

As this research is a multi-strategy and multi-technique (methods) research, different data collection tools were used in the research strategies shown above to gather information. The information about the number of studies and the data collection techniques used in the different strategies is given in the Table 4.1.

Table 4.1: Information about the Research Strategies

Research strategies	***Case study - Primary***	***Case study - Secondary***	***Action research***	***Qualitative Survey Research***	***Secondary Research***
Number of studies					
Single / Multiple	Multiple	Multiple	Single	Multiple	Multiple
Research techniques					
Interviews	✓	-	✓	✓	-
Focus Groups	✓	-	✓	✓	-
Direct observation	✓	-	-	-	-
Participant Observation	-	-	✓	-	-
Documentary Evidence	✓	✓	✓	-	✓

Chapters 5, 6, 7 and 8 discuss about the four objectives respectively, that also provides more information on the research methodology used to achieve the respective objectives.

4.8 Data Sources

Based on the relevance to the research and the sampling approach described above, the data sources were selected to identify the information that can address the research objectives. As the study was related to the supply chain of bioenergy it was important to collect information from the different process partners in the supply chain. Bioenergy supply chain can be categorised into 6 main process stages given in the Figure 4.5. All these processes were studied with the information from the data sources.

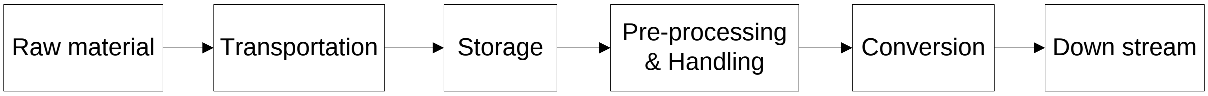

Figure 4.5: Simple Bioenergy Supply Chain

In this research 1 action research case, 13 primary case study cases, 13 secondary case study cases were studied. In addition to the observation and secondary documents, 37 interviews and 9 focus groups were conducted totally to collect information in this research. All sources names were coded in order to maintain the anonymity. The details about these data sources are as follows.

4.8.1 Cases

The Table 4.2below provides the detail about the primary cases used both in the action research and the case study. Case names, type of data collected from the cases and short description about the cases are provided in the table below.

Table 4.2: Details of the Cases

Case	***Data***	***Short Description***
		Action Research
ARC	Interviews (3), Focus groups (4), Participative observation & Documents	This project as a part of Science Bridge Project being implemented in a small village near to Jodhpur, Rajasthan, India. The researcher as a participant of the Science Bridge Project is related to this case, however not a direct decision maker in this work package. **Business:** Captive bioenergy power plant for the planned (self-owned) downstream industries. **Outputs:** Tri-generation (Electricity, Heat and Cold) **Capacity:** 2 MW equivalent **Technology:** Combustion **Processes:** Storage, Pre-processing & handling, Conversion & Downstream
		Primary Case Study
PCS1	Interviews (2), Observation	This plant is setup in a village near to a major textile hub in Tamil Nadu, India. PCS7 is their major biomass supplier.

Case	*Data*	*Short Description*
	&Documents	**Business:** Captive bioenergy power plant for the self-owned textile processing industry. **Outputs:** Heat **Capacity:** 435 KW equivalent **Technology:** Combustion **Processes:** Storage, Conversion & Downstream
PCS2	Interviews (2), Observation & Documents	This plant is setup in an educational institution in Tamil Nadu, India. **Business:** Captive bioenergy power plant that supply power to the student hostel buildings. **Outputs:** Electricity **Capacity:**100 KW electric **Technology:** Gasification **Processes:** Raw material, Transportation, Storage, Pre-processing & handling, Conversion & Downstream
PCS3	Interviews (3), Observation & Documents	This plant is run by the government. It is situated in a rural area of Karnataka, India. Total installed capacity is 1 MW electric but it is spilt into five small modular units' setup at 3 different locations in a cluster of villages. The size of the modular units ranges from 300 KW to 100 KW. **Business:** Bioenergy power plant that supply power to the grid. **Outputs:** Electricity **Capacity:** 1 MW electric (in total) **Technology:** Gasification **Processes:** Raw material, Transportation, Storage, Pre-processing & handling & Conversion
PCS4	Interviews (2) & Observation	The plant is located in an expanding town in the South Indian state of Tamil Nadu. **Business:** Captive bioenergy power plant for the self-owned rice mill. **Outputs:** Heat **Capacity:**165 KW equivalent **Technology:** Combustion **Processes:** Raw material, Transportation, Storage, Pre-processing & handling, Conversion & Downstream
PCS5	Interviews (1)	The plant is situated in the South Indian state of Tamil Nadu.

Case	*Data*	*Short Description*
	&Observation	**Business:** Captive bioenergy power plant for the self-owned textile processing industry. **Outputs:** Heat **Capacity:** 23 KW equivalent **Technology:** Combustion **Processes:** Storage, Conversion & Downstream
PCS6	Interviews (1) & Documents	The plant is situated in rural Bihar in India. **Business:** Off-grid bioenergy power plant that supply power to the rural community. **Outputs:** Electricity & Heat **Capacity:** 32 KW electric **Technology:** Gasification **Processes:** Raw material, Transportation, Storage, Pre-processing & handling & Conversion
PCS7	Interviews (1), Observation & Documents	This plant is situated in a village in Tamil Nadu, India. PCS1 is one of their customers of bio-bricks. Also, PCS11 is one of their suppliers of agro residues. **Business:** Producing bio-bricks by using the agro residues. That is supplied to the bioenergy plants. **Outputs:** Bio-bricks **Capacity:** 20 tonnes per day **Processes:** Transportation, Storage, Pre-processing & handling
PCS8	Interviews (2)	This plant is situated in Gujarat, India. **Business:** Producing bio-bricks by using the agro residues. That is supplied to the bioenergy plants. **Outputs:** Bio-bricks **Capacity:** 30 tonnes per day **Processes:** Transportation, Storage, Pre-processing & handling
PCS9	Interviews (1) & Documents	A privately owned grid supply plant in Tamil Nadu, India. **Business:** Bioenergy power plant that supply power to the grid. **Outputs:** Electricity **Capacity:** 1 MW electric (in total) **Technology:** Gasification **Processes:** Storage, Pre-processing & handling & Conversion

Case	***Data***	***Short Description***
PCS10	Interviews (1)	A large saw mill in Tamil Nadu, India. **Business:** Selling the industrial by-product, saw dust to the bio-bricks producers. **Outputs:** Sawdust **Processes:** Raw material
PCS11	Focus groups (1) & Observation	A group of farmers (6) from a community in Kerala, India (near to Tamil Nadu Border). PCS7 is the major buyer of their agro residues. **Business:** They sell their suitable agricultural by-products such as residues to the bio-bricks producers. **Processes:** Raw material
PCS12	Interviews (1), Focus groups (1) & Observation	A group of farmers (10) + an interview from a community in Punjab, India (near to Rupnagar). **Business:** They sell their suitable agricultural by-products such as residues to the bio-bricks producers. **Processes:** Raw material
PCS13	Interviews (1), Observation & Documents	An upcoming plant in a major town in Tamil Nadu, India. Plant was under construction during the visits. **Business:** Captive bioenergy power plant for the self-owned shopping complex and hotel. **Outputs:** Tri-generation (Electricity, Heat and Cold) **Capacity:** 2MW equivalent **Technology:** Gasification **Processes:** Storage, Pre-processing & handling, Conversion & Downstream

Apart from the above stated primary cases where the researcher collected the data directly, secondary cases were also used as additional information to address the research objective RO3. The report on the secondary case studies belongs to the PCS3, and they have provided access to the researcher to use that in this study. This report contains information about the 13 cases that uses gasification technology only; details of these cases are given in Table 4.3. These case studies were conducted during 2005 by the consultants appointed by the PCS3. This study was conducted in order to inform the PCS3 about the performance and barriers of the bioenergy plants with gasification technology. The information was used by them to support their decision making related to the system configuration and strategic decisions in the planning stage of the system. As the performance and barriers of the bioenergy plants (small scale) relate to the supply chain issues of the small scale bioenergy projects in India, these cases were considered in this research to achieve the related objective RO3. As this was secondary case study, the data from these cases were considered only as supplementary information. Furthermore, in order to avoid any bias the following properties of the report were taken into account:

- The study was limited to gasification technology only. It considered both complete producer gas system and dual fuel system.
- The study was conducted mainly in conversion plants; however most of the plants had other supply chain operations within their unit.
- The study limitation given in the report, which is quoted below, was also considered.

> *Most of the units observed that the data questionnaire was very exhaustive and the units do not have the classified data. Units in general are very reluctant to share the actual field data especially the financials and absence of the authentication letter from MNES [current MNRE] added to the cause. Thus, xxxxx consultants based on the discussions, observations and log sheets filled the data questionnaire. Some units refused to share any details in the absence of MNES [MNRE] letter. This resulted in a considerable delay in the unit visit scheduling and data collection. Thus, the study is based only on the data collected during the site visit and not furnished by the unit. (Report for PCS3, 2005)*

Table 4.3: Details of the Secondary Cases

Case	***Short Description***
SCS1	This plant is setup in an educational institution in Pondicherry, India. **Business:** Captive bioenergy power plant that supply power to the administrative block of the college. **Outputs:** Electricity **Capacity:** 100 KW electric **Technology:** Gasification - Dual fuel mode power generator (Biomass +Diesel)
SCS2	The plant is situated in the state of West Bengal in India. **Business:** Off-grid bioenergy power plant that supply power to the rural community. **Outputs:** Electricity **Capacity:** Total 500 KW electric (4 units of 125 KW each) **Technology:** Gasification - Dual fuel mode power generator (Biomass +Diesel)
SCS3	This plant is setup in an educational institution in Tamil Nadu, India. **Business:** Captive bioenergy power plant that supply power to the labs in the college. **Outputs:** Electricity **Capacity:** 100 KW electric **Technology:** Gasification

Case	*Short Description*
SCS4	The plant is located in the state of Maharashtra, India. **Business:** Captive bioenergy power plant for the self-owned Ferro Alloy plant. **Outputs:** Electricity **Capacity:** 500 KW electric **Technology:** Gasification - Dual fuel mode power generator (Biomass +Diesel)
SCS5	This plant is setup in a community based project in Tamil Nadu, India. **Business:** The project is commissioned to meet the energy requirement of the raw water pumping station in a village. **Outputs:** Electricity **Capacity:** 9 KW electric **Technology:** Gasification
SCS6	This plant is setup in a community based project in Tamil Nadu, India. **Business:** The project is commissioned to meet the energy requirement of the raw water pumping station and the lighting of the surrounding area in a village. **Outputs:** Electricity **Capacity:** 10 KW electric **Technology:** Gasification
SCS7	This plant is setup in an educational institution in Tamil Nadu, India. **Business:** Captive bioenergy power plant that supply power to the student hostels. **Outputs:** Electricity **Capacity:** 90 KW electric **Technology:** Gasification - Dual fuel mode power generator (Biomass +Diesel)
SCS8	This plant is setup in an educational institution in Tamil Nadu, India. **Business:** Captive bioenergy power plant that supply power to the student hostels and college buildings. **Outputs:** Electricity **Capacity:** Total 300 KW electric (200KW Biomass + 100KW Dual mode) **Technology:** Gasification - Dual fuel mode power generator (Biomass +Diesel)
SCS9	The plant is located in the state of Tamil Nadu, India. **Business:** Bioenergy power plant supplying to the partner, Food-Oil industry. **Outputs:** Electricity **Capacity:** 100 KW electric **Technology:** Gasification
SCS10	The plant is located in the state of Tamil Nadu, India. **Business:** Captive bioenergy power plant for the self-owned chemical factory. **Outputs:** Electricity

Case	*Short Description*
	Capacity: 200 KW electric **Technology:** Gasification
SCS11	The plant is situated in the state of West Bengal in India. **Business:** Off-grid bioenergy power plant that supply power to the rural community. **Outputs:** Electricity **Capacity:** Total 500 KW electric (5 units of 100 KW each) **Technology:** Gasification - Dual fuel mode power generator (Biomass +Diesel)
SCS12	This plant is setup in an educational institution in Karnataka, India. **Business:** Bioenergy power plant that supply power to the partner, college buildings. **Outputs:** Electricity **Capacity:** Total 200 KW electric (2*100KW Dual mode systems each) **Technology:** Gasification - Dual fuel mode power generator (Biomass +Diesel)
SCS13	The plant is located in the state of Tamil Nadu, India. **Business:** Bioenergy power plant supplying to the partner, textile industry. **Outputs:** Electricity **Capacity:** 120 KW electric **Technology:** Gasification

4.8.2 Interviewees

The details about the participants interviewed in the action research and primary case studies are given in Table 4.4.

Table 4.4: Interviewees Related to the Cases

Case	*Interviewee*	*Short Description*
		Action Research
ARC	**ARC-IN1**	**Position:** Co-principal investigator of the project and head of the work package related to the upcoming bioenergy plant. He is a senior professor in the engineering department of a renowned Indian institution. **Experience:** 30 + years of experience in teaching and research. **Process:** Initially 45mins interview was conducted to get information about the project followed by multiple informal discussions were conducted with the participant during the course of the project.

Case	Interviewee	Short Description
ARC	**ARC-IN2**	**Position:** Deputy in charge of the work package related to the upcoming bioenergy plant. She is a senior professor in the rural development department of a renowned Indian institution. **Experience:** 30 + years of experience in teaching and research. **Process:** Initially 60mins interview was conducted to get information about the project followed by multiple informal discussions were conducted with the participant during the course of the project.
ARC	**ARC-IN3**	**Position:** Partner in charge for the installation and operation of the upcoming bioenergy plant. He is the administrative head of a NGO working in various projects related to the social and rural development. **Experience:** 20 + years of experience in NGO and rural development. **Process:** Initially 45mins interview was conducted to get information about the project followed by multiple informal discussions were conducted with the participant during the course of the project.
	Primary Case Study	
PCS1	**PCS1-IN4**	**Position:** Owner of the factory. **Experience:** 5 + years of experience in bioenergy **Process:** Initially had an informal discussion during the pilot visit and then another 30mins interview was conducted.
PCS1	**PCS1-IN5**	**Position:** Manager of the bioenergy unit. **Experience:** 15 + years of experience in bioenergy **Process:** 45mins interview
PCS2	**PCS2-IN6**	**Position:** In charge of the bioenergy unit. Associate professor in the institution. **Experience:** 10 + years of experience in bioenergy **Process:** 45mins interview
PCS2	**PCS2-IN7**	**Position:** Operator of the bioenergy unit. **Experience:** 7 + years of experience in bioenergy **Process:** 30mins interview
PCS3	**PCS3-IN8**	**Position:** Head of the government department to manage the bioenergy unit. Senior Indian Forest Service Officer. **Experience:** 25 + years of experience in Forestry and 10+ years of experience in bioenergy

Case	*Interviewee*	*Short Description*
		Process: 60mins interview
PCS3	**PCS3-IN9**	**Position:** Project Engineer of the bioenergy unit. **Experience:** 20 + years of experience in engineering and bioenergy **Process:** 60mins interview
PCS3	**PCS3-IN10**	**Position:** Operator at one (out of 3) of the bioenergy site. **Experience:** 3 + years of experience in bioenergy **Process:** 30mins interview
PCS4	**PCS4-IN11**	**Position:** Partner of the factory. **Experience:** 25 + years of experience in bioenergy **Process:** 30mins interview
PCS4	**PCS4-IN12**	**Position:** Partner of the factory. **Experience:**6 + years of experience in bioenergy **Process:**20mins interview
PCS5	**PCS5-IN13**	**Position:** Owner of the factory. **Experience:** 8 + years of experience in bioenergy **Process:** 45mins interview
PCS6	**PCS6-IN14**	**Position:** Ex- in charge of the bioenergy unit. Currently Bioenergy Scientist in MNRE. **Experience:** 20+ years of experience in bioenergy **Process:** 60mins interview
PCS7	**PCS7-IN15**	**Position:** Owner of the bio-brick unit. **Experience:** 10 + years of experience in bioenergy **Process:** 45mins interview
PCS8	**PCS8-IN16**	**Position:** Partner of the factory. **Experience:** 3 + years of experience in bioenergy **Process:** 45 min interview
PCS8	**PCS8-IN17**	**Position:** Partner of the factory. **Experience:** 3 + years of experience in bioenergy **Process:** 20 min interview
PCS9	**PCS9-IN18**	**Position:** Ex- project engineer of the bioenergy unit. Currently an engineering institution lecturer. **Experience:** 10 + years of experience in bioenergy. **Process:** 30 min interview
PCS10	**PCS10-IN19**	**Position:** Owner of the saw mill. **Experience:** 12 + years of experience in timber industry **Process:** 30 min interview

Case	Interviewee	Short Description
PCS12	**PCS12-IN20**	**Position:** Farmer selling the agro residues. Also a part time technician in the field of electrical engineering. **Experience:** 10 + years of experience in farming **Process:** 30 min interview
PCS13	**PCS13-IN21**	**Position:** Project manager of the upcoming plant. **Experience:** 7 + years of experience in bioenergy **Process:** 45 min interview

The bioenergy relevant stakeholders such as equipment suppliers, government officials, bank officials, NGO people, consultants and researchers have been interviewed in this research in addition to the case study participants mentioned above. Information about them and their interview details are given in Table 4.5.

Table 4.5: Interviewees from the Related Stakeholder Groups

Interviewee	*Short Description*
	Bioenergy Technology Equipment Suppliers
QSR-IN22	**Position:** Owner of the industry manufacturing and supplying boilers and turbines for bioenergy sector. They are the suppliers of the components to ARC project. (Head office in New Delhi) **Experience:** 20 + years of experience in the sector **Process:** 60mins interview
QSR-IN23	**Position:** Manager of the industry supplying producer gas engines for the bioenergy sector. (Based in Bangalore) **Experience:** 5 + years of experience in the sector **Process:** 20mins interview
	Government Officials Related to the Bioenergy Department
QSR-IN24	**Position:** Scientist in the field of bioenergy, MNRE. **Experience:** 10 + years of experience in the sector **Process:** 30mins interview
QSR-IN25	**Position:** In charge for the bioenergy sector under renewable energy development department in one of the south Indian state. **Experience:** 20 + years of experience in the sector **Process:** 60mins interview
QSR-IN26	**Position:** In charge for the bioenergy sector under renewable energy development department in another one of the south Indian state. **Experience:** 15 + years of experience in the sector **Process:** 20mins interview

Interviewee	***Short Description***
	Bank Officials Related to the Renewable Energy Financing
QSR-IN27	**Position:** Financial manager for the bioenergy sector in a government bank for renewable energy development (Delhi) **Experience:** 7 + years of experience in the sector **Process:** 30mins interview
QSR-IN28	**Position:** Manager of a privatised bank which have provided loans for PCS1 bioenergy plant. (Tamil Nadu) **Experience:** 20 + years of experience in the sector **Process:** 20mins interview
	NGO Officials Working in the Bioenergy Sector
QSR -IN29	**Position:** Manager of a NGO that provides support to develop biomass gasifier based power plants in rural areas. (Karnataka) **Experience:** 5 + years of experience in the sector **Process:** 30mins interview
QSR -IN30	**Position:** Director of a NGO that provides support to develop biogas based power plants in rural areas. (Tamil Nadu) **Experience:** 10 + years of experience in the sector. **Process:**20mins interview
	Consultants Working in the Renewable Energy Sector
QSR -IN31	**Position:** Consultant in an organisation that provides support to develop bioenergy projects. Consultant for the PCS13 project as well. (Tamil Nadu) **Experience:** 8 + years of experience in the sector **Process:** 45 min interview
QSR -IN32	**Position:** Free lancing consultant (part time) who provides services to develop small scale renewable energy projects. (Tamil Nadu) **Experience:** 13 + years of experience in the sector **Process:** 30 min interview
	Relevant Researchers
QSR -IN33	**Position:** Associate Professor (Gujarat) in Mechanical engineering field. **Experience:** During the past 3+ years working in the bioenergy sector **Process:** 45mins interview
QSR -IN34	**Position:** Researcher (Punjab) in Chemical engineering field. **Experience:** During the past 5+ years working in the bioenergy sector **Process:** 20mins interview
QSR -IN35	**Position:** Professor (Delhi) in Management field. **Experience:** During the past 3+ years working in the bioenergy sector **Process:** 30mins interview

Interviewee	Short Description
QSR -IN36	**Position:** Professor (Punjab) in Rural development field. **Experience:** During the past 15+ years working in the bioenergy sector **Process:** 30mins interview
QSR -IN37	**Position:** Associate Professor (Delhi) in Mechanical engineering field. **Experience:** During the past 15+ years working in the bioenergy sector **Process:** 20mins interview

4.8.3 Focus Groups

Focus groups were conducted in the research strategies that use primary data namely *action research, case study* and *qualitative survey* research. These focus groups were partly used in addressing all the four research objectives. Details of these focus groups are given in Table 4.6.

Table 4.6: Details of the Focus Groups

Case	*Focus Group*	*Short Description*
		Action Research
ARC	**ARC-FG1**	**Participants:** 4 People - Two people in charge of the case work package, 1 operating partner of the case project and 1 in charge of the 'management solution for bioenergy' work package. **Process:** This focus group was mainly looking at the decision support required by the team for a sustainable bioenergy project. This focus group with its inputs helped to design the conceptual framework (RO1). The discussions were held in Delhi. (Duration: 2 hours)
ARC	**ARC-FG2**	**Participants:** 3 People - Two people in charge of the case work package and operating partner of the case project **Process:** This focus group with its inputs helped to apply the analysis framework in the project, with direct input from the project owners (RO4). This was conducted in UK. (Duration: 3 hours)
ARC	**ARC-FG3**	**Participants:** 9 People - All the participants were experts in bioenergy with varied speciality such as engineering, management, sustainability, rural development etc. Six people in that were members of the science bridge project. Three among them had very good contextual understanding of the ARC project but were not directly related to the work package.

Case	Focus Group	Short Description
		Process: This focus group with its inputs helped to apply the analysis framework in the project, with input from the relevant experts (RO4). This was conducted in UK. (Duration: 3.5hours)
ARC	**ARC-FG4**	**Participants:** 5 People - Two people in charge of the case work package, operating partner of the case project and two experts with very good contextual understanding of the ARC project. **Process:** This focus group was conducted into two segments, in two different days. A first day inputs helped to apply the analysis framework in the project (RO4). Second day the framework outputs, suitable mitigation measures and the functionality of the framework were discussed in detail (RO4). The discussions were held in UK. (Duration: 4 hours)
Primary Case Study		
PCS11	**PCS11-FG5**	**Participants:** A group of farmers (6) from a community in Kerala, India. **Process:** The discussions were related to the objectives RO2 & RO3. It was conducted in their village. (1.5 hours long)
PCS12	**PCS12-FG6**	**Participants:** A group of farmers from a community in Punjab, India (near to Rupnagar). **Process:** The discussions were related to the objectives RO2 & RO3. It was conducted in their village. (Duration: 2 hours)
Qualitative Survey Research		
QSR	**QSR-FG7**	**Participants:** 8 People - A mixed group of practitioners(2), NGO officials (1), consultants(2), policy makers (1) and researchers (2) related to the bioenergy sector from India **Process:** The discussions were related to the objectives RO1, RO2 & RO3. It was conducted in Delhi. (Duration: 2 hours)
QSR	**QSR-FG8**	**Participants:** 10 People - A group of research experts in different fields such as engineering, management, rural development, sustainability, waste management, agriculture and water management from India(9) and USA(1). **Process:** The discussions were related to the objectives RO1, RO2 & RO3. It was conducted in Delhi. (Duration: 3hours)
QSR	**QSR-FG9**	**Participants:** 7 People - A mixed group of practitioners (1), NGO officials (1), consultants (1), city council official (1) and researchers (3) related to the renewable energy and sustainability sector from UK.

Case	Focus Group	Short Description
		Process: The discussions were related to the evaluation of the framework for further use (RO4). It was conducted in UK (Duration: 1.5 hours).

4.9 Research Execution

Following steps were taken in order to effectively execute the research.

> *One of the biggest problems for qualitative researchers can be gaining access to the research site. You have to get past the gatekeepers to do the research. (Myers, 2008, p. 141)*

In this project, access to the action research case was bit easy when compared to other sources because the researcher was a team member of the Science Bridge project. In general access to the SME's and their data in India for research was limited. It might be because of the developing state of the research in India. Researcher got in touch with the suitable companies through his personal networks and the contacts built during the practitioner conferences. During the initial communications the companies were given short description of the project and information about the data required. Some of the requests have been turned down. Most of the participants have agreed to provide access. For that, the researcher is immensely thankful to them.

> *It can be helpful to construct an interview guide for use in talking with interviewees. (Myers, 2008, p. 133)*

The appropriate topic guides were developed beforehand, based on the literature and used as a navigator during the discussion to cover all the relevant topics. These topic guides were used in semi structured interviews and focus groups.

> *All evidence collected by the researcher should be recorded in an ordered and coherent manor for subsequent analysis and reflection. (Scapens et al., 2002, Ch:8, p.24)*

Most of the interviewees preferred not to tape record their conversation. Therefore, in this research all the data were noted down in the field work notebooks. Even few of the interviews and focus groups that have been recorded were used as a verifier for the discussion notes. These discussion notes were then transferred into a digital document to be used for analysis. All the data obtained are securely stored and maintained in electronic format for easy and quick access and accountability.

4.10 Data Analysis

> *[Need for] ...the analysis and interpretation of qualitative data is that a qualitative researcher almost always ends up with a huge amount of data. It is obvious that you cannot possibly include all of your data in a thesis. (Myers, 2008, p. 166)*

The research data need to be reduced or edited into a manageable form and it should also be meaningful. Qualitative data analysis methods allow us to interpret the data by focusing on the important aspects of the data and convey the insights of the study (Myers, 2008). Miles and Huberman (1994) defines three components of data analysis as data reduction, data display and conclusion drawing and verification. The interaction between the components of data analysis and data collection is portrayed in Figure 4.6 (Source: Miles & Huberman, 1994). They also argue that clear distinction between data collection and analysis is difficult in qualitative research because most of the time there will be repetitive activities between the various phases of a qualitative research project. Scapens et al. (2002) suggests that this type of parallel approach can be very helpful for evaluation and progression of themes. Therefore, in this research the part of data analysis such as transcribing the data, identifying patterns and explaining patterns were carried out in parallel to the data collection stage. The types of data analysis components used in this research are described below.

Figure 4.6: Components of Data Analysis

(Source: Miles & Huberman, 1994)

4.10.1 Data Reduction

Thematic analysis has been used as "...a method for identifying, analysing and reporting patterns (themes) within data" (Braun & Clarke, 2006, p. 79). In this research it was mainly applied to identify, interpret and explain the various aspects related to the topic of interest. This method was adopted in this research for analysing the data because of its appropriateness to respond to the research objectives, suitability with the research paradigm and other advantages given in the Table 4.7 (Source: Braun & Clarke, 2006).

Braun and Clarke (2006) argues that although it's straight forward to conduct a good thematic analysis there are potential pitfalls that might result into a poor analysis. Therefore in order to overcome the disadvantages and to conduct a rigorous analysis they propose a six step approach that has been followed in this research. The six steps of thematic analysis are familiarizing with data, generating initial codes, searching for themes, reviewing themes, defining and naming themes and producing the report.

Aston University

Illustration removed for copyright restrictions

(Source: Braun & Clarke, 2006)

The themes identified during the analysis, “capture something important about the data in relation to the research question, and represent some level of patterned response or meaning within the data set” (Braun & Clarke, 2006, p. 82). Inductive approach and deductive approach are the two primary ways of identifying the themes within the data. In inductive approach the themes are developed from the data and in the deductive approach the themes are developed from the theory. In this research a combined approach has been used, where the themes were developed using a hybrid inductive and deductive approach (Fereday & Muir-Cochrane, 2008; Joffe & Yardley, 2004). This hybrid approach provides room for both the theoretical and emerging empirical perspective in the data.

The literature was reviewed to address three main purposes they were, to identify the research gap, to identify, to understand and explain the relevant theories and concepts and to identify the deductive approach themes. The themes have been developed by integrating the findings of multiple studies by using the ‘thematic synthesis’ approach. Thematic synthesis is a “method that preserves an explicit and transparent link between conclusions and the text of primary studies; as such it preserves principles that have traditionally been important to systematic reviewing” (Thomas & Harden, 2008, p. 1). As the results of the thematic synthesis depend on the range of concepts found in the studies (conceptual saturation) rather than the statistical model that underpin the analysis as in the traditional meta-analysis, "it may not be necessary to locate every available study" (Thomas & Harden, 2008, p. 3). Therefore obtaining 'conceptual saturation' was the principle that underlies the literature search strategy for developing deductive themes (for thematic analysis) in this research. The themes developed in this literature review part of the study were both 'descriptive themes' and 'analytic themes'. While the descriptive themes relate directly to the primary studies, the analytical themes generate new themes based on the interpretation of the primary studies (Thomas & Harden, 2008). Sample coding of a field note transcript of an interview (PCS2 - IN6) is given in Appendix 7.

4.10.2 Data Display

"A [data] display is an organized, compressed assembly of information that permits conclusion drawing and action" (Miles & Huberman, 1994, p. 11). 'Extended text' is the frequently used data display method in qualitative research, however this type of display is very huge and it can exceed the information processing capabilities of the humans. This can lead to "hasty, partial and unfounded conclusions" (Miles & Huberman, 1994, p. 11). Therefore, in this research matrix data display approach has been used to show the information collected in a compiled, organized and compact form. This approach allowed accessing the analysed data in a quick and easy way that was used to understand the data and draw justified conclusions. (Miles & Huberman, 1994)

4.10.3 Conclusion Drawing and Verification

As in any qualitative research the process of identifying the regularities, patterns and explanations had started from the beginning of data collection itself. However these interpretations were considered tentative and the final conclusion drawing was carried out after the end of data collection as suggested by Miles and Huberman (1994). Some of the 'tactics' recommended by Miles and Huberman (1994) that has been used in this research to draw conclusions were noting themes, plausibility, clustering, making contrasts/comparisons, subsuming particulars into general, building logical chain of evidence and making conceptual coherence. Drawing conclusion is only half of the process. The other half is to confirm those findings. For that checking for representativeness, checking for researcher effects, triangulating, following up surprises, looking for negative evidence and getting feedback from informants were some of the tactics that has been used in this research (Miles & Huberman, 1994).

4.11 Standards for the Quality of Conclusions

> *The major justification for the research enterprise is that we have the time and skills to develop approximations of the truth that have a firmer warrant than common sense (Firestone, 1990, p.123 cited in Miles & Huberman, 1994).*

‘Firmer warrant’ requires high quality conclusions in order to achieve that we need to conduct a rigours research. Most generally accepted three axioms for a sound research methodology are reliability, validity and representativeness or generalizability (Lee & Lings, 2008). According to Kirk and Miller (1986), the objectivity of social scientific research is at stake on the issues of rigour such as reliability and validity. Kirk and Miller (1986) defines reliability as “the degree to which the finding is independent of accidental circumstances of the research” (p.20) and describe the validity as the concern for “whether or not the researcher is calling what is measured by the right name” (p.69).

Although, Riley et al. (2000) argues that we need to be careful in applying these concepts as they are the reflections of the positivist paradigm. Scapens et al. (2002, Ch.8, p.28) suggests that:

> *Whereas traditionally, empirical, and especially quantitative researchers have talked about reliability, validity and generalizability, we [qualitative researchers] should think in terms of procedural reliability, contextual validity and transferability.*

In order to increase the reliability and validity of findings in this research, following steps were taken based on the suggestions from scholars in this field (Lee & Lings, 2008; Miles & Huberman, 1994; Scapens et al., 2002; Schlappa, 2009). In this research:

- Clearly specified research questions were addressed with a matching research design that contains appropriate research methods and strategies.
- An appropriate sample within the defined study population that is relevant to the research questions has been selected both for cases and participants.
- The data collection tools such as interviews, focus groups, field work and documentary evidence were selected to provide flexibility, openness and rigour in data collection.
- Data was collected and recorded systematically. Then these data were checked for quality based on the informant bias and knowledgeability.
- Themes developed during analysis were double checked for accuracy, relevancy and consistency. The empirical data was related to the prior theory using the hybrid thematic analysis. This hybrid approach also provided the freedom for the theories to emerge out of the data.
- Triangulation of data sources and methods had been achieved in this research and findings were drawn based on the convergence in the data.
- In this chapter, to improve the rigour of the work, research paradigms of the researcher, role of the researcher within the sites and in relation to the participants have been clearly described.
- In addition to the above steps, this research process has gone through continuous peer review process by both the supervisors and other experts to check and improve the rigour of the research.

Representativeness or generalizability of the research is more related to the use of the research. In order, to increase the generalizability of the work cross-checking and comparison through multiple case studies were facilitated. Riley et al. (2000, p. 20) states that, as:

> *The explanatory power of a piece of research is increased the more likely it is believed to be applicable to subjects beyond the sample studied and replicable / reproducible by other researchers.*

Therefore, apart from the findings, the complete research process has been thoroughly explained in this research. In addition to that, the confidence on generalisation of the qualitative work can also be increased by offering a conceptual framework rather than a narrative, which can relate theory (Eisenhardt & Brown, 1998). Therefore, in this work a conceptual framework had been developed to address the purpose that connects the theories and concepts in a coherent way which can improve the generalizability of this study's findings.

4.12 Research Ethics

Oxford English dictionary defines the ethics as, "a set of moral principles and rules of conduct, morally correct, honourable". Research ethics, "addresses the question of how to conduct research in a moral and responsible way" (Blumberg et al., 2005, p. 91). In this work, ethical issues were carefully addressed in all the stages of the research in order to protect both participants and researcher from any harm, to preserve the participant's rights and to protect the reputation of researcher and their organisation. The researcher has adhered to the ethical guidelines set by the Aston Business School (2010) during this research. The detailed research plan had been scrutinised for any potential ethical issues, before the data collection began by the Aston Business School through a stringent ethical review process.

Some of the important ethical issues addressed in this research were selection of participants, obtaining informed consent, maintaining anonymity and confidentiality and secure data storage. The selection of participants was completely based on the relevance to the research purpose and utmost consideration has been given to avoid any bias in the selection of human respondents in terms of gender, race and ethnicity. Description of the use and procedures of the research, benefits to the subject or others, the likely time will be taken if the subject gets involved, voluntary participation and the freedom to stop the data collection anytime, the additional relevant information available to subjects after participation were some of the information that had been provided to the subjects in this research and written or verbal consent of participants had been obtained. Anonymity was assured and maintained for all the participants in this research. They had also been informed on how the confidentiality of records will be maintained, disclosure and description of the approved agencies and /or other designated parties that may access the records and how the data will be secured and stored.

4.13 Chapter Summary

Answering the question 'how it was carried out' is an important part for any research, as it enlighten the reader with the knowledge of production process that help them to evaluate the findings. Therefore this chapter has discussed about the research philosophy, research design and the components and considerations of the research design relevant to this project. The author of this study held a realist philosophical perspective during this research. Case study (primary and secondary), action research, qualitative survey research and secondary research were the important research strategies applied in this research, which used the data collection tools such as interviews, focus groups, observation and documentary evidences. The collected data was analysed using thematic analysis approach and displayed using matrix display. Noting themes, plausibility, clustering, making contrasts/comparisons, subsuming particulars into general, building logical chain of evidence and making conceptual coherence were some of the approaches used to draw conclusion and which is verified by checking for representativeness, checking for researcher effects, triangulating, following up surprises, looking for negative evidence and getting feedback from informants in this research. Ethical and quality considerations were taken into account and appropriate actions were taken to address those during the research. Given the research objectives in Chapter 3 and research design in this Chapter, the following chapters discuss the results for the research objectives respectively.

Chapter Five: The Conceptual Framework

5.1 Introduction

This chapter addresses the research objective RO1 that is 'to develop a sustainable supply chain risk analysis framework'. In Chapter 3, it has been identified that sustainable supply chain is important for the bioenergy industry and is essential for the success of the industry. It has also been recognised that due to the complexity involved in decision making process, there is a need for a decision support system (DSS) to achieve it. Therefore, in response, this part of the research develops a risk based decision support system that can analyse the supply chain sustainability to support practitioner decision making.

5.2 Approach to Develop the Framework

Mitroff et al. (1974) have proposed four stages of problem solving from systems point of view namely reality, conceptual model, scientific model and solution. Their interconnections are represented in the Figure 5.1 (Source: Mitroff et al., 1974). The conceptual model (second stage) developed through conceptualisation is presented in this chapter, whereas the scientific model (third stage) and the solution (fourth stage) of the problem are discussed in Chapter 8. Vaughan (2008) states that conceptual frameworks are of two forms namely, process frameworks and content frameworks. This work develops a process framework that addresses the how question and "set[s] out the stages through which an action moves from initiation to conclusion" (Vaughan, 2008, p. 14).

The steps taken to design the conceptual framework are shown in Figure 5.2. The different research strategies and research techniques adopted at this phase of the research are shown in Figure 4.3 and Table 4.1. The research problem had been established using practitioners and academic view point in the Chapter 3; however along with that the literature is also been reviewed simultaneously in order to know the current state of knowledge and to identify potential research gap. That is presented in the next section of this chapter.

Corley and Gioia (2011) conclude that in the management field the connection between the efforts to build theories and the practical relevance of those theories are very limited. Therefore they suggest that, we should address "a problem of direct, indirect or long linked relevance to practice, rather than narrowly addressing the (theoretical) problem" and such a problem solving should integrate the "scientific and practical utility dimensions" (Corley & Gioia, 2011, p. 22). Holmström et al. (2006) also argues that in operations management the specifications of the solution designs should be suitable to apply in practice. With this in mind, during the 'conceptualisation' (Mitroff et al., 1974) process, the specifications or requirements of the framework was identified through focus groups with practitioners and experts (ARC-FG1, QSR-FG7 and QSR-FG8) and secondary research, following the identification of need for the framework. The two main themes in this data collection process were to identify the influencers, enablers and constraints in implementing sustainable supply chain in small scale industries and the required features of the framework, so that it can be easily usable by the small and medium enterprises (SME).

The practical utility of the academic contributions can be increased by developing 'theoretical prescience' that can predict and influence the managerial knowledge required (Corley & Gioia, 2011). They suggest that to develop such a knowledge prospective sense making and sense giving approach are needed that can, give "meaning to ambiguous informational cues and articulating viable interpretations [(sense making)] and actions to cope with coming organisational and environmental demands [(sense giving)]" (p.24). It was therefore paramount that within this research an understanding of the practical issues was developed through the sense making approach during the research need, the requirements of the framework and the literature review steps.

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Figure 5.1: Systems View of Problem Solving

(Source: Mitroff et al., 1974)

Then through 'disciplined imagination' (Weick, 1989) process the framework was developed. Where large amount of literature was reviewed and few appropriate concepts and theories were selected from that to make the conceptual integration that is given in Section 5.5. However, the process of conceptual integration was iterative and went through multiple phases of development and refinement. Using the sense giving approach, the framework draws the contributions of a large amount of prior research that is integrated to address the research need and requirements for practical application. The integrated framework is described in the Section 5.6 after the relevant themes section below.

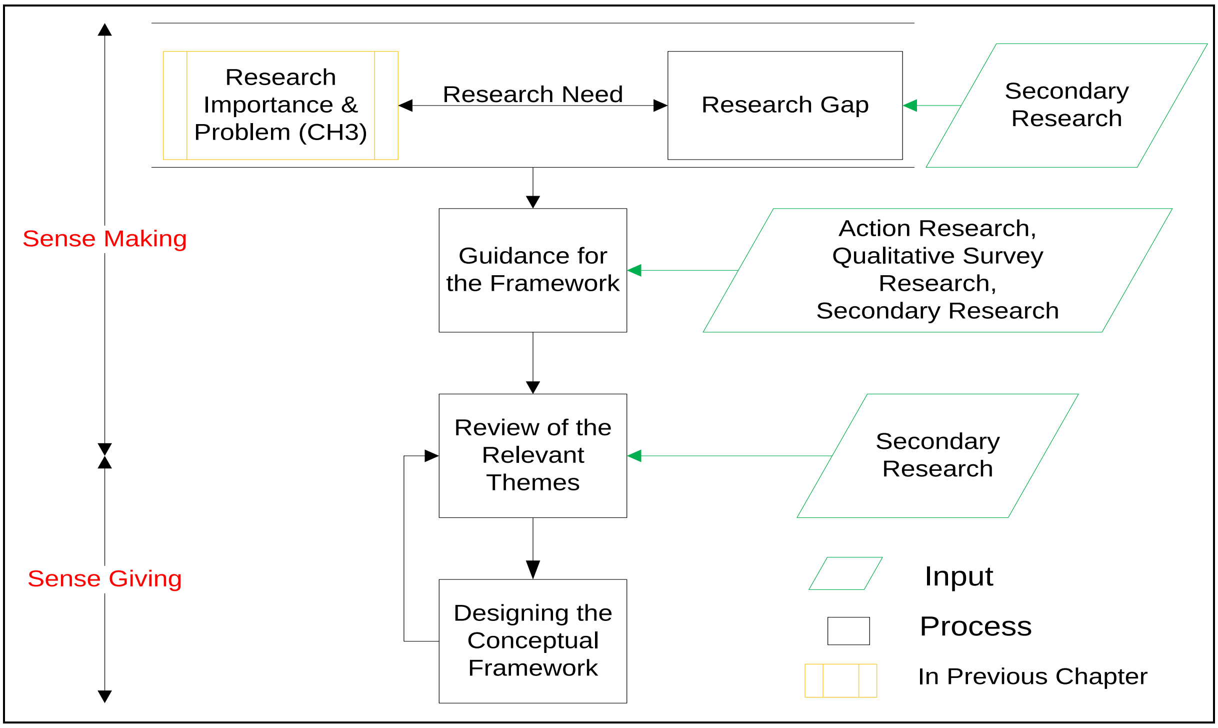

Figure 5.2: Approach for Designing the Conceptual Framework

5.3 Literature Review

To identify the current state of knowledge relevant to the research problem, literature on the application of DSS in the bioenergy sector and sustainable supply chain risk management (SSCRM) are reviewed respectively.

5.3.1 Decision Support Systems in Bioenergy Sector

One of the original definitions of the DSS is:

> *Decision support systems couple the intellectual resources of individuals with the capabilities of the computer to improve the quality of decisions. It is a computer based support system for management decision makers who deal with semi structured problems. (Keen and Scott Morton, 1978 cited in Turban et al., 2011, p. 16)*

DSS can be dissected into three very distinct components namely decision making, support and system (Keen & Scott-Morton, 1978), that can be represented using the Figure

5.3 (Source: Turban et al., 2011, CH2-PPT slide no 5). The ‘decision making’ part answers ‘what decision process is being supported by the DSS’ and relates to the criteria for selecting the application of DSS. The ‘support’ component emphasise that the purpose of the DSS is to support and not to replace the decision maker. Both the manager and the machine is implied in the ‘system’ phrase (Holsapple & Whinston, 1996; Keen & Scott-Morton, 1978; Turban et al., 2011). However, Rhodes (1993) argues that the main purpose of the DSS is to assist with the decision making process and it is not compulsory for it to be computerised or automated, this view is also accepted by Keen and Scott-Morton (1978). This is supported by Power (2003) who states that DSS are of multiple types and can be used in multiple ways to solve different problems.

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Figure 5.3: Decision Support Systems Components

(Source: Turban et al., 2011, CH2-PPT slide no 5)

In order to support the decision makers in various types of decisions, DSS are widely used in energy sector. Pohekar and Ramachandran (2004) present a review of more than 90 articles using multi criteria decision making (MCDM) methods for energy planning. Their work analyses the various methods applied for energy planning and classifies the application areas. Løken (2007) also have reviewed the multiple criteria decision analysis (MCDA) methods used for energy planning purposes. In that paper, widely used MCDA methods, their advantages, disadvantages and the case for MCDA as a useful tool to plan the energy systems are discussed. Wang et al. (2009) in their review paper argue that due to the “multi-dimensionality of the sustainability goal and the complexity of socio-economic and biophysical systems” (p.2263), MCDA is highly used as a decision support tool for sustainable energy. In their work they have summarised criteria of sustainable energy used in different papers and reviewed criteria selection, criteria weighting, evaluation, and final aggregation methods used in those papers. These reviews in addition to the contribution to the literature with the knowledge about the variety of methods and wide range of application of DSS in energy sector, also demonstrate the extent to which the DSS is used in the energy sector and the complexity of decision making in the sector that requires support for taking better decisions.

Similarly, in the bioenergy sector (sub-sector within energy) lots of DSS have been developed to address the decision making process due to the multi-faceted and complex nature of the sector (Scott et al., 2012). Some of the important supply chain related DSS that have been developed to assist in the decision making process in the bioenergy sector have been reviewed are given in Table 5.1.

Table 5.1: Bioenergy Decision Support Systems

Source	***Method***	***Model developed***
(Čuček et al., 2012)	Mixed integer (non)-linear programming	To optimise a regional biomass supply chains through the maximisation of economical performance and minimisation of the environmental and social footprints.
(Papapostolou et al., 2011)	Mixed integer linear programming	To support the decisions related to infrastructure investments, raw materials, optimal design of the bio fuels supply chain. Technical and economical parameters are considered in the model.
(Bowling et al., 2011)	Mixed integer linear programming	To determine the optimal placement and configuration of distributed bio-refineries for higher profits
(Rentizelas & Tatsiopoulos, 2010)	Hybrid optimization method	To find the optimum location of a bioenergy generation facility
(A. A. Rentizelas et al., 2009)	Hybrid optimization method	To support selection of suitable bioenergy model for high return on investment. Technical, regulatory, social and logical parameters were considered.
(Alfonso et al., 2009)	Optimisation model based on GIS	To optimize distributed biomass resources management and energy use
(Ayoub et al., 2009)	Multi criteria optimisation	To support the selection of biomass sources and technologies needed for different processes to realize the bioenergy supply chain in local and national level. Social, environmental and economic factors were considered.
(Buchholz et al., 2009b)	Four multi criteria analysis tools (2	To assess the sustainability of bioenergy systems. Four MCA tools were compared

Source	Method	Model developed
	Value measurement models&2 Outranking models) were compared.	to find the suitability for the purpose. (Analytic hierarchy process, DELTA method, Promethee II & NAIADE approach).Multi-stakeholder inclusion was given a special focus in this work.
(Elghali et al., 2007)	Multi criteria decision analysis	To assist in sustainability assessment of the bioenergy systems
(Sokhansanj et al., 2006)	Object oriented simulation model	To simulate the collection, storage and transport of raw materials
(Gunnarsson et al., 2004)	Mixed integer linear programming model	To support the decisions for collection, pre-treatment and transportation
(Freppaz et al., 2004)	Combination of GIS, mathematical modelling and optimization	To calculate the transportation cost in various settings, identify optimal sizing of the power plant, and biomass collection and harvesting scheduling.
(Tatsiopoulos & Tolis, 2003)	Linear programming optimization model	A model for the biomass delivery scheduling
(Papadopoulos & Katsigiannis, 2002)	Two stage dynamic programming optimization	To identify power plant location and the optimum biomass fuel mix.
(Voivontas et al., 2001)	GIS based model	To estimate the potential for electricity production from multiple agricultural residues
(Nilsson & Hansson, 2001)	This discrete event simulation model	To simulate multiple feedstock's impact on supply chain
(Nagel, 2000)	Mixed-integer linear programming optimization	To simulate feedstock's impact on supply chain in order to determine an economic energy supply structure
(Graham et al., 2000; Graham et al., 1997)	GIS based model	To calculate the exact transportation distances for supplying specific amounts of energy crop feedstock
(Mitchell et al., 1999)	Spread sheet models	To identify the cost of producing energy crops focusing on the operations of biomass production, collection and storage
(Gallis, 1996; Gemtos & Tsiricoglou, 1999; Huisman et al., 1997)	Analytical supply chain simulation models	To simulate transporting and handling activities

Source	***Method***	***Model developed***
(Cundiff et al., 1997)	Linear programming optimization model	To optimize a cost function including the biomass logistics
(Allen et al., 1998)	Analytic supply chain simulation modelling	To simulate transporting and handling activities, also identifies the transport cost
(Mitchell et al., 1995)	Biomass to electricity and ethanol model	A comparative economic evaluation of various bioenergy conversion technologies

In addition to the above studies, the papers reviewed were also carefully examined to understand the current status of knowledge in the field. Some of the major literature review studies are discussed below.

Figure 5.4: Waste Biomass Supply Chains - Decision making processes

(Source: Iakovou et al., 2010)

Iakovou et al. (2010) have synthesised the literature related to the design and management of waste biomass supply chains (WBSC). They have offered a framework that recognises the relevant decision-making processes in the strategic, tactical and operational levels for the design and planning of WBSC, it is shown in the Figure 5.4 (Source: Iakovou et al., 2010). One of their objectives was to identify the research gap in this sector, where they state:

There is a plethora of literature findings regarding the assessment of biomass potential, the selection of collection sites and the location and optimal capacity of the energy conversion facilities. However, only a few of the research works tackle the biomass supply chain network design systemically. In addition, despite the fact that sustainability of supply chains in general is a research field of emerging interest, only a handful of papers address the critical issue of designing sustainable biomass supply chains in which both profitability and environmental impact are balanced. (p.1868)

Baños et al. (2011) presented a review of more than 200 papers that applied computational optimization methods to renewable and sustainable energy problems. They present 13 papers related to bioenergy sector as well, that enhance the understanding of the DSS available in bioenergy sector. They state that mixed-integer and interval linear-programming, LagRangian relaxation, quadratic programming, and Nelder Mead Simplex search are some of the most commonly used methods and conclude that "the use of heuristic approaches, Pareto-based multi-objective optimization and parallel processing are promising research areas in the field of renewable and sustainable energy" (p.1763).

Gold and Seuring (2011) reviewed articles that cover the issues of bioenergy logistics and supply chain management published from 2000 to 2009, they state that supply chain and logistics issues have high relevance for the implementation and operation of successful bioenergy systems; and the supply chain of the bioenergy have the crucial role to ensure the economic, environmental and social sustainability of the systems. They also argue that there is clear majority of techno-economic assessments, multi-criteria assessment for ranking bio-energy systems and environmental assessments models but the approaches addressing the supply chain management issues are limited.

Awudu and Zhang (2012) reviewed the biofuel supply chain management papers related to the uncertainties and sustainability concepts. Through their findings they emphasise the importance of considering the sustainability and uncertainties in supply chain management. They also search the literature for the models addressing the uncertainties and/or sustainability in biofuel supply chain they state that, "literature does not provide sufficient source on modelling the uncertainties in bio fuel supply chain management" (p.1364) and "there is little literature that models the sustainability issues in biofuel supply chain" (p.1366). Due to this gap they conclude that "the biofuel supply chain management should apply models that incorporate uncertainty and sustainability concepts" (p.1367).

Scott et al. (2012) through a systematic review process reviewed 57 papers from 2000 to 2010 that used MCDM methods in the bioenergy sector. They have identified that in the bioenergy sector there is a clear gap in the breadth of the availability of DSS literature, while most of the papers reviewed aim to support the decisions of policy makers, the papers addressing operational and development issues to support the practitioner's decision making are limited. They state that biomass supply chains, "have not received the same focus from multi-criteria methods as other barriers to implementation such as technology choice or policy choice" (p.154). They suggested that there is a need for future work to address the issues during the implementation and design stages of the bioenergy systems also there is a need to engage with the practitioners during this process in order to increase the practical utility of the models.

Shabani et al. (2013) reviewed studies that used optimization techniques for the decision making of the supply chain of forest biomass for energy generation, they suggest that the future studies should also consider environmental and social objectives, as most of the current studies only considered the economic objectives. Moreover, they also state that only very few studies considered uncertainty in the forest biomass supply chain and the methods such as fuzzy sets and fuzzy logic, expert systems, reinforcement learning, neural networks, genetic algorithms and multi-agent systems were never applied in this sector. Furthermore, they argue that there are challenges to consider uncertainties in models which limited its wider application in this sector. Some of the challenges are:

> *First, these mathematical models are usually complex. Second, considering uncertainty in the models usually requires more time and solving them requires more computational effort compared to the deterministic cases. When uncertainty is considered in several parameters, the size of the problem might become too large to be solved. Another challenge is the difficulty in quantifying uncertainty in mathematical terms. (p.309)*

From the review of above mentioned models and studies the following annotations can be made. Firstly, supply chain management research is an emerging area in the bioenergy sector and the current DSS addressing the complete supply chain and its network design are confined. Secondly, environmental and social sustainable objectives are not given required attention in the bioenergy DSS literature; particularly social parameters are very much neglected. Even the studies that consider these objectives limit the number of parameters they consider in their models and the models do not have the flexibility to take all the relevant parameters into account. Thirdly, the studies considering uncertainties in the decision making process of the bioenergy sector is extremely limited. A small number of authors have discussed about the risks in the bioenergy supply chain, but to the authors knowledge none of the work has taken a systematic supply chain risk management (SCRM) approach so far. Furthermore, none of the current studies have addressed the sustainability issues and supply chain issues simultaneously in the decision support system, which is of prime importance to the practitioners (Chapter 3). Fourthly, the above studies were predominantly focused on the developed countries context and there is only handful of studies in the Indian context, mostly they address biomass potential and plant location issues. Fifthly, most of the DSS have been shaped for the use by the large scale systems practitioners or policy makers, whereas the features required by the small scale bioenergy system operators can be very different. In particular, the quantity and the type of data required for these DSS and the mathematical complexity of these DSS make it unattractive for small and medium enterprises (SME). Finally, while there is a growing number of DSS in the bioenergy sector reported their practical application and usage is scant (Mitchell, 2000).The literatures reviewed above do not indicate any steps taken to incorporate practitioners usability requirements (Ovaska, 1991), during the development of the DSS. Whereas, Arnott and Pervan (2008) argues that the main issue for the DSS is that they should be relevant to the practice, if not that contradicts with the purpose of developing the DSS itself.

Given the limitations of the current DSS in the bioenergy sector above, there is a need to address practitioners' call for the risk based decision support system for a sustainable supply chain. However, it should also be noted that such a DSS not only need to be a rigours model but also must be relevant to the practice and should address the practical challenges of the small scale bioenergy industry.

5.3.2 Sustainable Supply Chain Risk Management

The SSCRM literature was reviewed after the review of bioenergy DSS to find any suitable approaches that can be adopted in the bioenergy sector to address the sustainable supply chain issues. However, the literature in the SSCRM field is very rare, with few relevant papers found. A possible explanation for this may be because sustainable supply chain management (SSCM) itself is an new and evolving discipline (Ashby et al., 2012). Some of the papers that have been identified, which are related to the SSCRM field are discussed below.

Nakano (2010) proposed a conceptual framework for sustainable manufacturing that views the manufacturing organisation and supply chain from the risks viewpoint. They consider two aspects of the sustainable manufacturing in the work namely society and the sector. They categorised risk into the two perspectives discussed above and, this paper suggests that some system engineering techniques such as Vee model and multi view model can be used to visualise and analyse the sustainable manufacturing problems. Moreover, it also suggests an inter-sectional analysis technique for analysing green manufacturing and the green supply chain. However, the essential theoretical background is not provided for the relationships in the conceptual framework and the application of such a framework is not articulated adequately are some of the limitations of this work.

Foerstl et al. (2010) explored how the sustainability demands of the stakeholders are met by the organisation's purchase and supply management functions across their supply base. They argue that, "the applicability of supply risk assessment and supplier assessment methods have not been evaluated for sustainability" (p.118) and propose a conceptual lens to view the supplier sustainability risk management process. In addition to the analysis of five case studies regarding their supplier sustainability risk assessment processes (through their conceptual framework), they also provide insights on the performance outcomes of sustainability engagement and the organisations response for the changes in the external pressure for sustainability. This work is limited to the supplier management part of the supply chain only and the sustainability risk management activities are conceptually analysed using the supply chain risk management approach (Ritchie & Brindley, 2007) as a basis with little information on how this can be applied in practice.

Yilmaz and Flouris (2010) have proposed a conceptual enterprise sustainability risk management framework, as shown in Figure 5.5. They argue that this framework will provide guidance to the managers to carry out a systematic sustainability risk management processes within an organisation. This framework is more related to enforcing the sustainability adoption in an organisation rather than across the supply chain.

Figure 5.5: Enterprise Sustainability Risk Management Framework

(Source: Yilmaz & Flouris, 2010)

Stonebraker (2007) argue that, “little research has emerged to define the factors and identify the risks associated with supply chain sustainability, and less has been put forward to posit the factor relationships and to model supply chain sustainability” (p.2). They propose a “Fragility Index” approach to model the supply chain risks that considers the impact and threat level as inputs. This work considers internal, external and other sources of fragility in its approach. It considers four external sources of fragility namely legal, political & acts of government, behaviour of competitors, financial and economic factors and environmental impact. Here, instead of risks severity the risk sources are accounted for their fragility, that undermines the important risk identification stage of the risk management process and this approach addresses the risks of the organisational sustainability perspective rather than universal (combined organisational and external) sustainability perspective.

Teuscher et al. (2006) argue that risk oriented supply chain management can lead to a sustainable supply chain. They have illustrated this using GMO-free soybean supply chain as a case study, where the risk prevention has led to sustainable soybean supply chain. This work is reinforcing the point that the external pressure sources can influence the supply chain to be sustainable and there is a business case for addressing the external sustainability issues in supply chain.

New Zealand Business Council for Sustainable Development (NZBCSD, 2003) have prepared a report for its member companies to support the implementation of sustainable supply chain. In this they state the importance of the sustainability across the supply chain and suggest a risk monitor to consider economic, environmental and social dimensions across their supply chain. While this work is one of the initial steps taken by practitioner related organisations in sustainable supply chain, its suggestion is limited to consider the three dimensions of sustainability in risk identification and monitoring. It does not provide steps to assess and analyse these risks or an integrated approach for the supply chain risk management.

Furthermore, the following recent literature review papers in the sustainable supply chain management field also emphasise the need for this sustainable supply chain risk management framework. Ashby et al. (2012) and Seuring (2012) states that the literature integrating the three dimensions of sustainability is very limited.Cristina and Elcio (2012) argue that assessment is an important first step to have a positive impact on the supply chain sustainability. Carter and Easton (2011); Carter and Rogers (2008) also argue that risk management is one of the facilitators for SSCM. Ashby et al. (2012)argue that risk management covering environmental and social dimensions is one of the very specific topics that need attention in SSCM field. On top Carter and Easton (2011) suggests that the efforts to develop the SSCM field can be enhanced by using the conceptual theory development methods as its lacking in the field now. While,

> *Very few of the reviewed papers provided tangible outputs such as an explicit framework or model to inform the implementation of sustainability and sustainable supply chains were discussed largely in theoretical terms. This may be due to the new and evolving nature of the research field, but does represent a significant gap. (Ashby et al., 2012, p. 509)*

The above mentioned studies signifies the importance of this field, highlighting the preliminary stage of this field and strongly calls for further research to develop it. These studies provide initial guidance for the field that need to be developed further. However, none of the above mentioned studies or other studies to the authors' knowledge presents a framework that can systematically integrate the organisational and external sustainability across the supply chain and analyse and manage the risks. This clearly shows a research gap in this field that need to be addressed.

5.3.3 Re-emphasising the need

There is an increasing pressure on organisations from its stakeholders and the wider society to address the environmental and social sustainability concerns along with its interest for profit (Carter & Rogers, 2008; Vachon & Klassen, 2006). Especially in the bioenergy sector, these aspects are of prime importance due to its unique selling point i.e. being renewable and sustainable energy when compared to other conventional energy sectors. These demands for an improved ethics and sense of responsibility from business is further echoed widely after the negative consequences of the recent financial crisis (Zingales, 2009). Hence, growingly organisations are adopting the sustainability as an important part of their strategy (Mann et al., 2010; Matos & Hall, 2007).

Addressing the financial sustainability of organisations through rise in earnings and curtailing the risks is one of the vital drivers for the adoption of SCM in the business (Fawcett et al., 2008). Similarly, SCM can be one of the ways to encourage the SME's to address environmental and social sustainability concerns more systematically (Ashby et al., 2012; Walker & Preuss, 2008). As it can enhance the adoption of sustainability as a way of doing business not only within their internal processes of the SMEs, but also across the supply chain processes in order to utilize any potential opportunities (for example market demand, reduced cost of production) or to minimize any risks (for example brand reputation risks, losing the business) for the business due to the sustainability concerns (Constantinos et al., 2010; Tischner & Nickel, 2003; Trade and Investment Division-UNESCAP, 2005; Walker & Preuss, 2008). The above arguments and the findings in the Chapter 3 clearly show the importance of the need for sustainability in the supply chain and the rising demand on organisations to deal with sustainability impacts created not only by their internal processes but also related to their supply chain (Jayaraman et al., 2007; Vachon & Klassen, 2006; Walker & Jones, 2012).

The current state of literature (Ashby et al., 2012) and practice (American Society of Mechanical Engineers - ASME, 2011) shows an emerging need for an effective mechanism to integrate the sustainability across the supply chain. Risk management approach can be a significant tool to persuade more reluctant businesses to seriously consider sustainability and to integrate sustainability in their business activities (Trade and Investment Division-UNESCAP, 2005). This is believe to be effective because minimizing the risk and increasing the prospective opportunities are the two most important drivers for the businesses to adopt sustainability (Crittenden et al., 2011; Schaltegger, 2008). Therefore based on the research gap identified in the bioenergy DSS and SSCRM field, and the research importance established for the sustainable supply chain issues in Chapter 3, an integrated conceptual framework for sustainable supply chain risk analysis has been developed to support the bioenergy decision makers which can also enhance the current state of knowledge in the SSCRM field.

5.4 Guidance for the Framework

Simpson et al. (2012) in their study on the adoption of voluntary management standards for environmental and social sustainability, argue that when there is a mismatch between the institutional requirements and the firm's capabilities, it leads to a problem of 'fit' between the requirement and the capability. This 'fit' issue also exists in the adoption of voluntary sustainability management systems, especially for SME's. When the systems do not consider the capabilities or requirements of the SME to adopt these systems, it will lead to the malfunction in adoption due to the mismatch.

In order to avoid this, requirements for the sustainable supply chain risk analysis framework were guided by the SME's capability information collected using the focus groups as mentioned above. The data collected were summarised into appropriate themes and the important directional aspects are discussed below. The guidance aspects were classified into two categories based on if the aspects were related to the framework or execution of the framework namely, framework requirements guidance and usability requirements guidance respectively.

5.4.1 Framework Requirements Guidance

In this section, the important aspects that direct the functional features required in the framework for it to be helpful for SME's are discussed.

5.4.1.1 Business Case

Most of the participants in the focus group articulated that for SME's to adopt the concept of sustainability, it should have a business case. In developing country like India, most of the SME's are just operating with enough to survive and in this situation for them to adopt sustainability; there should be a very strong reason. SME's will be highly motivated to adopt the concept of sustainability if it saves money or increase the profit for the organisation. One of the participants gave an example that:

> *"Energy efficiency is becoming important in SME's because of the (financial) savings attached with it" (FG Participant)*

Customer requirements, new market opportunity, brand value, legislation, business risks and tax incentives are stated by focus group participants as other important reasons that will make a case for the adoption of the sustainability concept in SME's. Importance of the business case for sustainability adoption is also echoed in literature (Biondi et al., 2002; Epstein & Roy, 2003; Preuss & Walker, 2011). Comparing these external influences on the organisation with the operational issues will make it realise the real price of these external issues, was one of the important suggestions from the participants that can provide the business sense for sustainability adoption.

5.4.1.2 Awareness

It is believed that a lack of information and awareness about the sustainability impacts makes it difficult to adopt the sustainability concept. Biondi et al. (2002); Welford (2005) also have identified this as an important barrier for sustainability adoption in SME's. The main challenge being to visualise the sustainability impacts which make it harder for the SME's to really understand the consequence of their actions. Preuss and Walker (2011) support this by arguing that there is 'a degree of confusion' in applying the knowledge to understand the sustainability impacts. Some of the participants suggested that, if the framework can show the impacts in a better manner, then it can increase the effectiveness of the framework.

5.4.1.3 Complexity

" ... [The] multidisciplinary aspect is difficult to handle" (FG Participant)

The above quotation is from one of the participant, whereas most of them agreed with this view. Integrating and balancing all the pillars of sustainability at the same time is challenging due to the complexity of processing information related to the contradicting aspects. This complexity is further enhanced while incorporating short term and long term aspects of sustainability together. Therefore, the framework needs to reduce the complexity of information processing while achieving balance between the sustainability dimensions.

5.4.1.4 Proactive

The current practices of SME in the developing countries regarding sustainability issues are very much reactive actions that create lot of challenges and increase the cost of addressing it. On the other hand, proactive engagement can reduce the total cost involved in addressing those issues. Due to this some of the participants suggested that the framework should address the sustainability concept proactively and enable the organisations to foresee the issues that might arise.

5.4.1.5 Involvement

"Involvement of all the organisation member's is important for success." (FG Participant)

Involvement of the internal stakeholders in decision making and collecting the inputs from the external stakeholder are emphasised as a significant requirement to make a real progress. One of the participants gave an example that, in some cases, the current certification process such as ISO's do not make much improvement as the process does not engage the participants across the organisation. Preuss and Walker (2011) also support that the balanced composition of decision making group is important for achieving good results.

5.4.1.6 Context

The local conditions and requirements need to be taken into account while applying the concept of sustainability (Preuss & Walker, 2011). Sustainability cannot be adopted using a ‘one size fits all’ approach. Even if the concept of sustainability is absolute, to make it practical it needs to be relative to the reality on the ground. Therefore, the framework should be flexible to allow the variation for local contexts and requirements.

5.4.2 Usability Requirements Guidance

The following aspects were identified during the focus groups that provide the usability requirement for the framework that is to be adopted by the SME’s.

5.4.2.1 Resource Constraints

Lack of capacity and resources are identified as one of the biggest barriers for SMEs adopting sustainability (Biondi et al., 2002; Srinivasan, 2009; Srinivasan & Joseph, 2008; Welford, 2005). This view was echoed during the focus groups. The capital expenditures including the cost of consultants are also an issue for SMEs. Some of the participants suggested that it is important to utilize the available expertise within the organisation, as they possess invaluable knowledge about the industry. However, the human resource availability limitation within SME’s and their skill level can impact the time and process complexity of the framework. In summary, the framework should utilize the internal expertise, consume minimum amount of time and avoid complex processes due to the capital, human resource and capability constraints in SME’s.

5.4.2.2 Information Availability

The availability of information and data related to the sensible indicators has been mentioned by the participants as a challenge. This is supported by Welford (2005) who recognized the same issue in SME’s. One of the participants said that in India the measurement and availability of sustainability indicators is less (local government data) when compared to the developed world with access to information being very difficult and it is time consuming bureaucratic process. The measurement of sustainability dimensions by SMEs is not very common as it involves cost. Therefore, the suggestion is to develop a framework that can work with the limited information available that is also mostly subjective.

5.4.2.3 Practicable

During the focus group some delegates have suggested that, some of the theories cannot be easily applied in practice and to avoid that pitfall. They suggested that if the tool is to be used it should be relevant to pragmatic application. Some of the recommended characteristics for the framework to be practical are that it should be: simplistic, user friendly, free to use, consistent and efficient.

5.5 Review of the relevant conceptual framework themes

Mitchell (2000, p.274) asserts that, "where the concepts and relations are unknown then building the DSS (decision support systems), as with models, is, in many respects, an end in itself." Hence the important concepts and theories that can be relevant to develop the framework were reviewed. Sustainable supply chain risk analysis framework lays in the intersection of the sustainability science, supply chain management and risk management disciplines as shown in the Figure 5.6. In this section, brief overviews of those themes are presented.

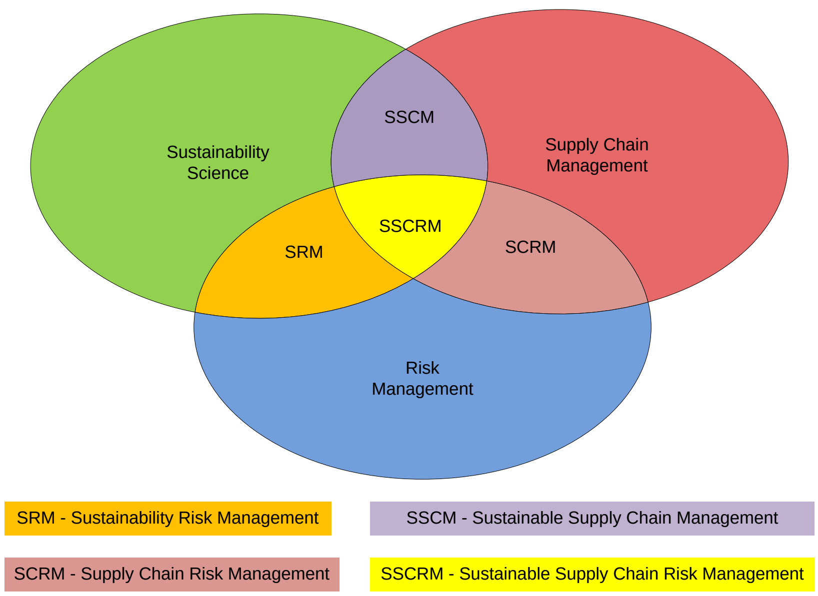

Figure 5.6: Relevant Themes

5.5.1 Sustainability

> *The concept of sustainability and particularly of sustainable development figure among the most ambiguous and controversial in the literature (Gallopín, 2003, p. 7).*

The vagueness in defining the sustainability, as expressed above, has led to lot of confusion and numerous definitions of these concepts. Therefore, in order to summarize the basic elements of these concepts Gallopín (2003) have reviewed a variety of perspectives on these concepts and defined them using a systems perspective (Figure 5.7), which is given below.

Figure 5.7: Systems Perspective

(Source: Gallopín, 2003)

> *Sustainability is a property of a system open to interactions with its external world. It is not a fixed state of constancy, but a dynamic preservation of the essential identity of the system amidst permanent change. A small number of generic attributes may provide the foundations of sustainability. (Gallopín, 2003, p. 35)*

Gallopín (2003)argues that the important point regarding the concept of sustainability is not to create change but to avert the damage to the sources of replenishment that can help the system to recuperate from the ‘unavoidable disturbances’ that it is exposed to. When discussing about the sustainability related to a system it is important to make it clear if the interest is about the ‘sustainability of the system itself’ or ‘sustainability of the output(s) of the system’ as both not necessarily means the same and the implications can be different for these cases.

Sustainable development is described more commonly by the definition of Brundtland Commission (WCED, 1987):

> *Sustainable development seeks to meet the needs and aspirations of the present without compromising the ability to meet those needs of the future. Far from requiring the cessation of economic growth, it recognises that the problems of poverty and under-development cannot be solved unless we have a new era of growth in which developing countries play a large role and reap large benefits.*

Gallopín (2003) states that sustainable development means change and it is not a state like sustainability instead it is a process of change that can improve the system in a sustainable manner. This transformation of the system can be either to improve the system or to improve the output or to improve both.

5.5.1.1 Corporate Sustainability

Similar to the concept of sustainability the definition of corporate sustainability is confusing and sometimes misleading (Ivory & MacKay, 2012). Montiel (2008) present a review of various definitions of the corporate sustainability and corporate social responsibility concepts in literature. Ivory and MacKay (2012) explored the evolution of corporate sustainability and critically reviewed the literatures that exist.

However, triple bottom line (TBL) namely Economic, Environmental and Social (Elkington, 1997, 1998) approach become one of the very famous sustainability approach in the business world due to its simplicity. As per this approach sustainability requires the reconciliation of environmental, social and economic demands. Adams (2006) states that the three pillars of sustainability are not mutually exclusive but mutually reinforcing as expressed in Figure 5.8using three overlapping ellipses. Dyllick and Hockerts (2002) also argues that corporate sustainability can be seen as three components such as business case (economic), the natural case (environmental), and the societal case (social) and all of this three need to be meet in order to sustain. Boyle et al. (2003), describes the sustainability in the context of energy sector, as energy sources which are not substantially depleted by regular usage, not polluting or creating other hazards to the environment in major scale, not involving any social injustice or health hazards to the people.

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Figure 5.8: Three Pillars of Sustainability

(Source: Adams, 2006)

Ivory and MacKay (2012) conclude that corporate sustainability can be classified into two categories namely 'sustainability business' and 'sustainable business', where (p.1):

> *A 'sustainability business' focuses on the business contribution to global SD [sustainable development] while a 'sustainable business' focuses on the business' own sustainable development: that is its own survival and success.*

For instance, as per this classification the above description of Boyle et al. (2003) falls into the ‘sustainable business’ category. Garvare and Johansson (2010) have portrayed the business sustainable development and ‘global sustainable development’ processes with the stakeholder influence in a figure, where they term it as organisational sustainability and global sustainability respectively.

Figure 5.9: Global Sustainability and Organisational Sustainability

(Source: Garvare & Johansson, 2010)

However, in long run the business which focus only on the organisational sustainability or the business that focus only on global sustainability cannot succeed. Johansson (2008) states that organisational sustainability can be achieved by meeting the important stakeholders concerns; but it does not mean that global sustainability is promoted unless all the interested parties concerns are addressed. As global and organisational sustainability become more and more interconnected, it is difficult for the business to succeed with anyone preference stated above, so there is a need for a balanced approach. Cheung (2011) articulates such a balanced business as sustainable company and that it should include, “an explicit objective to reduce their negative economic, social and environmental externalities, but in a manner that increases the wealth of the corporation” (p.162). Due to the balanced perspective offered between the global and organisational sustainability by the following ‘corporate sustainability’ definition, it has been adopted in this study.

> *Corporate sustainability is a multi-faceted concept that recognizes the importance of corporate growth and profitability on one hand, and also requires the corporation to pursue societal goals on the other hand, specifically those relating to sustainable development(Cheung, 2011, p. 162).*

5.5.2 Supply Chain Management

Lummus and Vokurka (1999) defines supply chain as, "all the activities involved in delivering a product [or service] from raw material through to the customer" (p.12). While, supply chain management (SCM) is seen as a set of practices aimed at managing and coordinating the whole supply chain from raw material suppliers to end customers (New & Ramsay, 1997) and it integrates both upstream and downstream processes of the chain (Christopher & Jüttner, 2000). SCM seeks improved performance of the whole supply chain by bringing trading partners together with common goal (Harwick, 1997), through elimination of waste and better use of internal and external supplier capability and technology (Morgan & Monczka, 1996). Mentzer et al. (2001) have reviewed various definitions of the SCM in the literature and by compiling all the distinct aspects of the SCM have defined it as below.

> *Supply chain management is defined as the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole (p.18).*

5.5.3 Risk Management

In general, risk can be seen as any possible damage which can occur from unexpected events (Waters, 2007). According to Cowan (2006, p.3), "any event which may prevent or impair the achievement of objectives" is a risk. Risk can be stated using a combination of two dimensions, these are: probability for an event to occur and its potential consequences (Institute of Risk Management, IRM, 2002). Waters (2007, p.31) argues that risk management encompasses all the activities to deal with "situations of uncertainty" and identifying the risk, analysing their magnitude and effect and framing suitable responses are some of those activities.

> *IRM (2002, p. 2) defines the risk management as "the process whereby organisations methodically address the risks attaching to their activities with the goal of achieving sustained benefit within each activity and across the portfolio of all activities."*

5.5.4 Sustainable Supply Chain Management

All the three aspects of sustainability, mainly the environmental and social characteristics extend beyond the organisations boundary and include supply chain activities. Craig and Dale (2008) states that considering and managing these sustainability aspects across the supply chain can be organisations one of the important competencies which will be less imitable. However, the research focused on incorporating these sustainability aspects in supply chain is in its early stage and still emerging (Ashby et al., 2012; Seuring & Müller, 2008; So et al., 2012). Additionally, Seuring and Müller (2008) added that the consideration of the social dimension in supply chain management is very weak, also the simultaneous integration of the three dimensions of sustainability in supply chain management is still rare. This shows the emerging nature of this field, which have also led to the varying definitions of sustainable supply chain management (SSCM).

> *Craig and Dale (2008, p.368) defines the SSCM, "as the strategic, transparent integration and achievement of an organisation's social, environmental, and economic goals in the systemic coordination of key inter organisational business processes for improving the long-term economic performance of the individual company and its supply chains."*

However, this definition focuses on the economic performance of the organisation and tends to be more lenient towards the sustainability of the organisation rather than the balanced approach between organisational and global sustainability that has been adopted in this study. While Seuring and Müller (2008) have defined the SSCM that takes the goals from all the three dimensions of sustainability into account and provides a balanced consideration for both the global and organisational sustainability, that is adopted in this study.

> *SSCM is, "the management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements." (Seuring & Müller, 2008, p. 1700)*

5.5.5 Supply Chain Risk Management

> *Supply chain risks comprise any risks for the information, material and product flows from original supplier to the delivery of the final product for the end user (Jüttner et al., 2003, p. 7).*

The scope of occurrence of unanticipated distractions in the flow of supplies from initial supplier to final customer in a supply chain is considered as the event of supply chain risk (Waters, 2007). Barbara and Antonio (2006) argues that supply chain risk management (SCRM) is an integral part of supply chain management, where it supports to attain SCM objectives.

> *Whereas, "the overall aim of supply chain risk management is to ensure that supply chains continue to work as planned, with smooth and uninterrupted flows of materials from initial suppliers through to final customers." (Waters, 2007, p.86)*

The SCRM recognize, assess, manage, mitigate and control the impact of risks across the supply chain (Basu et al., 2008; Jüttner et al., 2003) in order to "ensure profitability and continuity'' of the supply chain (Tang, 2006, p. 453).

5.5.6 Sustainability Assessment

> *Sustainability assessment frameworks help to focus and clarify what to measure, what to expect from measurement and what kind of indicators to use (Waheed et al., 2009, p. 448).*

Sustainability assessment frameworks are used to identify the important sustainable aspects and measure its performance, which than can lead to responses to attain the desired sustainability impact. Van Cauwenbergh et al. (2007) distinguishes it into two, system-based frameworks that provides the indictors for a system as a whole and content-based frameworks that provides indicators based on the specific function of the system. Whereas, Waheed et al. (2009) classified these frameworks into six types:, objective-based, impact-based, influence-based, process-based, material flow accounting and life cycle assessment and linkages-based framework. In addition to this Madlener et al. (2006) proposed a hierarchical framework for the sustainability assessment of their project, shown in the Figure 5.10. This framework provides the connection between the sustainability issues (impact) and sustainability principles (objective) using the notion of action and control path respectively, which is adopted in the conceptual framework below.

Figure 5.10: Sustainability Assessment Framework

(Source: Madlener et al., 2006)

5.6 Sustainable Supply Chain Risk Analysis Framework

Development of the sustainable supply chain risk analysis framework and widening of the conceptual borders of the field are achieved by examining and synthesising the different concepts and frameworks into a more concrete and scientific framework for the purpose of sustainable bioenergy sector. Mitchell (2000, p. 265) argues that when the task is multidisciplinary, it is important to have the transparency about “how the model functions and why”. To answer this question, this section examines the relevant linkages between the different concepts in the framework and describing the conceptually developed framework.

One of the prime confusions related to the corporate sustainability concept is the ambiguity of ‘whose sustainability is considered’. Garvare and Johansson (2010); Ivory and MacKay (2012) from a corporate sustainability point of view assert that the intentions can be to achieve organisational sustainability or global sustainability. Whereas the notion of ‘global sustainability’ denotes the sustainable development of the globe (society) and the term ‘organisational sustainability’ indicates the sustainable development of the business. As stated above both the ‘organisational sustainability’ and ‘global sustainability’ are important for business long term sustainability. It is therefore essential for both ‘organisational sustainability’ and ‘global sustainability’ to be considered and balanced while adopting the concept of sustainability in business. In this framework, sustainability is classified into organisational sustainability and global sustainability in order to account for both, and to avoid any confusion between the intentions and to reduce complexity.

In order to increase clarity about the goals to be achieved, it is important to define the aspects of sustainable development to be addressed for ‘organisational sustainability’ and ‘global sustainability’. As Madlener et al. (2006) suggests in their framework, the sustainability dimensions can be viewed using the prism of action path or control path which defines the sustainability aspects into sustainability issues or sustainability principles (objectives) respectively. Defining the aspects as the sustainability issues to be addressed leads to a reactive sustainability approach and limits its scope of consideration to specific issues only. Whereas, Regev and Wegmann (2005) argues that these objectives (goals) can help to identify and manage the requirements as well as expanding the requirements across the process. Moreover, they also discuss the different types of objectives and how they can be derived. Therefore, in order to increase the transparency about ‘organisational sustainability’ and ‘global sustainability’ goals and to approach the sustainability implementation proactively (which is also the foundation of risk management (PWC, 2008)) in this framework the sustainability aspects are defined as the organisational and global ‘sustainability objectives’ to be achieved. However, as shown in Figure 5.10 the sustainability issues (risks) are related to the sustainable objectives through the relationship that, the risks are the events that affect the achievement of objectives (PWC, 2008). Therefore, these sustainability objectives will provide the basis for identifying and analysing the risks (sustainability issues) during the risk analysis process.

The organisational sustainability objectives and global sustainability objectives both are context dependent and specific to the business. Organisational sustainability objectives are linked to the business’s mission and vision. The global sustainability objectives will depend on the kind and level of social responsibility embraced by the business. Carroll (1991) suggests that there are four kinds of social responsibility constitute the different level of corporate social responsibility namely economical, legal, ethical and philanthropic, which are depicted as a pyramid (Figure 5.11). Whereas Kemp (2001) adds the social responsibility 'due to the resource need' into the list. Thus, sustainability aspects are not limited to few aspects or to a set of universal sustainability objectives in this framework instead it shall allow to include the objectives related to the type and context of the business. This flexibility allows it to be a generalised framework which is not only limited to bioenergy sector and adoptable to the environment.

Figure 5.11: Pyramid of Corporate Social Responsibility

(Source: Carroll, 1991)

Porter and Kramer (2006) argue that business and society are interdependent and therefore to attain the long term prosperity of both, 'shared value' principles must underpin both the business decisions and social policies. They also classify the points of intersection between the business and society into two categories namely inside-out linkages and outside-in linkages. Inside-out linkages are the points of intersection between both where the business operations impinges on the society (influence of the business on the global sustainability). The point of intersections where the external social conditions influences the business is termed as outside-in linkages (impact of the society (global sustainability) on the business). However these outside-in intersections are not completely independent they are to a degree related to the business influence on the society (inside-out linkage) as well.

During the focus groups the need for business case was highly emphasised in order to adopt sustainability. Societal Impact on the business and the supply chain (outside-in linkages) are mostly the rationale providing the business case for sustainability. Whereas, risk avoiding (threat) and utilising the opportunity are the two important types of business case rationalization for sustainability (Kemp, 2001; Kemp et al., 2004). Hence, the business case outlook should not be limited to looking at the risks alone and it should also take the value of opportunity into account because an opportunity lost is a loss for the business.

Stakeholder expectations, making good financial sense, imperatives for continuous resource availability, specific core ideology and regulatory or compliance-led requirements are some of the organisation's reasons for adopting sustainability (Kemp, 2001). While, Schaltegger (2008) identifies cost, sales and profit margin, risk, reputation and brand value, influence on attractiveness as employer and innovation as some of the core drivers of a business case for sustainability.

While the above arguments clearly state the highly potential business case for sustainability, a word of caution regarding business case for sustainability from Kemp (2001, p. 08) that,

> *It is not always possible to demonstrate a direct statistical link with financial performance, as the benefits may be intangible or indirect.*

Therefore, given the requirements for business case for sustainability, in this framework it is taken into account by assessing the sustainable objectives in relation to the business case.

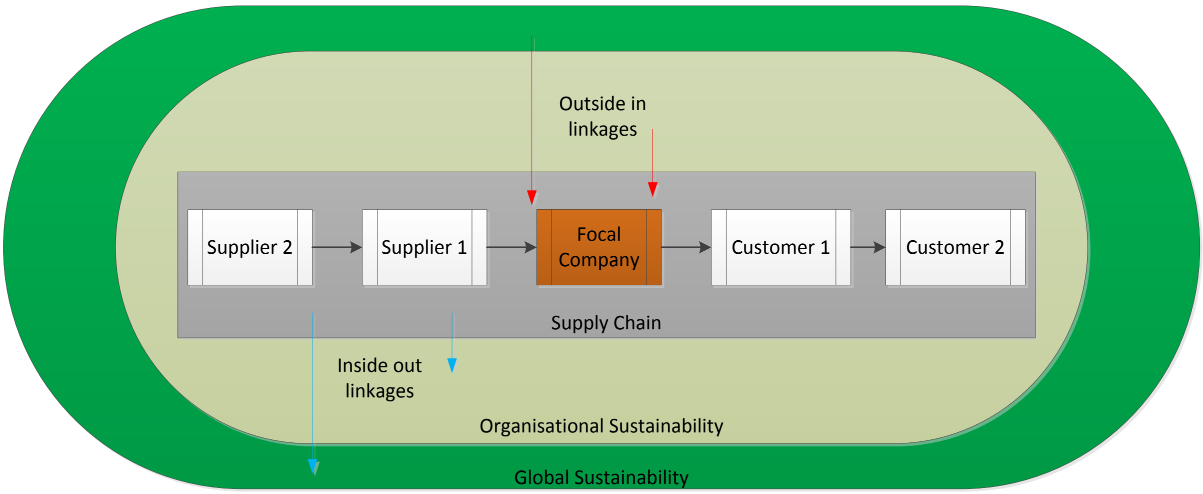

Figure 5.12: Sustainable Supply Chain

The above discussed concepts of sustainability when viewed from a supply chain perspective can be portrayed as shown in Figure 5.12. These concepts of sustainability are integrated with the process of supply chain risk management in order to achieve the objective of designing a sustainable supply chain risk analysis. The sustainability concepts adopted in the SCRM leads to the definition of sustainable supply chain risks and sustainable supply chain risk management as stated below.

Sustainable supply chain risks include any risks for the organisational sustainability (organisations own development) and global sustainability (sustainable development of the society) across the supply chain. While, sustainable supply chain risk management aims to identify and manage the potential sources of risk for the organisational and global sustainability across the supply chain.

These organisational sustainability risks (also termed as internal sustainability risks) and global sustainability risks (also termed as external sustainability risks) are integrated under the umbrella of corporate sustainability risk, which is termed as 'risk magnitude'. Risk magnitude can be calculated by combining outputs of the assessment of objective for corporate sustainability and the individual risk assessment. This combined corporate sustainability risk analysis output (risk magnitude) besides answering the question "how these pieces of the puzzle fit together to create their organisation's overall sustainability position" (Carter & Easton, 2011, p. 47) also provides the visibility of the impact of supply chain on society using a common measure.

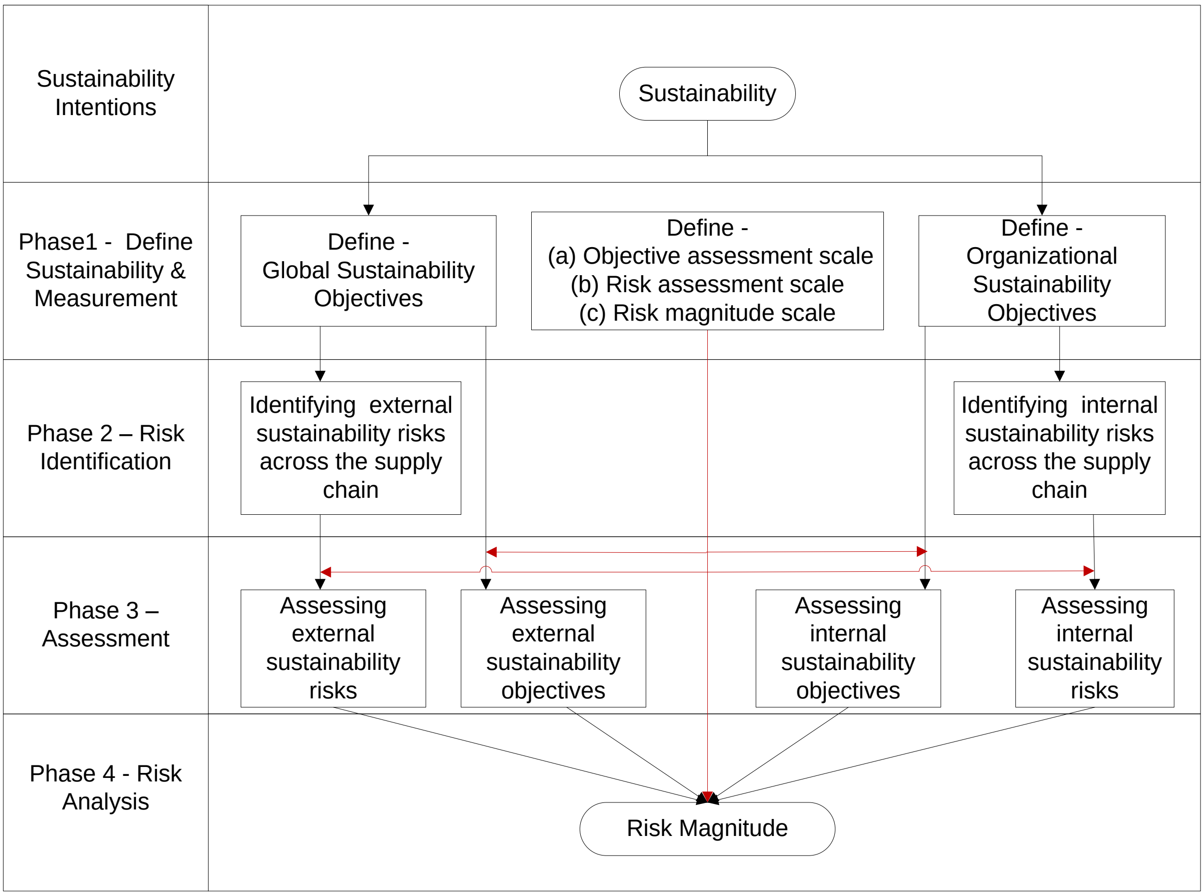

Figure 5.13: Conceptual Framework

Keeping the need for sustainable supply chain risk analysis (SSCRA) and the SME requirements to adopt in mind, a conceptual framework to analyse the sustainable supply chain risk was designed by integrating the sustainability concepts and supply chain risk analysis processes as shown in Figure 5.13. In particular, the risk identification, risk assessment and risk analysis phases of the SCRM along with the above discussed concepts are adopted in the SSCRA framework. In chapter 3, it has been identified that a supply chain that achieves both organisational and global sustainability is important for a successful bioenergy project. Information about the risks is necessary to take effective decisions that can help to attain such a sustainable supply chain. These requirements projected one of the research objectives, that is 'to develop a sustainable supply chain risk analysis framework', which is addressed by this framework.

The proposed framework categorises the concept of sustainability into two main categorise namely, organisational sustainability and global sustainability. The sustainability aspects are defined as objectives to achieve. It is then mapped across the supply chain to identify the risks to achieve those sustainability objectives. Then the global sustainability and organisational sustainability risks are converted into a single related business effect scale 'risk magnitude' for an enhanced indication of the corporate sustainability risks to the stakeholders. The practical guide to execute this framework is given below.

5.6.1 Implementation Guide

The interest for sustainability by organisation leads to the adoption of the framework, which is actionable with 4 phases which are discussed below.

Phase 1: In this phase the sustainability intentions of the organisations are defined as the organisational and global sustainability objectives to achieve. The organisational sustainability objectives are the objectives related to the business process and will depend on the business ambitions. The global sustainability objectives are those objectives which can impact the society and will also be dependent on the type of social responsibility considered by the business. Development of these objectives in consultation with the relevant stakeholders can enhance its practical value. In addition to this, as there are different possible approaches and mathematical tools (ex: severity- likelihood risk analysis, rule based output, etc.) that can be used to analyse and assess the objectives and risks it is important to decide the suitable approach based on the information availability and the level of expertise available; the measurement scales relevant to the approach need to be selected.

Phase 2: The sustainability objectives defined in Phase1 are used in this phase to guide the risk identification. During the risk identification process, threats that can hinder the achievement of each of the sustainability objectives (both the organisational and global) should be identified across the supply chain processes.

Phase 3: The sustainable objectives and risks are assessed using the measurement approach and scale selected in the Phase 1. The objectives should be evaluated for its contribution for the corporate sustainability and the risks should be evaluated for its impact on the related objective.

Phase 4: The risk magnitude can be derived using the assessment of the importance of the sustainable objectives and the risk evaluation carried out in Phase 3 as inputs. These inputs can be processed using the appropriate approach selected in the Phase 1. These risk magnitudes provide a value of the risk significance from the corporate sustainability perspective. This can be used as decision making information to manage the risks in order to achieve sustainability across the supply chain.

This framework can be applied with subjective or objective data based on the data availability, which will influence the mathematical approaches used to execute. This framework can be used for the decision making process both during the design stage of supply chain or to re-design the existing supply chain to improve its sustainability.

5.7 Application in Bioenergy Sector

This sustainable supply chain risk analysis framework can be easily adoptable and widely applicable in different sectors. However it is designed with inputs from the practitioners and experts in the fields related to the bioenergy sector. This framework was developed as a part of the 'Science Bridge' project with an intention to be applicable in the bioenergy sector. Therefore, this framework was applied and tested in the ARC case, which is given in the Chapter 8. Still, in order to execute the framework effectively the information regarding the sustainable objectives and risks were required in Phase 1 and Phase 2 of the framework respectively. This required information related to the ARC project and was informed by the empirical data of the global sustainability objectives and issues (RO2) and supply chain issues (RO3) of the small scale bioenergy sector in India, which is discussed in the Chapter 6 and Chapter 7 respectively.

5.8 Chapter Summary

In order to address the sustainable supply chain requirement in the bioenergy sector an integrated conceptual framework for sustainable supply chain risk analysis has been developed. The resulting framework links the sustainability and supply chain risk management fields through a conceptual approach. A range of dimensions related to the sustainability and its impact on business are explored through the review of conceptual and empirical studies. The findings are then rationally put together by applying the supply chain risk management perspective as an analytical lens to develop the proposed conceptual framework. The findings of the RO2 and RO3 were used to inform the inputs of the framework application and testing in ARC case (RO4), which is discussed in detail in chapters 6, 7 and 8 respectively.

Chapter Six: Sustainability Issues of the Indian Bioenergy Sector

6.1 Introduction

Chapter 3 outlined the interactions between bioenergy systems and global sustainability aspects, establishing the importance of the latter for the long term success of the former. Also established was a need for better understanding about the global sustainability aspects of the Indian bioenergy sector from a practitioners' perspective, as it can lead to better decision-making. The current status of research in the field was recognized through literature review, which is discussed in the literature review section of this chapter. The research significance, need in practice and current research gap have led to the formulation of the second research objective (RO2) (Hedrick et al., 1993) that is, to identify the global sustainability issues of the small scale bioenergy sector in India, which is addressed in this chapter. In addition to that, in order to have a highly proactive risk management approach the conceptual framework proposed in Chapter 5 adopts objective based risk identification. Therefore, in this chapter along with global sustainability issues, global sustainability objectives of the small scale bioenergy sector in India are also identified.

Following the establishment of the need to identify global sustainability objectives and issues in the Indian bioenergy sector, a systematic research approach is used to achieve the objective; this is shown in Figure 6.1. The global sustainability issues and objectives of the bioenergy sector were reviewed and collated using the thematic synthesis approach (Thomas & Harden, 2008). These themes were used as the deductive themes during data analysis. The empirical data were collected using primary case studies, qualitative survey research and secondary research approach. The interview and focus group discussion related to this objective was based on the following topics:

- How important it is to consider sustainability aspects in the bioenergy industry?
- What is the general opinion about concerns related to the sustainability aspects of bioenergy?
- What are the sustainability issues (concerns / benefits) of the industry? Are any sustainability issues raised by other stakeholders? How does the industry address those issues?
- Does the bioenergy industry (organisation) have any sustainability objectives? What are they? Why are these objectives important? How can those objectives be influenced by the industry?

Secondary and observational data were collected in addition to the interview and focus group data. After the data collection the data were analysed using thematic analysis. The analysed data is then presented using the matrix data display approach in the findings section of this chapter. Following that the findings are discussed in the discussion section.

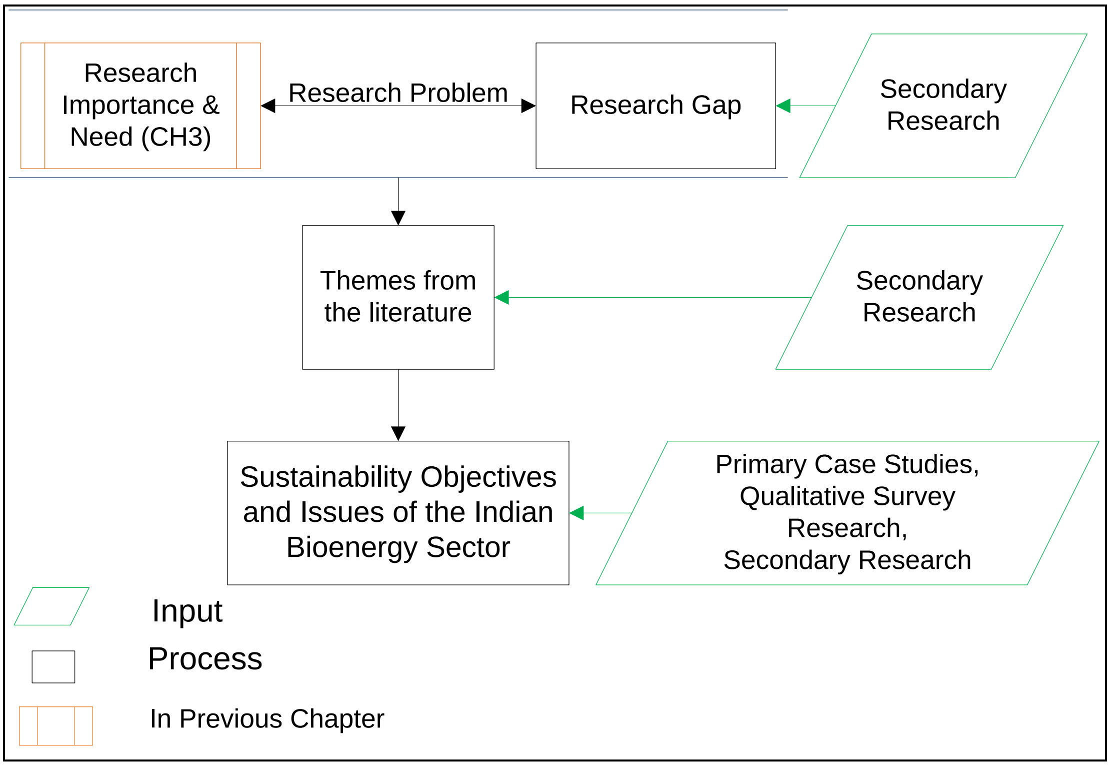

Figure 6.1: Research Approach to Address 2nd Research Objective

6.2 Analysis of Existing Literature

As discussed in Chapter 3, bioenergy can have positive impact on the society and environment. For example OECD and IEA (2012, p. 47) in their report recognise this by stating that,

> *Several small-scale bioenergy projects in developing countries have already been shown to lead to greater access to energy and to offer new opportunities in rural areas, by creating new employment and revenues along the supply chain.*

At the same time there are concerns about possible negative impacts on sustainable development by the industry (Escobar et al., 2009; Evans et al., 2010; Rovere et al., 2010; Thornley et al., 2009a). These negative impacts can develop a bad public perception about the bioenergy plants and can lead to rejection of the bioenergy projects by the stakeholders' (Buchholz et al., 2009b; Cherni et al., 2007; Roos et al., 1999; Rösch & Kaltschmitt, 1999; Thornley et al., 2009a; Wegener & Kelly, 2008; Wright, 2006).

> *Where, Wegener and Kelly (2008, p.107) argues that, "best technology does no good unless people use it. Thus, the future of bio-fuels depends not only on development of effective and efficient technologies but also on the social, economic, and political climate within which people decide to use or avoid these new fuel sources and technologies."*

The potential of the bioenergy industry to have either positive or negative impacts on sustainable development, depending on its performance, makes it important to identify the relevant sustainable development aspects. Then the objectives and issues related to those sustainability aspects can be carefully considered and addressed by the industry, which can boost the positive impacts and avoid or minimise any potential negative impacts.

Different certification schemes exist, which deal with the integration of sustainability aspects in the bioenergy industry. These include renewable energy directive (RED) (European Commission, 2009) and Roundtable on Sustainable Biofuels (2011).

> *However, "fewer schemes include biomass used for heat and power generation, which reflects the lack of specific legislation, among other factors" (OECD & IEA, 2012, p. 19).*

In addition to the deficiency of sustainability certification related to the bioenergy plants generating heat and power, The OECD and IEA (2012) report also argues that special attention must be given to small scale industries for them to integrate sustainability concepts in their operations. As they cannot afford the additional costs of complying with certification schemes (FAO, 2012). However to the knowledge of researcher, work related to the sustainability assurance schemes for small scale bioenergy industries is scant (FAO, 2012).

GBEP (2007) argues that the significance of sustainable bioenergy and a need for internationally agreed sustainability requirements are well recognized, "yet no international sustainability assurance system exists for biofuels or bioenergy more broadly" (p.vi).

Table 6.1 summarizes the bioenergy development policy objectives in G8 + 5 countries (Source: GBEP, 2007). Most of the countries in that list want to develop their bioenergy sector to address climate change and environmental aspects along with other objectives. The policy objectives of the bioenergy industry in India do not have this emphasis; instead it intends to achieve cost effectiveness, technological progress, rural development and energy security. This variation in policy objectives of the countries to develop bioenergy influences the importance of different sustainability factors related to the bioenergy industry in those countries through its policies. Therefore, sustainability aspects relevant to the bioenergy industry can be different in countries that have special objectives to promote the bioenergy sector, such as India.

The shortcomings of the current work related to the sustainability aspects of the bioenergy industry, such as lack of sustainability certification schemes for heat and power bioenergy plants, lack of work related to the sustainability aspects of small scale bioenergy industry and no universally accepted norms for bioenergy sustainability, are discussed above. In addition to that, the need to identify sustainability aspects of bioenergy industry relevant to a particular countries context is articulated above. Given these reasons it becomes important to identify the relevant sustainable objectives and issues of the small scale bioenergy industry in India. This investigation starts with the review of current literature relevant to the sustainability of Indian bioenergy sector, which follows the terminology section below.

Table 6.1: Main Objectives of Bioenergy Development in Country Policy Frameworks

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(Source: GBEP, 2007)

6.2.1 Terminology

Some of the terms related to the sustainability concept are often used in multiple contexts with different meanings. In order to avoid any confusion these terms are defined in the given context below.

6.2.1.1 Global Sustainability

In chapter 5the concept of sustainability adopted in this thesis is discussed, which includes both organisational and global (Garvare & Johansson, 2010; Johansson, 2008). In this chapter global sustainability related to the bioenergy industry is examined, which is also termed as sustainability within this chapter. Garvare and Johansson (2010) states that global sustainability is the sustainable development of the globe. While, sustainable development is a process of change that can improve the system in a sustainable manner (Gallopín, 2003). Therefore, global sustainability can be derived from the above definitions as a sustainable development process that can improve the globe / world (system) in a sustainable manner.

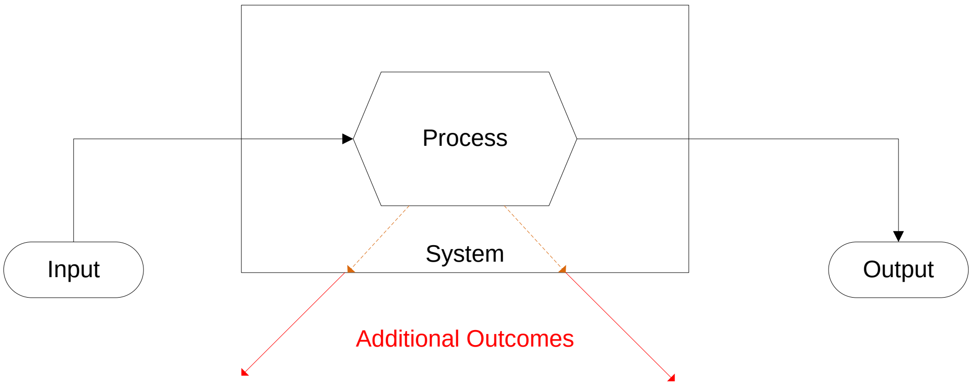

Figure 6.2: Sustainability of the Manufacturing Process

ASME (2011) dissects the goal of sustainability manufacturing into two main categories: product and process design for sustainability. A similar distinction from systems perspective is advocated by Gallopín (2003), that it should be made clear if the aim is to achieve the sustainability of the process or sustainability of the output(s) of the process. However this boundary between process and product is blurred for the service sector and in particular in the energy sector due to the nature of the sector. The sustainability of the manufacturing process (process only) and sustainability of both product and process (input, process and output) is shown in Figure 6.2 and Figure 6.3 respectively. These additional outcomes shown in the figures are the global sustainability impact created by the systems. In bioenergy sector, considering the manufacturing process only as shown in Figure 6.2 will limit the view of its global sustainability impacts, as most of the global sustainability impacts occur in input and output stages of the system, rather than in process stage alone. For example, some of the important reasons of the Indian government to promote bioenergy such as rural development and energy security are closely linked to the output (energy) of the bioenergy industry. Therefore the sustainability impact of both product and process collectively need to be taken into account for bioenergy sector, as shown in Figure 6.3.

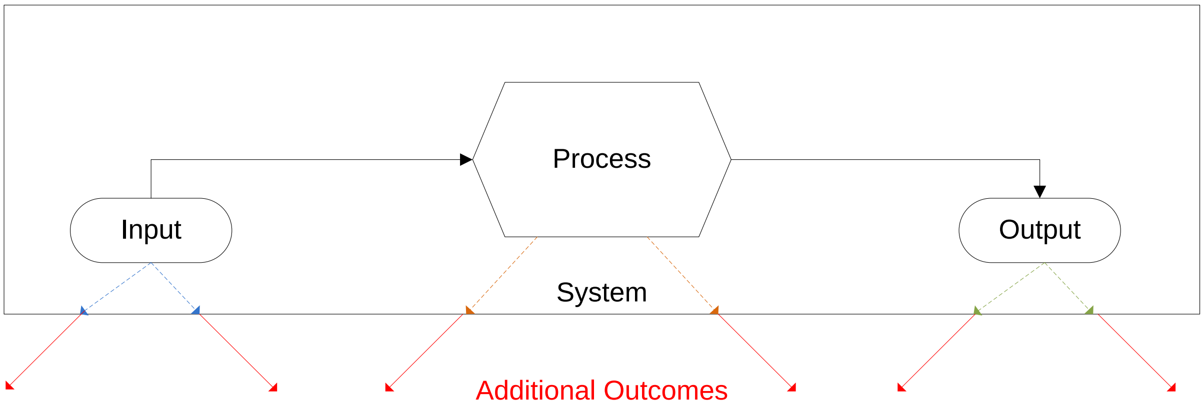

Figure 6.3: Sustainability of both Product and Process

6.2.1.2 Dimensions

Economic, environmental and social sustainability are the famous three dimensions of the sustainability concept (Elkington, 1997, 1998). If we view this dimensions, from the corporate sustainability perspective, then economic pillar of the concept can be related to the organisational sustainability and environmental and social pillars can be related to global sustainability. Economic aspects such as business transactions and profitability can be covered under organisational sustainability. But some of the economic aspects are related to the global sustainability as it impacts the societal sustainable development. Therefore, in this chapter the global sustainability aspects will be classified under two dimensions namely environmental and socio-economic sustainability.

6.2.1.3 Aspects

Aspects are specific big topics under the dimensions of sustainability. It is described using other terms in literature such as 'area of concerns and / or benefits', 'topic', 'theme' and even some times as 'issue'.

6.2.1.4 Objectives

Objectives are "basic rules of sustainable development, typically formulated as a commandment" and allow for the assessment of sustainability (Madlener et al., 2006, p. 247). It is also alternatively termed as 'principles'.

6.2.1.5 Issues

Issues are the positive or negative impact on global sustainability expected as a result of the system. For example, in Figure 6.3 the distinct additional outcomes of the system (which can be due to input, process or output) are the issues. Other terms used to describe issues are 'concerns', 'benefits', 'impact (positive / negative)' and 'effect'.

6.2.2 Overview of Current Literature on Sustainable Bioenergy in India

There are many studies in Indian context (for example: Cust et al., 2007; Ravindranath & Balachandra, 2009; TERI, 2010) that discuss the potential global sustainability impacts (mainly benefits) of the bioenergy sector. However, these studies do not identify or investigate the sustainability requirements of bioenergy industry. Instead they discuss the generic benefits or concerns of the bioenergy sector based on the literature in order to support their arguments. As the objective of this research chapter is to identify the global sustainability objectives and issues of the small scale bioenergy sector in India, the papers that investigate those global sustainability objectives and issues in an Indian context are discussed in this section. A summary is also given below.

Sudha and Ravindranath (1999) in their work have assessed land availability and biomass production potential in India. After taking the demand for food, fuel wood and timber into account they have conservatively estimated the land availability and biomass production potential of India as 43 MHA and 231 MT respectively.

Kumar et al. (2009) have considered the possibility of negative impact on food security due to bioenergy sector growth in India and therefore they have developed and analysed hypothetical case study scenarios of bioenergy development in the 'Tumkur' region of India. They have concluded that by using the waste land in the region it is possible to have optimal production of bioenergy without impacting the food security.

The study by Rootzén et al. (2010) compared use of land for bioenergy with use of land for carbon sequestration through plantations which supply wood for non-energy purposes, to identify the effective strategy for climate change mitigation. The study was conducted in the context of a case study from a south Indian village. The study concluded that carbon sequestration through long rotation plantations is suitable for a shorter time frame (i.e. 30 years) and the bioenergy option is favoured for a longer time frame (i.e. 100 years) for effective climate change mitigation.

Gonsalves (2006) assess the biofuel industry in India. In his work he recognizes the global sustainability benefits of biodiesel industry as reduced emission of harmful pollutants, reduction in greenhouse gas emissions, increased employment, energy security, decreased dependence on oil imports, improved social well-being, increase in nutrients to soil and decrease in soil erosion and land degradation.

Kumar et al. (2012) in their study have identified the sustainability issues relevant to the Jatropha biodiesel in India. They have categorised the sustainability issues into four categories namely technological, environmental, economic and social. Self-sustainable energy, reduction in greenhouse gas (GHGs) emissions, improvement of the degraded ecosystem, improving the fertility of degraded lands, employment generation, food security and toxicity and safety issues are the sustainability issues identified in the study.

Tiwari et al. (2009) present their initial findings from the Indian segment of the rural energy production from bio-energy (RE-Impact) project, which is implemented across four countries – India, China, South Africa and Uganda. One aim of the project was to develop a sustainability framework for assessing bioenergy projects. In this work they present their observations related to the biofuels program, which was part of the initial work undertaken towards developing the framework. The following major policy objectives were recognised as the foundation for the Indian National Biofuels Policy (p.1):

- Generating rural employment opportunities,
- Saving foreign exchange reserves,

- Promoting energy security in the country,
- Promoting environmental security,
- Meeting climate change commitments and
- Promoting renewable energy sources

They have also compiled and highlighted some of the concerns about the policy by the civil society organisations. Issues raised are the livelihood of people who depend on wastelands, monocultures of bio fuel plantations, diversion of good agricultural lands for biofuel production and lease availability of the marginal lands for the community members. These issues are related to the global sustainability aspects such as land availability, impact on biodiversity, food security and livelihood of people.

Some other reports from the same project analyse the impact assessment methodologies in bioenergy sector (Harrison et al., 2009; Harrison et al., 2011). These reports discuss the above mentioned findings (Tiwari et al., 2009) and draw additional comments on sustainability of bioenergy based on their field experience in India as well. Based on the interviews with stakeholders in the State of Chhattisgarh in India the authors have acknowledged sustainability goals of the biofuels program as follows:

> *The sustainability criteria identified include rural employment, increased livelihood diversity, degraded land rehabilitation, rural electricity provision and economic gains from sale of feedstock. (Harrison et al., 2009, p. 5)*

They acknowledged that the impact on water resources and rural development are other indirect sustainability aspects associated with the biofuels program. Furthermore, they stated that biodiversity, carbon storage and clean development mechanism were not considered as of primary importance by the stakeholders.

Ravindranath et al. (2004) and Somashekhar et al. (2000) present performance of bioenergy systems in India and impact of decentralised bioenergy generation in India respectively based on the same two case studies in Karnataka, India (Hosahalli and Hanumanthanagara project). In both of the studies, the impacts of those case studies are discussed. Both studies have recognized sustainability benefits of those projects as improvement in quality of life especially for women and children, more employment generation, additional income generation, improving the fertility of degraded lands, soil conservation, promotion of biodiversity, fossil fuel conservation and carbon dioxide emission reduction. In addition the projects also had sustainable objectives such as equitable distribution of benefits and minimum ash output, which was achieved.

The above mentioned studies (Kumar et al., 2009; Rootzén et al., 2010; Sudha & Ravindranath, 1999) have analysed the potential of the Indian bioenergy industry with respect to individual global sustainability aspects such as food security, climate change mitigation and land availability but they do not investigate about the real sustainability impacts or concerns of Indian bioenergy sector. Gonsalves (2006) and Kumar et al. (2012) recognise the sustainability impacts of the biodiesel sector in their studies. However, in both of the studies the context of analysis was biodiesel sector and not bioenergy sector and the impacts acknowledged are based on the literature and secondary data.

The outputs of RE-Impact project (Harrison et al., 2009; Harrison et al., 2011; Tiwari et al., 2009) need to be cautiously examined before any further application and generalisation because of the following reasons. Firstly, the sustainability concerns discussed in Tiwari et al. (2009) are based on a consultation with civil society organisations only. Secondly, the details and process of stakeholder consultations are not provided in the other two studies (Harrison et al., 2009; Harrison et al., 2011), which limits the suitability of findings for the purpose (RO2). Finally and most importantly the discussion with civil society organisations and stakeholder consultations were both focused on the national biofuels policies, particularly about bio fuel plantation process for biodiesel.

Ravindranath et al. (2004) and Somashekhar et al. (2000) have identified sustainability impacts of the bioenergy projects which produce electricity in India. However the case studies were not typical bioenergy 'business like' projects, as their capital funding was from government, international and charitable organisations. The implementation and operations management of the plants were assisted by one of the leading research institutions in India, as one of the important reasons behind the project was to study the practical feasibility of the bioenergy based rural electrification. This enabled them to carry out sustainability development activities easily when compared to other organisations.

The above studies highlight some of the important global sustainability impacts of the bioenergy sector in India. In spite of this, primary research is warranted because these studies are limited in their capacity to cater for the requirements of the research objective (RO2). However, these findings can be very helpful in evaluating the results of this study, which will be addressed in the discussion section of this chapter.

6.2.3 Review of sustainability issues and objectives of bioenergy

Numerous sustainability certification systems of bioenergy are in operation in different parts of the world. Some of these systems are regulatory frameworks proposed by governments or regional regulating authorities, for example EU renewable energy directive (RED) (European Commission, 2009) and Testing Framework for Sustainable Biomass, Netherlands (Cramer et al., 2007). However currently there is no bioenergy regulatory framework in India. Other systems are voluntary certification systems or score cards, for example Roundtable on Sustainable Biofuels (2011) and Global Bioenergy Partnership (GBEP, 2011). These certification systems or standards list different sustainability aspects, objectives, issues or criteria on which they evaluate the bioenergy systems. However, all of these certification systems or standards are not entirely similar as the sustainability aspects covered in these different certification systems fluctuate due to various factors such as scope, context, purpose, etc.

There are studies (Grinsven, 2009; Guariguata et al., 2011; Schlegel & Kaphengst, 2007; UNCTAD, 2008; UNIDO, 2009; Vallesi et al., 2012; Vis et al., 2008), which reviewed these certification systems or standards and evaluated their performance, functionality and usability. The different certification schemes and standards discussed above have been reviewed and their core sustainability aspects / objectives / criteria are compiled in various studies (FAO, 2011; Lewandowski & Faaij, 2006; Scarlat & Dallemand, 2011; Van Dam et al., 2008; Van Dam et al., 2010). For example FAO (2011) have compiled the sustainability aspects addressed in 23 certification systems, this is shown in Table 6.2. Fritsche et al. (2010); Fritsche et al. (2006) and Thornley et al. (2009b) have reviewed sustainability issues from various studies and compiled a list of sustainability issues of bioenergy sector in their work.

Hämäläinen et al. (2011) have identified the sustainability requirements for a bioenergy industry through stakeholder consultations in Finland. Similarly, Haughton et al. (2009) and Dockerty et al. (2012) have recognised sustainable objectives of bioenergy sector in UK. Van Dam and Junginger (2011) and Buchholz et al. (2009a) have conducted a survey with experts across the world to identify the important bioenergy sustainability criteria.

In order to locate relevant bioenergy sustainability issues and objectives, the above mentioned standards and studies were reviewed. From that the relevant information was collated and they were grouped under classification of aspects. In total 23 sustainability aspects were identified in which 9 aspects are related to the environmental dimension and 14 related to the socioeconomic dimension. Sustainability issues of bioenergy that are categorised based on their aspects are given in Table 6.3 (Source: Buchholz et al., 2009a; Dockerty et al., 2012; FAO, 2011; Fritsche et al., 2010; Fritsche et al., 2006; Hämäläinen et al., 2011; Haughton et al., 2009; Lewandowski & Faaij, 2006; Scarlat & Dallemand, 2011; Thornley et al., 2009b; Van Dam & Junginger, 2011; Van Dam et al., 2008; Van Dam et al., 2010).

Similarly, bioenergy sector sustainability objectives that are categorised based on their aspects are given in Table 6.4 (Source: Buchholz et al., 2009a; Cramer et al., 2007; Dockerty et al., 2012; FAO, 2011; Fritsche et al., 2010; Fritsche et al., 2006; Hämäläinen et al., 2011; Haughton et al., 2009; Lewandowski & Faaij, 2006; Roundtable on Sustainable Biofuels, 2011; Scarlat & Dallemand, 2011; Thornley et al., 2009b; Van Dam & Junginger, 2011; Van Dam et al., 2008; Van Dam et al., 2010).

Table 6.2: Compilation of Bioenergy Sustainability Initiatives

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(Source: FAO, 2011)

Table 6.3: Sustainability Issues of Bioenergy Sector from Literature

Aspects	*Issues*
	Environmental Sustainability
Carbon Conservation	Greenhouse Gas Emissions - Reduce greenhouse gas emissions, Using transport modes that release less greenhouse gases Preservation of above/below ground carbon
Air	Protection of Air Quality Potentially hazardous atmospheric emissions other than greenhouse gases No burning for land clearing/waste disposal No burning residues, waste, by- products
Water	Water availability Access to water Water quality - Avoidance of pollution of ground and surface water Water management and conservation - No depletion of ground and surface water resources Efficient water use
Soil	Soil management - Measures to prevent soil erosion Soil protection - No pesticide residues in the soil No impoverishment of the soil; nutrient balances should remain in equilibrium Optimized utilization of the soil's organic nitrogen pool No accumulation of heavy metals in soil No irreversible soil compaction
Biodiversity & Ecosystem	Genetically Modified Organism (GMO) Biodiversity

Aspects	***Issues***
	Natural habitats, ecosystems - Avoidance of pollution of natural ecosystems neighbouring the fields High conservation value areas Native, endangered and invasive species Deforestation - Plantations should not replace forests, No logging activities in protected forests Crop diversity No replacement of staple crops
Land Use	Land-use changes (both direct and indirect) issues
Resource Efficiency	Productive capacity of land Energy efficiency Energy balance Sustainable use of resources - Minimization of the use of raw material, resources and land Crop management - Sustainable rate of harvesting
Waste Management	Minimization of wastes- Residues, wastes, by-products Sorting of wastes - Environmental training of employees, to facilitate waste sorting Proper handling and disposal of waste Recycling of waste where possible - Recycling of ashes from biomass combustion
Sustainable Agriculture	Agrochemical use - No use of persistent organic pollutants (POPs) and substances that deplete the ozone layer Good farming practice The development and adoption of environmentally friendly non-chemical methods of pest management
Socio-Economic Sustainability	
Food Security	Food availability

Aspects	***Issues***
	Food access Food utilisation Food stability
Human rights	Human health and safety issues Accident prevention measures Human right issues - Indigenous people and tribe's rights have to be respected, Women should not be discriminated and their rights have to be respected
Labour Rights	Wages - Equal pay for equal work Labour Working conditions - Workings hours, No illegal overtime, A safe and healthy work environment, with aspects such as machine and body protection, sufficient lighting, adequate indoor temperature and fire drills Contracts Freedom of association, bargaining Discrimination Child labour Forced labour Training, capacity building Regulations are in place to protect the rights of pregnant women and breastfeeding mothers Spouses have the right to search work outside the entity where the husband works
Rural and Social Development	Economic benefits to community - The activity should contribute to poverty reduction, Increase of income level Social benefits to community - Access to sanitary facilities, adequate housing, education and training, transportation, and health services

Aspects	*Issues*
	Local organisations, institutions or companies should be involved in the process Capacity building - Support of infrastructure development, Enhancement of democratic development Improve public enjoyment of the countryside Enhance tourism potential
Energy Security and Access	Reduce energy costs Local energy security Energy supply in the region of biomass production should not suffer from biomass trading activities
Employment Generation	Jobs should be generated Building and use of local labour and skills
Fossil Fuel Conservation	Decreasing fuel consumption
Land Rights	Land tenure/access - Land ownership should be equitable Displacement effects Land use right compliance - Avoidance of land tenure conflicts
Fair Trade Conditions	Transparency and accountability of negotiations Direct and long-term trading relationships Fair and equal remuneration—all supply chain partners are able to cover costs and receive fair remuneration for their efforts through prices that reflect the true value of the product. Risk sharing mechanisms are actively encouraged Communication and information flow—supply chain partners communicate openly with each other showing a willingness to share information
Access to Resources	Access to firewood Access to other natural resources

Aspects	***Issues***
Participation	Stakeholder involvement in the decisions that concern them - Community Participation Establishment of a communication systems that facilitates the exchange of information Cultural acceptability
Landscape View	Visual impacts
Noise Pollution	Noise impacts
Traffic	Increased transport movements

Table 6.4: Sustainability Objectives of Bioenergy Sector from Literature

Aspects	***Objectives***
	Environmental Sustainability
Carbon Conservation	• The greenhouse gas balance of the production chain and application of the biomass must be positive. • Biomass production must not be at the expense of important carbon sinks in the vegetation and in the soil.
Air	• In the production and processing of biomass the air quality must be maintained or improved.
Water	• Biofuel operations shall maintain or enhance the quality and quantity of surface and ground water resources, and respect prior formal or customary water rights.
Soil	• In the production and processing of biomass, the soil, and soil quality must be retained or even improved.
Biodiversity & Ecosystem	• Biomass production must not affect protected or vulnerable biodiversity and will, where possible, have to strengthen biodiversity. • Biofuel operations shall avoid negative impacts on ecosystems, and conservation values
Land Use	• Minimization of (direct and indirect) land-use changes
Resource Efficiency	• The use of technologies in biofuel operations shall seek to maximize production efficiency
Waste Management	• Maximize waste management opportunities
Sustainable Agriculture	-
	Socio-Economic Sustainability
Food Security	• The production of biomass for energy must not endanger the food supply • Biofuel operations shall ensure the human right to adequate food and improve food security in food insecure regions
Human rights	• Biofuel operations shall not violate human rights
Labour Rights	• Biofuel operations shall not violate labour rights, and shall promote decent work and the well-being of workers.

Aspects	*Objectives*
Rural and Social Development	• Biofuel operations shall contribute to the social and economic development of local, rural and indigenous people and communities. • Enhance tourism potential • Enhance viability of farming
Energy Security and Access	• Reduce energy costs • Increase amount of energy produced and used locally
Employment Generation	• Enhance employment
Fossil Fuel Conservation	-
Land Rights	• Biofuel operations shall respect land rights and land use rights
Fair Trade Conditions	-
Access to Resources	• The production of biomass for energy must not endanger the local biomass applications (energy supply, medicines, and building materials).
Participation	-
Landscape View	Safeguard the historic environment • Enhance local landscape character
Noise Pollution	-
Traffic	• Minimize transport movements

Maignan and Ralston (2002) argue that an organisation committed to CSR has two components namely principles and processes. Principles “represent the motivational inputs driving the commitment” and processes “designate the managerial procedures and instruments employed by businesses to bring their motivational principles into practice” (Maignan & Ralston, 2002, p. 498). The above given Table 6.3and Table 6.4 collate all the objectives (or principles) and the issues related to those objectives (or principles) respectively. However it does not summarise the issues related to the processes(sustainability implementation) as the procedure to implement can be different from one business to another; the issues related to them can also be different. Most importantly the focus of this study is on the principles of sustainability and issues related to them rather than on the processes of sustainability implementation by an organisation.

6.3 Findings

The data about bioenergy sustainability aspects collected from multiple primary case studies and stakeholder groups are presented using matrix data display approach (Miles & Huberman, 1994) in Table 6.5 and Table 6.6 respectively. These matrices list the different sustainability aspects of the bioenergy industry and refer to the case study or participant in column and row respectively. The recognition about relevance of a particular global sustainability aspect by a participant or a case study company is shown using a ✓mark in the respective cell. Apart from sustainable agriculture, human rights, land rights, landscape view, noise pollution and traffic aspects, all other sustainability aspects identified above from the literature review is at least recognised by one of the participants in this study as a relevant aspect for small scale bioenergy sector in India.

Government regulations are seen as the important means to address the sustainability aspects in bioenergy sector by most of the case study companies. One of the researchers interviewed in line with this view argues that,

> *Unfortunately voluntary adoption of sustainable criteria is not that much feasible in current Indian context and hence sustainability need to be achieved through the government regulations. (QSR-IN36)*

The respondents of companies such as PCS1 and PCS8 state that existing regulations cover most of the environmental sustainability aspects. PCS3 and PCS8 further add that current requirement to achieve sustainability of bioenergy is improved enforcement of the regulations rather than new regulations.

The individual sustainability aspects recognised as relevant and the respective issues related to those aspects raised in the collected empirical data are discussed below.

Table 6.5: Matrix Display of Relevant Sustainability Aspects - Primary Case Studies

Aspects	***PCS1***	***PCS2***	***PCS3***	***PCS4***	***PCS5***	***PCS6***	***PCS7***	***PCS8***	***PCS9***	***PCS10***	***PCS11***	***PCS12***	***PCS13***
Environmental Sustainability													
Carbon Conservation	✓		✓	✓	✓	✓	✓	✓	✓			✓	✓
Air			✓	✓	✓			✓	✓		✓	✓	
Water			✓						✓				
Soil			✓								✓	✓	
Biodiversity & Ecosystem			✓					✓				✓	
Land Use			✓										
Resource Efficiency	✓	✓	✓			✓	✓	✓					✓
Waste Management		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	
Socio-Economic Sustainability													
Food Security			✓			✓				✓			
Labour Rights		✓		✓		✓	✓			✓		✓	
Rural and Social Development			✓			✓	✓		✓		✓		
Energy Security and Access	✓	✓	✓	✓	✓	✓		✓	✓		✓		✓
Employment Generation			✓			✓	✓	✓					
Fossil Fuel Conservation		✓	✓			✓	✓	✓	✓	✓	✓	✓	✓
Fair Trade Conditions			✓			✓						✓	
Access to Resources			✓	✓		✓					✓		
Participation			✓	✓	✓	✓		✓					

Table 6.6: Matrix Display of Relevant Sustainability Aspects - Stakeholders

Aspects	***Equipment Suppliers***		***Government Officials***			***Bank Officials***		***NGO Officials***		***Consultants***		***Researchers***				
	IN22	IN23	IN24	IN25	IN26	IN27	IN28	IN29	IN30	IN31	IN32	IN33	IN34	IN35	IN36	IN37
Environmental Sustainability																
Carbon Conservation	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Air	✓	✓	✓	✓		✓		✓	✓		✓	✓	✓	✓	✓	
Water			✓					✓	✓					✓	✓	✓
Soil			✓					✓					✓	✓	✓	✓
Biodiversity & Ecosystem								✓					✓	✓		
Land Use			✓			✓		✓				✓		✓	✓	
Resource Efficiency	✓					✓						✓	✓	✓	✓	✓
Waste Management		✓	✓	✓		✓		✓	✓	✓		✓	✓	✓	✓	
Socio-Economic Sustainability																
Food Security			✓			✓		✓		✓		✓		✓	✓	
Labour Rights								✓					✓			
Rural and Social Development			✓	✓		✓		✓	✓		✓		✓	✓		✓
Energy Security and Access		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Employment Generation			✓	✓		✓		✓	✓	✓	✓		✓	✓		
Fossil Fuel Conservation		✓	✓	✓		✓		✓	✓	✓			✓	✓		
Fair Trade Conditions				✓					✓		✓		✓			✓
Access to Resources					✓										✓	
Participation					✓	✓			✓					✓	✓	✓

6.3.1 Carbon Conservation

Bioenergy can contribute to the climate change mitigation through the greenhouse gas (GHG) emission savings of energy production and carbon sequestration during the biomass growth. Even if the policy initiatives of the Indian government do not emphasize climate change mitigation as one of their aims for promoting bioenergy sector as shown in Table 6.1, it has been widely recognised by case studies and stakeholders in this study as one of the important sustainability benefits of bioenergy industries. In the case study, energy end use organisations such as PCS1 and PCS5, which use the heat produced from bioenergy for their textile products processing, view bioenergy as one of their marketing advantages. As the processing emits less greenhouse gas emission, it is an advantage for them to promote their products among international buyers as green product.

The issues related to the carbon conservation found in the empirical data are given below:

- **Non-replenishment of carbon**: Using forest wood without re-plantation of trees can lead to non-replenishment of carbon stock in forest (IN36).
- **Greenhouse gas emissions compared to fossil fuel sources**: Most of the case studies and stakeholders expressed that bioenergy produces less GHG emissions compared to fossil fuel and hence the adoption of bioenergy can reduce the greenhouse gas emissions for energy production from fossil fuels.
- **Greenhouse gas emissions from biomass transportation**: The GHG emissions due to the transportation of biomass can be huge depending on the distance travelled and type of transport. This can impact the total GHG savings from bioenergy (PCS3, IN22 & IN36). Due to this a respondent from PCS3 argues that small scale bioenergy is better suited as it can reduce the need for biomass transportation.
- **Greenhouse gas emissions from open burning of agro residues**: Open burning of agro residues in agricultural land after the harvesting is widespread in India (Sagi et al., 2012). This contributes to the GHG emissions (from unutilised source of energy), which can be avoided by using the residues for bioenergy (PCS8 & PCS12).

Following global sustainability objectives related to the carbon conservation aspect can be derived from the above mentioned issues, for the small scale bioenergy sector in India.

- The greenhouse gas balance of the production chain and application of the biomass must be positive.
- Biomass production must not be at the expense of carbon sink in the vegetation.

6.3.2 Air

Air quality is one of the sustainability aspects that are relevant in the Indian context. Companies such as PCS1 and PCS3 argue that the norms for exhaust air emissions are very stringent in India and it should be maintained within the permissible limits set by the pollution control board in India to avoid any regulatory risks. Given below are the issues related to this aspect in the data.

- **Local air pollution**: The exhaust gases from the bioenergy plant affecting the local air quality in the past has been identified as an issue in case studies PCS4 and PCS5, which have led to concerns from the local community. This issue was developed due to improper exhaust design in PCS5 and particular type of feedstock used in PCS4. This issue along with its impact on the case study companies is further discussed in the paper Eswarlal et al. (2013).
- **Potentially hazardous atmospheric emissions other than greenhouse gases**: Emission of other hazardous gases such as sulphur, nitrogen, etc. from the bioenergy plant is a concern as it can impact the health of local population (PCS8 & IN36).
- **Pollution from burning of residues**: Open burning of residues which is discussed in section 6.3.1 also impacts the air quality, whereas the systematic use of bioenergy can minimize that impact (PCS8, PCS11 &PCS12).

From the above mentioned issues the following sustainability objectives related to the aspect 'Air' can be derived.

- In the production and processing of biomass the (local) air quality must be maintained or improved.
- Bioenergy production must not produce any potentially hazardous atmospheric emissions.

6.3.3 Water

Water is an important resource for both production and processing of biomass for bioenergy (PCS3). The issues related to the sustainability aspect 'Water' identified in the data are discussed below.

- **Water availability for drinking and other purposes**: Security of water for drinking, cooking and other day to day consumption of local people should be given priority (PCS3 & IN37). The bioenergy related processes should not have any impact on this basic need of people.
- **Water availability for other existing demand**: There should be water available for bioenergy in addition to the existing demand for other agricultural and commercial needs (IN36 & IN37).

- **Water catchment area**: The biomass growth in water catchment area can impact on the local water conservation (PCS3).
- **Water treatment and recycling**: The water used should be treated within the plant and recycled (PCS9 & IN37). Case Study Company PCS9 has installed an in-house effluents treatment plant to maintain the quality and reuse water.

Summarising the above mentioned issues into the objectives related to the sustainability aspect 'Water' is given below.

- Bioenergy operations should respect prior formal or customary water rights (both residential and commercial).
- Bioenergy production must not impact on the ability to conserve water.
- In the production and processing of biomass the quality of water resources should be maintained or enhanced.

6.3.4 Soil

The issues raised in the empirical data about the sustainability aspect 'Soil' due to bioenergy are discussed below.

- **Soil quality**: The soil quality should not be affected due to biomass growth (PCS3 & IN36). Avoiding the open burning of agricultural residues in farm lands (discussed in section 6.3.1) and using it as a feed stock can avoid adverse effect on soil quality (PCS11 & PCS12).

  The sustainability objective based on the above issue is given below.
- In the production and processing of biomass soil quality must be retained or even improved.

6.3.5 Biodiversity & Ecosystem

The issues relevant to the sustainability aspect of 'biodiversity & ecosystem' identified are given below.

- **Biodiversity and Wildlife protection**: No harm to the biodiversity or wildlife due to bioenergy operations (PCS3). The respondents from case study PCS12 gave an example of earthworms getting affected due to the open burning of residues. Avoiding the open burning of residues in agricultural fields can avoid any negative effect on biodiversity (PCS11 & PCS12).
- **Eco-conservation value areas**: No biomass production activity should be carried out in highly eco-sensitive zones or conservation areas (PCS3).

From the above mentioned issues following sustainability objectives related to the 'biodiversity & ecosystem' aspect can be derived.

- Bioenergy production must not affect biodiversity and wildlife and should (where possible) strengthen biodiversity.
- Bioenergy production operations should be avoided in eco conservative areas.

6.3.6 Land Use

Land use is one of the environmental sustainability aspects mostly related with the biomass production process of the bioenergy supply chain. Issues related to this aspect are raised mostly by stakeholders from general perspective apart from case study PCS3. This is because apart from case study PCS3 (using wood fuel), other case studies are engaged in activities related to the agro residues or industrial-agro/wood residues. The issues related to the land use aspect found in the empirical data are given below.

- **Land availability**: The land available in the region and competition for land for other purposes need to be carefully considered (PCS3 & IN36).
- **Utilization of degraded lands**: Unused degraded agricultural lands should be improved and utilized to grow biomass (PCS3 & IN37). This can address the issue of unavailability of land to grow biomass and at the same time improve the quality of the soil (IN37).
- **Land use change (direct and indirect)**: Changing the use of land to grow biomass either directly or indirectly (IN33 & IN36). This change can also lead to other sustainability impacts such as increased GHG emissions (IN33), negative impact on biodiversity (IN33), deforestation (IN36) and affect food security (IN36).

The following global sustainability objectives related to the land use aspect can be derived from the above mentioned issues.

- Biomass production should consider the land availability in the region.
- Biomass production should utilise degraded lands and must not lead to other (direct or indirect) land use changes.

6.3.7 Resource Efficiency

The issues related to the resource efficiency aspect found in the empirical data are given below.

- **Energy efficiency**: This issue is related to the efficient use of energy and minimization of the energy loss (PCS1, PCS2, PCS3, PCS6, PCS8, IN22, IN33, IN36 and IN37). Some researchers argued that the energy efficiency of bioenergy systems can be further increased through the cogeneration process (IN36 and IN37). In line with this view, Case Study Company PCS6 was already utilising exhaust heat for other small scale industry processes. Case Study PCS2 during the visit by the researcher was planning to use the exhaust heat for cooking in a hostel and drying the biomass. The small scale bioenergy sector's ability to minimise transmission and distribution losses when compared to large scale systems is highlighted by case study companies such as PCS1, PCS3 and PCS8 as one of the merits of small scale systems. However, there is a need for proper transmission infrastructure to avoid heat or electricity transfer losses (PCS1).

- **Positive net energy gain**: The bioenergy conversion should result in a positive net energy gain taking energy consumption of all the processes related to the conversion into account such as briquetting, drying, transportation and auxiliary requirements (PCS3, IN22, IN33 and IN36).
- **Efficient use of biomass**: Utilising the biomass for maximum useful energy retrieval (PCS8 and IN36). Technology used can influence the energy obtained from the biomass (IN36). One of the researchers stated that the biomass used for cooking in rural areas can be more energy efficiently used by modern technologies with additional health benefits (IN36). The agro residues burnt in agricultural fields (discussed in section 6.3.1) can be efficiently used as biomass resource for energy (PCS8).
- **Productive capacity of land**: The biomass production per acre of land should be high; it can be improved through modern farming practices (PCS3).

The following global sustainability objectives related to the resource efficiency aspect can be derived from the above mentioned issues.

- The biomass productive capacity of the land should be improved.
- The biomass should be utilised efficiently to retrieve maximum energy.
- In the production and processing of biomass and transmission of energy, the energy losses should be minimised and the net energy gain should be positive.

6.3.8 Waste Management

The issues related to the waste management aspect found in the empirical data are given below.

- **Utilisation of residues**: Utilising the agro and industrial-agro residues which are wasted (PCS8, PCS11 and IN36). In India, availability of the agro residues is huge and it can be used positively for bioenergy, which is not used at all currently (PCS8). This potential to utilise the residues can avoid the open burning of agro wastes (PCS11).
- **Utilisation of by-products**: The by-products of the bioenergy conversion process such as charcoal, char, ash, etc. should be utilised (PCS2, PCS3, PCS4 and PCS9). By-products of the bioenergy plants have multiple uses in other sectors and have reasonable economic value in the market; therefore it can be an additional source of

income for the companies. For example the business case document related to one of the case studies state that,

Biomass after undergoing the required (conversion) processes produces approximately 1.5 to 2 tons of charcoal per day, which is sold in the market … at an attractive price (PCS9).

- **Proper handling and disposal of waste**: The waste from the conversion process should be handled and disposed of properly. Case Study Company PCS4 faced some local opposition for their plant due to the poor handling of bioenergy conversion waste (Eswarlal et al., 2013).

From the above mentioned issues the following sustainability objectives related to the 'waste management' aspect can be derived.

- The agro and industrial-agro residues should be effectively utilised as a biomass resource (where possible).
- The wastes of the bioenergy conversion process should be utilised as a by-product where possible and if not possible it should be appropriately handled and disposed.

6.3.9 Food Security

Food security is one of the important social sustainability aspects from the bioenergy sector's point of view. The issues related to this aspect are outlined below.

- **Food vs. Fuel Competition**: There is potential for there to be competition between food and fuel, if the bioenergy sector not properly managed. Even when most of the case study companies in this study and most of the bioenergy companies in India use residues / wood waste as their main source of fuel there is a general perception among some of the stakeholders that there is a potential for conflict between food and biomass (PCS6, IN33 and IN36). Also for the residues one of the researchers (IN36) stated the order of utilising the residues should be, "food, fodder, fuel and fertilizer". The biomass and food sectors can compete for land and water available which is dependent on the financial returns and energy crops should not be allowed to replace food crops (IN36).

The following global sustainability objectives related to the food security aspect can be derived from the above mentioned issues.

- The biomass production should not impact on the food security.

6.3.10 Labour Rights

The issues related to the labour rights aspect found in the empirical data are given below.

- **Labour working conditions**: Good working conditions should be provided for the workers (PCS4 and PCS12). There are potential health hazards for workers in a bioenergy industry (PCS4), therefore proper safety equipment should be provided to workers (PCS12).
- **Training**: The employees should be properly trained to process the biomass and operate machines (PCS6). This can increase the efficiency and reduce any hazard to workers.

From the above mentioned issues the following sustainability objectives related to the 'labour rights' aspect can be derived.

- Decent working conditions and training for the workers should be provided in bioenergy companies.

6.3.11 Rural and Social Development

Rural development is one of the important policy objectives for the promotion of bioenergy in India, as bioenergy has the potential to contribute to rural and social development. The issues related to the 'rural and social development' aspect are given below.

- **Economic benefits to community**: Bioenergy operations should contribute to the economic benefits of the community (PCS3, PCS6, PCS9, PCS11 and IN37). Direct benefits through local employment opportunities and raw material procurement from local farmers (PCS3, PCS6 and PCS9), for example, the case study PCS3 procured raw material worth of 20 million Indian rupees from the local farmers every year. These direct benefits also influence local community's perception of the bioenergy industry (Eswarlal et al., 2013). In addition the indirect economic benefits are attained by providing electricity to previously un-electrified rural areas. Electricity supplied can help to grow agriculture and rural industries in the region which can lead to further economic prosperity (PCS6, PCS9, PCS11 and IN37).
- **Social benefits to community**: Bioenergy operations should contribute to the social benefits of the community (PCS3 and PCS6). Case study companies such as PCS3 and PCS6 have carried out various social development activities for the local people. They argue that bioenergy companies have moral responsibilities towards the local people and they should carry out corporate social responsibility activities. The respondent related to the case study PCS6, stated that social inclusion and women's empowerment are their two important social development objectives in rural areas of Bihar.

The following global sustainability objectives related to the 'rural and social development' aspect can be derived from the above mentioned issues.

- Bioenergy operations should contribute to the economic and social development of local people and communities.

6.3.12 Energy Security and Access

Energy security is another one of the important reasons for the promotion of bioenergy by the Indian government. The issues related to the energy security and access aspect are given below.

- **Investment needs**: The low investment cost to setup small scale bioenergy plants when compared to other conventional large scale fossil fuel plants, can lead to fast investment in this type of projects which in turn can lead to quick access to energy for millions of un-electrified people in India (PCS3).
- **Cost of energy**: Cost of energy from biomass should be competitive with energy from other sources (PCS1, PCS2, PCS4, PCS6, PCS9 and IN36). The low cost of the energy is an important necessity for the rural poor to access it in rural areas. Case study companies agree that bioenergy is cheaper than energy generated from some fossil fuel sources such as diesel, furnace oil and kerosene (PCS1, PCS2, PCS4 and PCS6). The current cost of bioenergy is competitive with the grid electricity for industrial purposes (PCS1) but not when compared to domestic pricing (PCS2). However, if bioenergy is to penetrate the market it needs to be priced competitively (PCS9 and IN36).
- **Energy access**: Bioenergy should provide access to energy for the people in un-electrified areas and address growing supply demand gap (PCS3, PCS6, PCS11 and IN36).
- **Energy security**: Bioenergy can minimize the foreign energy dependence (PCS3, PCS8 and IN36), which makes the country dependent on imported fuel and impacts the country economy as well.

The following global sustainability objectives related to the ‘energy security and access’ aspect can be derived from the above mentioned issues.

- Bioenergy should be able to provide energy at competitive prices.
- Bioenergy should contribute to improve energy access and energy security.

6.3.13 Employment Generation

The issues related to the employment generation aspect found in the empirical data are given below.

- **Employment Generation**: New local jobs should be created by the bioenergy industry (PCS3, PCS6 and PCS8). As most of the population in rural India are dependent on agriculture the new employment generation in rural areas can be a major contribution (PCS6 and PCS8).

From the above mentioned issue the following sustainability objective related to the 'employment generation' aspect can be derived.

- Bioenergy operations should create new jobs.

6.3.14 Fossil Fuel Conservation

The issues related to the fossil fuel conservation aspect are given below**.**

- **Decreasing fossil fuel consumption**: Bioenergy can help to minimize the consumption of fossil fuel (PCS3, PCS6, PCS8, PCS, PCS11 and PCS12). From an Indian perspective fossil fuel conservation is more related to achieving energy independence (or energy security) rather than climate change mitigation (PCS3 and PCS8). Avoiding the open burning of agro wastes can also save on fossil fuel consumed to burn those residues in field (PCS11 and PCS12).

From the above mentioned issue the following sustainability objective related to the 'fossil fuel conservation' aspect can be derived.

- Bioenergy should contribute to fossil fuel conservation.

6.3.15 Fair Trade Conditions

The issue related to the 'fair trade conditions' aspect found in the empirical data is given below.

- **Fair remuneration for biomass**: A fair purchasing price should be paid to the farmers for the biomass procured (PCS3, PCS6, PCS12 and IN37). This can help to build trust among the farmers about the economic benefits of the biomass they produce and influence the regular availability of biomass (PCS3). One of the farmer groups stated that the cost of labour to cut and pack the agro residues is more than what the bioenergy companies are ready to pay for them, so it does not make financial sense for them to do that (PCS12).

The following global sustainability objectives related to the 'fair trade conditions' aspect can be derived from the above mentioned issue.

- Fair remuneration should be paid for the biomass procured.

6.3.16 Access to Resources

The issues related to the 'access to resources' aspect found in the empirical data is given below.

- **Access to firewood for cooking**: Utilising wood for energy can impact on the firewood needed for cooking in rural areas in India, as a significant rural population still depend on firewood for cooking (IN26 and IN36).

- **Access to biomass for fodder and other industries**: The biomass requirement of the bioenergy industry can impact on the demand for the same resource for animal fodder and other industrial applications such as paper mill (PCS4, PCS6, PCS11 and IN36). This competition can influence the price and availability of biomass.

From the above mentioned issue the following sustainability objective related to the 'access to resources' aspect can be derived.

- Biomass consumption for bioenergy must not endanger other local biomass applications (cooking, fodder and other industries).

6.3.17 Participation

The issue related to the 'participation' aspect found in the empirical data is given below.

- **Community and Stakeholder Engagement**: Community and stakeholders should be engaged in taking the decisions that concern them (PCS1, PCS3, PCS4, PCS5, PCS6, PCS8, IN26, IN36, IN37). The importance and impact of community engagement in bioenergy projects is further discussed in Eswarlal et al. (2013). Creating public awareness about bioenergy is an important first step in engaging with the community (PCS8 and IN36). Engagement with stakeholders such as farmers or suppliers is very vital for the success of the industry, given the significance of biomass availability (IN37).

From the above mentioned issue the following sustainability objective related to the 'participation' aspect can be derived.

- The bioenergy industry should improve its engagement with community and stakeholders.

6.4 Discussion

The above discussed findings respond to the research objectives (RO2), i.e. to identify the sustainability issues of the small scale bioenergy projects in India. Furthermore, it also categorise the issues into objectives. These issues and objectives are summarised in the Table 6.7 below.

Table 6.7: Summary of Findings

Aspects	***Issues***	***Objectives***
	Environmental Sustainability	
Carbon Conservation	• Non-replenishment of carbon • Greenhouse gas emissions compared to fossil fuel sources • Greenhouse gas emissions from biomass transportation • Greenhouse gas emissions from open burning of agro residues	• The greenhouse gas balance of the production chain and application of the biomass must be positive. • Biomass production must not be at the expense of carbon sink in the vegetation.
Air	• Local air pollution • Potentially hazardous atmospheric emissions other than greenhouse gases • Pollution from burning of residues	• In the production and processing of biomass the (local) air quality must be maintained or improved. • Bioenergy production must not produce any potentially hazardous atmospheric emissions.
Water	• Water availability for drinking and other purposes • Water availability for other existing demand • Water catchment area • Water treatment and recycling	• Bioenergy operations should respect prior formal or customary water rights (both residential and commercial). • Bioenergy production must not impact on the ability to conserve water. • In the production and processing of biomass the quality of water resources should be maintained or enhanced.
Soil	• Soil quality	• In the production and processing of biomass soil quality must be retained or even improved.

Aspects	Issues	Objectives
Biodiversity & Ecosystem	• Biodiversity and Wildlife protection • Eco-conservation value areas	• Bioenergy production must not affect biodiversity and wildlife and where possible, have to strengthen biodiversity. • Bioenergy production operations should be avoided in eco conservative areas.
Land Use Change	• Land availability • Utilization of degraded lands • Land use change (direct and indirect)	• Biomass production should consider the land availability in the region. • Biomass production should utilise degraded lands and must not lead to other (direct or indirect) land use changes.
Resource Efficiency	• Energy efficiency • Positive net energy gain • Efficient use of biomass • Productive capacity of land	• The biomass productive capacity of the land should be improved. • The biomass should be utilised efficiently to retrieve maximum energy. • In the production and processing of biomass and transmission of energy, the energy losses should be minimised and the net energy gain should be positive.
Waste Management	• Utilisation of residues • Utilisation of by-products • Proper handling and disposal of waste	• The agro and industrial-agro residues if possible, should be effectively utilised as a biomass resource. • The wastes of bioenergy conversion process should be utilised as a by-product where possible and if not possible it should be appropriately handled and disposed.
	Socio-Economic Sustainability	
Food Security	• Food Vs. Fuel Competition	• The biomass production should not impact on the food security.

Aspects	***Issues***	***Objectives***
Labour Rights	• Labour working conditions • Training	• Decent working conditions and training for the workers should be provided in bioenergy companies.
Rural and Social Development	• Economic benefits to community • Social benefits to community	• Bioenergy operations should contribute to the economic and social development of local people and communities.
Energy Security and Access	• Investment needs • Cost of energy • Energy access • Energy security	• Bioenergy should be able to provide energy at competitive prices. • Bioenergy should contribute to improved energy access and energy security.
Employment Generation	• Employment Generation	• Bioenergy operations should create new jobs.
Fossil Fuel Conservation	• Decreasing fossil fuel consumption	• Bioenergy should contribute to fossil fuel conservation.
Fair Trade Conditions	• Fair remuneration for biomass	• Fair remuneration should be paid for the biomass procured.
Access to Resources	• Access to firewood for cooking • Access to biomass for fodder and other industries	• Biomass consumption for bioenergy must not endanger other local biomass applications (cooking, fodder and other industries).
Participation	• Community and Stakeholder Engagement	• Bioenergy industry should improve its engagement with community and stakeholders.

In this work, sustainability issues are identified through primary data collection from case study companies and stakeholders. In total 39 issues (24 environmental and 15 socio-economic issues) have been identified in this study which relates to 17 different sustainability aspects (8 environmental and 9 socio-economic aspects). Identified sustainability issues are then analysed, collated and formulated into 27 sustainability objectives in total (17 environmental and 10 socio-economic objectives), which can guide the Indian small scale bioenergy industry to focus on relevant global sustainability factors.

The issues related to the sustainability aspects such as carbon conservation, air, resource efficiency, waste management, rural and social development, energy security and access, employment generation, fossil fuel conservation and participation are recognised as very significant issues both by the case studies and stakeholders equally. Energy security, rural development, technological progress and cost effectiveness are the major underlying intentions of the Indian government to promote bioenergy sector (GBEP, 2007). These intentions embedded in the policy are well recognised by the participants in this study and clearly reflected through issues related to the sustainability aspects such as resource efficiency, rural and social development, energy security and access, employment generation and fossil fuel conservation. In particular energy security and access is recognised by most of the participants as very important issue from Indian perspective, given its current energy deficit (Central Electricity Authority, 2012c; IEA & OECD, 2009; Legros et al., 2009).

Even when the bioenergy promotion policies in India are not intended to address climate change or environment (GBEP, 2007), issues related to those intentions (carbon conservation, air, waste management) are still highlighted as significant by most of the participants. Some of the reasons for issues related to carbon conservation aspect to get prominence are growing awareness about climate change, potential for carbon credit and associated economic value (IN36) and marketing potential for low carbon foot print products internationally (PCS1 and PCS5).

Some of the reasons for the increasing significance of waste management issues are associated economic returns (utilisation of residues and by-products) and increasing public pressure to properly dispose of waste in India. This is because of public awareness about health impacts of improper waste disposal (Eswarlal et al., 2013). The significance of issues related to sustainability aspects such as air, waste management and participation are recognised because of community opposition if those issues are not addressed properly (Eswarlal et al., 2013).

Labour right issues are mostly recognised by the case studies; in particular better working conditions (safety gears and equipment) and training are identified as important issues. Issues related to this aspect are not raised much by stakeholders, perhaps because it is a common need across different sectors in India.

On the other hand, issues related to the aspects such as water, land use change and food security are predominantly recognised by various stakeholders as important sustainability issues and to a lesser extent by case study participants. This may be because most of the case studies deal with agro residues or industrial agro residues as their raw material, which is also the predominant type of biomass used in India (MNRE, 2012a). While the impact of residue type biomass on the sustainability aspects such as water, land use change, food security, soil and biodiversity & ecosystem can be very low as the biomass is not primarily grown for the bioenergy purpose and it's just a by-product that can be utilised effectively.

The issues related to the aspects such as soil, biodiversity & ecosystem, fair trade conditions and access to resources were recognised as important sustainability issues by only a small number of respondents. Fair trade conditions are raised mostly by case study companies who deal with the procurement of biomass from farmers directly or the farmer group itself in addition to the stakeholders. This is because in India biomass is mostly procured by intermittent suppliers or bio-brick manufacturers from farmers who then supply them to the bioenergy companies at market price. Therefore the fair remuneration for biomass is raised by farmers but not by most of the bioenergy companies. Regarding the access to firewood most of the stakeholders agreed that traditional biomass use for cooking causes indoor pollution and related health issue (IEA & OECD, 2006). However they argued that demand for energy (especially for cooking) by local people should be addressed through other forms of energy and the bioenergy companies should make sure of that. Regarding the access to biomass for other industries issue, some of the participants had a view that biomass should be traded in an open competitive market and there should not be any prioritisation.

The points discussed above provide possible explanations for the findings based on circumstances of the investigation. However as a word of caution it is important to note that the intention of this study (RO2) was to explore and identify all the relevant sustainability issues of the small scale Indian bioenergy sector (theory building) and not to prioritise the issues or quantitatively authenticate the findings (theory testing). Therefore it should be noted that the above discussed points should not be used to prioritise the findings (sustainability issues) rather it is a reflection on the findings.

The findings from the studies Hosahalli and Hanumanthanagara project (Ravindranath et al., 2004; Somashekhar et al., 2000) and RE-Impact project (Harrison et al., 2009; Harrison et al., 2011; Tiwari et al., 2009), which investigate about the sustainability impacts of the bioenergy projects in India and closely related to the current study are shown in Table 6.8. These studies are also discussed in the literature review section of this chapter. The findings of those studies are tabulated based on the sustainability aspect categories used in this study.

Table 6.8: Findings from Relevant Literature

Aspects	Hosahalli and Hanumanthanagara project (Ravindranath et al., 2004; Somashekhar et al., 2000)	RE-Impact project (Harrison et al., 2009; Harrison et al., 2011; Tiwari et al., 2009)
Environmental Sustainability		
Carbon Conservation	• Carbon dioxide emission reduction	
Air		
Water		• Impact on water resources
Soil	• Soil conservation	
Biodiversity & Ecosystem	• Promotion of biodiversity	• Monocultures of bio fuel plantations
Land Use Change	• Improving the fertility of degraded lands	• Diversion of good agricultural lands for bio fuel production • Lease availability of the marginal lands for the community members • Degraded land rehabilitation
Resource Efficiency		
Waste Management	• Minimum ash output	
Socio-Economic Sustainability		
Food Security		
Labour Rights		
Rural and Social Development	• Additional income generation • Equitable distribution of benefits • Improvement in quality of life especially for women and children	• Increased livelihood diversity • Livelihood of people who depend on wastelands • Rural development • Economic gains from sale of feedstock

Aspects	Hosahalli and Hanumanthanagara project (Ravindranath et al., 2004; Somashekhar et al., 2000)	RE-Impact project (Harrison et al., 2009; Harrison et al., 2011; Tiwari et al., 2009)
Energy Security and Access	• Rural electrification	• Rural electricity provision
Employment Generation	• Employment generation	• Rural employment
Fossil Fuel Conservation	• Fossil fuel conservation	
Fair Trade Conditions		
Access to Resources		
Participation		

As described in section 6.2.2 Ravindranath et al. (2004) and Somashekhar et al. (2000) are the two studies linked to the same Hosahalli and Hanumanthanagara project. These projects are not ‘regular business like’ projects (funded research projects) and the sustainability impact findings are based on the reflections of the authors who were associated with the projects. Similarly, the other three studies (Harrison et al., 2009; Harrison et al., 2011; Tiwari et al., 2009) are linked to the Re-Impact project. The findings of the Re-Impact project is based on consultations with one group of stakeholders in Chhattisgarh state of India, which was also focused on issues related to the energy plantation process (raw material) for biodiesel, rather than on the complete bioenergy supply chain.

The Table shows the sustainability issues identified in both of the above mentioned projects. The current study findings are supported by those studies. However the research identifies additional and new relevant issues, which are not recognised in those papers. Both of those projects do not even recognise any issues related to 7 sustainability aspects (Air, Resource Efficiency, Food Security, Labour Rights, Fair Trade Conditions, Access to Resources and Participation) when compared to the current study. In addition to that, only 14 sustainability issues are identified by both of the papers combined. Whereas this work adds to the existing knowledge base with 25 further relevant global sustainability issues (39 in total) from an Indian context, which is not recognised by these studies. Also, this research has formulated 27 global sustainability objectives based on the sustainability issues, for the bioenergy companies to focus, address and account for global sustainability. Furthermore, the current study findings are more generalizable when compared to those projects as the data are collected from multiple case studies based in 6 different states of India and multiple relevant stakeholders.

The following comments can be made when comparing the compilation of sustainability aspects addressed in 23 different international certification systems (FAO, 2011) shown in Table 6.2 with the current study findings. Apart from the one aspect (namely crop management and agro chemical use) all other environmental aspects are recognised in the Indian context as well. This exclusion can be because of the type of biomass (residues) predominantly used in the sector. However, the soil aspect found in this study can be partly linked to the environmental sustainability (cross cutting) and the productive capacity of land aspect recognised in the compiled list can be associated with the resource efficiency aspect found in this study. Labour rights, employment generation, rural and social development, energy security and access, fossil fuel conservation, access to resources are the socio-economic aspects found in both of the studies, either explicitly or implicitly. Food security and participation aspects recognised in this study are also shown in the compilation but under different classification namely food security and governance categories respectively. It is important to take into account that in the current study food security issue is generally recognised as a potential pitfall, if the bioenergy sector is not properly managed rather than as a current issue affecting food availability or access. The issues related to the aspects such as land tenure access and displacement, human health and safety (this one related to the general public, as the workers' health and safety is considered under labour rights aspect), governance, transparency, and good management practices and continuous improvement (apart from fair trade conditions) are not identified in this study, which is recognised in the compiled list of aspects (FAO, 2011).

The comprehensive list of sustainability issues derived from literature is given in Table 6.3. In comparison of the current study to that list, none of the issues related to sustainable agriculture, human rights, land rights, landscape view, noise pollution and traffic aspects are found in the Indian context. With regard to other sustainability aspects, most of the issues identified in this study are also recognised in the literature but this is not true other way around. All the issues recognised in the list of issues from the literature are not repeated in the current study, there is a noticeable difference.

The difference between the findings of current study and compiled list of aspects (FAO, 2011) or the list of issues from literature review (given in Table 6.3) can be due to the contextual and intentional difference between India and the developed nations on which most of those studies are based (Cushion et al., 2010; Tiwari et al., 2009). Some of the relevant distinctions of India when compared to other developed countries are bioenergy policy objectives(GBEP, 2007), poverty and inequality level (World Bank, 2012), current rate of energy consumption, electricity shortage in normal and peak loads (Central Electricity Authority, 2012c), significant amount of population without access to electricity (IEA & OECD, 2009; Legros et al., 2009), fossil fuel dependence (Arora et al., 2010; Buragohain et al., 2010) and affordable cost per unit of energy. The differences can also be attributed to the inherent nature of the small scale bioenergy sector in India such as company size, raw material used, technology used and its supply chain characteristics.

This work contributes by providing relevant issues from the perspective of a developing country such as India, heat and power plants and small scale bioenergy sector which are limited in the literature as identified above. Also, this work is based on inputs from all the relevant (both primary and secondary) stakeholders, which offers a multi-perspective finding. In addition, the categorisation of the issues into sustainability objectives informs both academics and practitioners about the required considerations by bioenergy related organisations to realize bioenergy which supports global sustainable development. Findings of this work provide a platform for the policy makers to understand the current state of discussion about the sustainability issues, objectives and aspects of bioenergy sector in India. It can also assist them by providing the foundation for developing required policy frameworks to promote sustainability of bioenergy. In particular, it can help the international organisations such as IEA, which is intended to develop an internationally agreeable standard for bioenergy (OECD & IEA, 2012), as it provide the perspective of a developing nation. These findings can support proactive practitioners' to recognize and evaluate their business operations for sustainability.

As with any research project, this study as well has its limitations which provide future research opportunities. Firstly, even though the case studies and stakeholders were selected through a structured and careful approach to explore all the potential sustainability issues of the bioenergy sector in India, still the findings of this study may only be applicable and limited to the type of bioenergy cases studied in India. This limited scope of the study is described in Chapter 2. Therefore future research is encouraged to repeat a similar study in other type of bioenergy companies in India (for example large scale industries or energy plantation based industries) for further generalizability.

Secondly, expansion of these (small scale bioenergy sector) findings to other developing countries needs to be carefully explored as all the participants and case studies of this study are based in India and there may be significant contextual differences. So, future research is encouraged in other relevant developing countries for generalising it further.

Thirdly, findings of this work are derived from a limited number of case studies and stakeholder interviews and the participants identified sustainability issues that were important from their point of view. Furthermore, the findings do not present any order of priority for the issues. Instead the study was constructed to explore all the potential issues of the small scale bioenergy sector in India. Therefore, future studies should test the identified propositions through a large scale survey which can both prioritize and generalize the findings further.

Fourthly, in this study the impacts of bioenergy on the local community and public perception of bioenergy were measured through inputs from other stakeholders (for example government officials, NGO's, farmers and researchers), secondary documents and observations. However, in this study local public opinions were not collected directly due to the time, access and resource constraints, which is a limitation of the study. Therefore, further studies need to investigate the local public opinion on the bioenergy industry directly in addressing this limitation.

Finally, this study's intention was to identify all the relevant sustainability issues of the bioenergy sector from relevant stakeholders' point of view, which is successfully addressed. However, the sustainability impacts need to be scientifically factual in certainty, which can only be proven through studies (for example life cycle analysis) measuring the true impacts of all these issues individually (for example actual greenhouse gas emission reduction). Therefore further studies are required which precisely measures the actual contributions of the sustainability issues of the small scale bioenergy sector.

6.5 Chapter Summary

In this chapter the research objective (RO2), to identify the sustainability issues and objectives of the small scale bioenergy projects in India, was successfully addressed. Findings of this study contribute to the academic literature from new perspectives. Also, it is a very useful source of knowledge for the practitioners and policy makers, which can help them to realize a successful bioenergy sector with positive global sustainable development benefits.

7.1 Introduction

In this chapter, investigation addressing the 3rd research objective (RO3), i.e. the identification of supply chain issues of the small scale bioenergy projects in India is presented. The significance of bioenergy supply chain issues (which affect its performance) and need to identify those issues were recognized during the research definition stage (Chapter 3). At the same time, existing knowledge on this field both from Indian and international perspectives, were reviewed to identify the research gap which is discussed in the literature review section of this chapter. Both the research need and the research gap have concurrently led to the rise of the research objective RO3 (Hedrick et al., 1993), which is answered in this chapter.

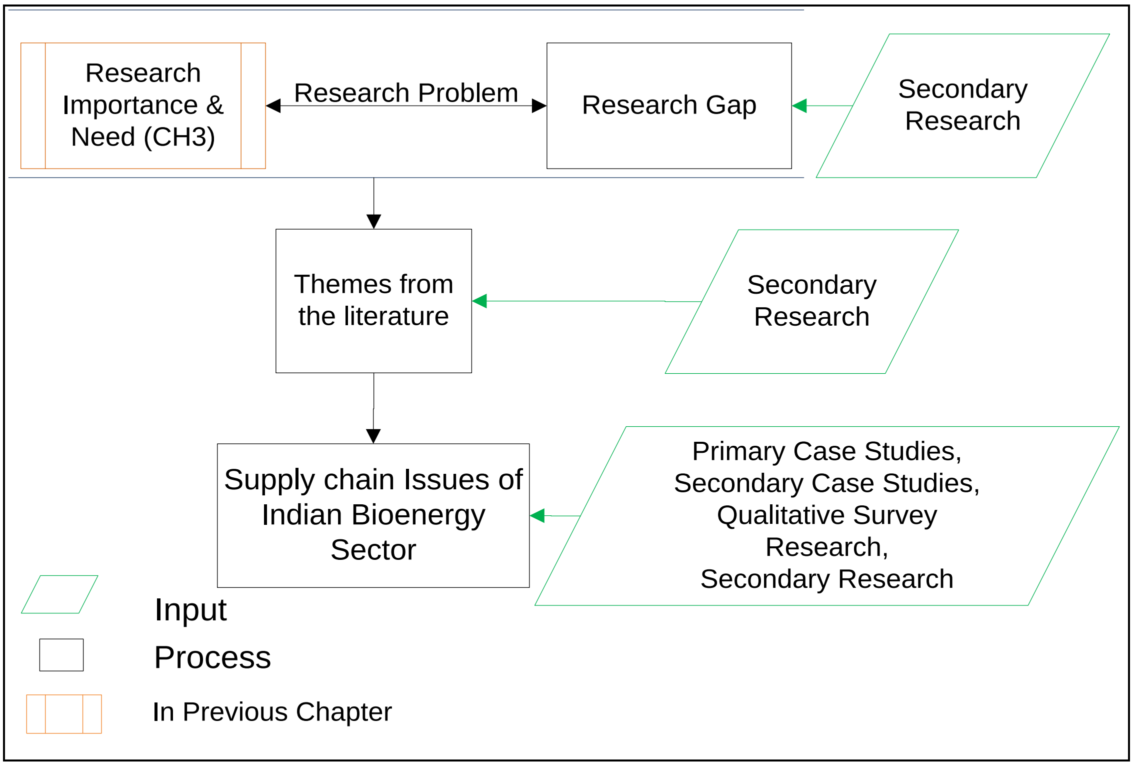

Figure 7.1: Research Approach to Address 3rd Research Objective

The research approach taken to address the RO3 is shown in Figure 7.1. Subsequent to the development of the research objective, through thematic synthesis approach (Thomas & Harden, 2008) relevant supply chain issues of the bioenergy sector were collated from the literature. These collated themes are presented in the literature review section of this chapter, which were used as the deductive themes during the empirical data analysis. Primary case studies, secondary case studies, qualitative survey research and secondary research were the research strategies used for collecting the empirical evidence in this part of the study. Interviews, focus groups, participant observation and documentary evidence were the research techniques used to collect data.

The interview and focus group discussion related to this research objective were based on the following topics:

- What are the issues (risks) that hinder the bioenergy organisations from performing well?
- What are the issues which affect your suppliers and customers?
- What are the other important supply chain issues of the bioenergy industry?
- Are any other issues raised by other external stakeholders across the supply chain?
- How significant are these above mentioned issues?
- What are the causes and effects of those issues?
- How does the above mentioned issues are addressed (risk mitigation measures)?

Similarly observations and documentary evidences were also scrutinised for information related to the above mentioned topic guide. Using thematic analysis (Braun & Clarke, 2006) approach, the data collected were analysed. Matrix data display (Miles & Huberman, 1994) approach is used to present the analysed data themes, which is presented in findings section of this chapter along with the description of the identified themes. This is then followed by the discussion section.

7.2 Literature Review

Managing the supply chain was recognised as one of the great challenges of the bioenergy industry (Allen et al., 1998; Hooper & Li, 1996) more than a decade ago. It is still recognised in the recent literature (Elghali et al., 2007; McKendry, 2002a; Athanasios A. Rentizelas et al., 2009) and recently by practitioners in India as well as the most important challenge for the bioenergy sector as discussed in Chapter 3. This shows the severity of this matter and strongly calls for immediate steps addressing this challenge.

Allen et al. (1998, p. 467) states that there is, “need to take a total supply chain perspective when planning any single activity in the chain rather than considering that activity in isolation.” This is due to the complex nature of its supply chain (Allen et al., 1998; Elghali et al., 2007) and the impact of the supply chain on successful operation of the industry (Ballou, 1992; Elghali et al., 2007; Athanasios A. Rentizelas et al., 2009). However, the bioenergy industries struggle to manage their supply chain as they do not pay enough attention to the practical issues across the supply chain (Allen et al., 1998; Clements & Sense, 2010; Elghali et al., 2007; McKendry, 2002a; Athanasios A. Rentizelas et al., 2009). Therefore it becomes important to identify supply chain issues of the bioenergy sector which can then be addressed effectively, leading to successful operation of bioenergy industries and utilising its complete potential.

In addressing this call for attention on bioenergy supply chain issues firstly the following sub sections review the current state of literature related to bioenergy supply chain in Indian and international contexts respectively. Then all the relevant issues synthesised from literature are given in the last subsection of this literature review section.

7.2.1 Relevant Literature from Indian Bioenergy Sector

Studies on Indian bioenergy sector from supply chain perspective seems to be an under researched area. However, the studies on Indian bioenergy sector that is close to the research interest of this thesis chapter are reviewed below. These studies findings are critically reviewed for their relevance to address the research interest, i.e. supply chain issues of bioenergy sector in India.

Village Energy Security Program (VESP) was the program intended to cater for the energy requirements of Indian villages, “through the use of biomass gasifier systems, straight vegetable oil (SVO) engines, biogas engines and improved biomass and biogas cook stoves” (Palit et al., 2013, p. 2). This scheme was launched by the Indian Ministry of New and Renewable Energy (MNRE) in 2004 and it was discontinued at the end of 2011 due to serious challenges. Palit et al. (2013) have analysed sample of these projects, while this program had limited success. Their work investigates the trials and tribulations of the VESP. In their work, they have identified issues related to institution, technology, plantations and fuel supply management, finance and policy.

However, investigation of this study was focused on the projects related with the VESP program only; whereas VESP is a unique program and it has significant differences when compared to the normal business like bioenergy setup. Some of the unique characteristics of the VESP program are as follows:

Firstly, it’s important to note that, “VESP project receives two types of financial support, a onetime capital subsidy of up to 90% of the project cost and an operation and maintenance (O&M) support fund to cover two years of operations” (World Bank, 2011, p. 21), which makes their financial requirements completely different when compared to other plants. Secondly, VESP projects were not managed by business administration instead it was managed by the local village administration (Gram Panchayat) through a setup called as village energy committee. Thirdly, the biomass was arranged, “either as a contribution from the project beneficiaries on a rotation basis or through the purchase of biomass from biomass collection agents, such as self-help groups” (World Bank, 2011, p. 22). Fourthly, as it were community projects village forest land or community land were allocated freely “to ensure a sustainable supply of biomass” (World Bank, 2011, p. 22). Fifthly, this study sample considered all the different bioenergy technologies promoted by VESP into account which includes improved biomass and biogas cook stoves as well. Finally, size of the single units supported under this program where 10kw (or less). These distinctive features of the VESP program limit its generalizability across small scale bioenergy industry. In addition, this study's aim was to investigate problems with the particular program rather than investigation of issues related to the bioenergy supply chain. These above mentioned reasons limit its usability for the purpose of this study.

Ravindranath and Rao (2011) conducted a study to analyze the barriers for bioenergy and proposed recommendations to overcome them. This study was carried as part of the activities sponsored by United Nations Development Programme to promote bioenergy in India. The barriers were identified through literature review. Institutional, informational, financial, policy related, technology specific and overall market barriers were the type of barriers recognised in the study. Based on their review of literature they argued that multiple studies have recognised the existence of multiple barriers. However they suggested future research to explore the barriers in detail and to discuss with various stakeholders during that process to get a complete understanding of those issues. They also argued that such an output will help to develop targeted policies that "will have a more bespoke role to play in closing the gap between existing and potential capacity" (p.7).

Ravindranath and Balachandra (2009) through a literature review have analysed the bioenergy's ability to address rural energy needs from technical, economical and policy perspective. The study identifies 10 important barriers for the bioenergy projects to spread in India. However the focus and result of the investigation was technical, economical and policy barriers which hinder the spread of bioenergy. Therefore, it does not shed much light on the supply chain issues of the bioenergy sector.

As stated before in chapter 6, the work of Ravindranath et al. (2004) and Somashekhar et al. (2000) analyse the performance and impact of the same two decentralised bioenergy generation case studies in Karnataka, India (Hosahalli and Hanumanthanagara project). These studies have identified few issues that hinder the plants from performing well. They are technical problems, input supply, operator availability, economical problems and social problems. Firstly, both of the studies were not carried out from supply chain perspective instead it was intended to investigate the feasibility of bioenergy in rural areas. Secondly, the scope of issues identified were limited and the issues which were covered (mentioned above) also not discussed in detail, as it was not the main aim of this study. Most importantly, the case study projects were financially supported from grants and they were not typical bioenergy 'business like' projects.

Jagadish (2003) in his study titled 'Bioenergy for India: prospects, problems and tasks' claims biomass availability and low conversion efficiency as the two important problems of bioenergy sector in India. Animal fodder requirement is identified as one of the major competitor for the biomass, impacting its availability. However, it's important to note that aim of the study was to examine the biomass availability in India and its potential for energy production. In addition to that these problems were conceptual constructs for his analysis and not based on any investigation.

Rao and Ravindranath (2002) assessed the policy barriers for the bioenergy technologies in India. Institutional, technical, market and credit barriers were identified as the major policy barriers for bioenergy technologies in India. This study highlight some of the issues for bioenergy sector however it is based on the policy analysis with an intention to provide policy recommendations. Also, the scope of study was wide covering "improved cook stoves, family and community biogas for cooking gas production, biomass gasifier-based rural electrification, grid-connected power systems, cogeneration and biomass combustion power technology" (p.67). They have suggested future research studies to study the barriers of different bioenergy technologies from the stakeholders' perspective, as "it is still remains to be understood"(p.59).

In summary, studies such as Palit et al. (2013), Ravindranath et al. (2004) and Somashekhar et al. (2000) have analysed bioenergy sector in India using empirical data. While studies such as Ravindranath and Rao (2011), Ravindranath and Balachandra (2009), Jagadish (2003) and Rao and Ravindranath (2002) have examined it through literature review. However, none of these studies assess bioenergy sector in India from supply chain perspective and do not provide 'the supply chain issues of the small scale bioenergy sector in India'. Instead these studies have looked at the barriers for bioenergy technologies to spread or technology, policy and / or economical analysis of the bioenergy sector in India or feasibility of bioenergy in rural areas. In addition to this, the divergences of these papers findings when compared to the research interest of this thesis chapter are discussed above for individual papers. Therefore, this clearly indicates the gap in research which analyse the Indian bioenergy sector from supply chain perspective. Following this sequential next step is to review all relevant supply chain literature in bioenergy sector, which is discussed below.

7.2.2 Review of Relevant Supply Chain Literature in Bioenergy Sector

In this section the relevant supply chain literature in the bioenergy sector are critically reviewed. These studies have been assessed in the backdrop for its ability to recognise important supply chain issues of the bioenergy sector.

Awudu and Zhang (2012) have studied the uncertainties and sustainability concepts in biofuel supply chain management and how to model them through literature review. In one section of this paper, they discussed uncertainties in biodiesel supply chain. They conclude that "due to the nature of the biofuel supply chain, uncertainties exist in all the echelons of the supply chain. In order to eliminate the impact of these uncertainties, we need to incorporate them into the decision making process" (p.1364). Their study has highlighted few important uncertainties of biofuel supply chain however it does not cover all the relevant issues. When assessing this paper from the research need for this thesis chapter viewpoint there are following divergences. Firstly, this study was about biodiesel supply chain uncertainties and there are considerable differences between bioenergy and biodiesel supply chains, not only in downstream part of the chain but also in conversion and in upstream as well up to an extent. Secondly, this study finding were based on literature review and not based on empirical evidence. Finally, this study was not particularly focused on any particular size, technology or (location) context.

Alakangas et al. (2012) provide synthesis of key results of EUBIONET III project, which addresses biomass trade and market barriers. In this they recognize key barriers for biomass trade as raw material scarcity, logistical issues, fuel quality and sustainability criteria from literature review. Other closely related publications such as Junginger et al. (2011) and Junginger et al. (2010) recognize similar barriers for biomass trade. However, the barriers recognized in this study were limited to the international biomass trade rather than bioenergy supply chain issues.

The work of Gold and Seuring (2011) presents upstream supply chain and logistics issues of bio-energy production. The research was carried out with an intention to identify "issues and challenges of designing and operating biomass chains that secure stable and competitively-priced feedstock supply for bio-energy plants" (p.32). The information for this study was collected through literature review. This article presents the assessment of literature initially, followed by the operational issues classified based on the operations such as harvesting and collection, storage, transport, and pre-treatment techniques and finally supply system design issues. Some of the important drawbacks of this work from the perspective of addressing the research interest of this thesis chapter are given below. Firstly, this paper does not deal with complete bioenergy supply chain instead it only considers upstream part of the supply chain. Secondly, this paper finds design and operational issues within different operations of the chain but it is not looking at the issues or risks arising from different operations impacting the whole supply chain (which is the focus of this thesis). Thirdly, this paper's findings are based on the literature review and not directly based on the empirical evidence. Fourthly, as stated in the paper literature from "other regions such as Asia and Latin America are underrepresented" (p.34), which are considered in this study. Finally, the papers studied were predominantly related to the techno-economic assessments and environmental assessments while the papers from supply chain perspectives were lacking.

In order to answer research questions namely, how to run bioenergy businesses efficiently through collaboration and how to foster the relationships with most relevant external stakeholders in order to maintain the license to operate the bioenergy industry, Gold (2011) have reviewed papers related to the bioenergy supply chain. In this study they find issues related to the supply chain coordination and collaboration and impact of bioenergy on external stakeholders. However, this study do not present any issues related to the operation of bioenergy supply chain.

Adams et al. (2011) have identified barriers and drivers impacting bioenergy development in UK. The initial list of barriers and drivers were identified through literature review. Followed by that barriers and drivers were assessed through an online survey by four categories of respondents from UK namely, farmers/suppliers, developers/owners of bioenergy projects, primary end-users, and government/policy stakeholders. Then the findings related to the UK bioenergy development were presented from these different stakeholders perspectives. Findings of this study are interesting; however it fundamentally address a different research problem when compared to the call for research related to this chapter, established in chapter 3. Some of the reasons for this difference are as below. Firstly, "the study focused on more overarching aspects of development [of bioenergy] as opposed to specific (or plant-dependent) issues" (Adams et al., 2011, p. 1219). Secondly, the study received opinions from different stakeholders however it was not from the supply chain perspective instead from spread of bioenergy in UK. Finally, the study was very generic and it was not focused on any particular size and technology of the bioenergy plant.

Iakovou et al. (2010) present a critical synthesis of the relevant literature on waste biomass supply chains. In their paper they discuss about (1) system components of waste biomass supply chains, (2) conversion technologies and classification of literature on them, (3) categorize waste biomass supply chain decision making hierarchy and map all the relevant literature onto this decision making hierarchy and (4) critical synthesis of all the relevant literature on the biomass supply chains to finish. Based on their review they conclude that "very few studies address the critical supply chain management issues, and the ones that do that, focus mainly on the assessment of the potential biomass and the allocation of biomass collection sites and energy production facilities" (p.1868). This study do not recognise any study which investigates issues of bioenergy from complete supply chain perspective and highlights the significant gap in the bioenergy supply chain literature.

Athanasios A. Rentizelas et al. (2009) have recognized storage and combining multiple biomass supply chains as two important logistical issues of the biomass. In their study, they have used different combination of scenarios with varying storage and multiple biomass systems to identify more advantageous solution. In this study, some issues related to the biomass logistics have been identified. However, it is limited to the storage and multiple-biomass use and the study was intended to analyse biomass storage systems and to come up with comparative results rather than investigating about all the supply chain issues.

Carlos and Khang (2009) present a framework to assess the success of grid-connected bioenergy projects along with the drivers for success. The framework was validated using the data collected from a project in Thailand. In this they identify fuel availability, spare parts availability and service as some of the important success driving factors for the plant operation stage. This study offers some important success factors for the operational phase in the life-cycle based project evaluation framework but it does not examine supply chain issues or offer a detailed list of operational issues either.

Han et al. (2008) have carried out a techno-economical analysis of the small-scale bioenergy projects in China, which have used pyrolysis gasification technology. The study concludes that the projects analysed were not performing well. In addition to the lack of public support, the failure was also attributed to the institutional, technical, policy and financial shortcomings. Though, this is one of the very few studies which are small-scale bioenergy specific. However as like other studies mentioned above focus of this study was to analyse economical and technological performance and not to discover supply chain issues of the small scale bioenergy projects.

Uslu et al. (2008) recognized that pre-treatment have significant impact on the biomass logistics. In their paper, they have carried out a techno-economic analysis of pre-treatment technologies, namely torrefaction, pyrolysis and pelletisation. This study investigated the impact of different pre-treatment technologies on the cost and energy used by biomass. This is one of the very few studies which have looked at the biomass pre-treatment technologies very closely. It highlights the issues related to a particular process of supply chain and not addressing the research interest of this work.

Sugathapala (2002) identifies the barriers to the widespread use of bioenergy in Sri Lanka by analysing the policies. The paper identifies barriers related to the financial, technical, institutional, policy and information categories. As stated above the focus of this paper was to identify the barriers for promotion of bioenergy in Sri Lanka from policy perspective and it does not offer findings from supply chain perspective.

Allen et al. (1998) argue that biomass fuel logistics is complex and problematic for large scale power plants. They add that logistics cost will impact on the total cost of biomass. With this background, in their study they assess the supply systems and delivery costs of different supply chains for four biomass fuels. This study highlight some important logistic issues for biomass however it do not investigate the issues instead it develop fuel supply scenarios considering some of the issues.

To summarise, the studies such as Awudu and Zhang (2012), Alakangas et al. (2012), Gold and Seuring (2011), Gold (2011), Iakovou et al. (2010), Athanasios A. Rentizelas et al. (2009), Uslu et al. (2008), Sugathapala (2002) and Allen et al. (1998) highlight few supply chain issues based on the literature review. While, Junginger et al. (2011), Adams et al. (2011), Junginger et al. (2010), Carlos and Khang (2009) and Han et al. (2008) have studied the bioenergy sector through empirical data.

However, all of the above mentioned studies apart from Awudu and Zhang (2012) and Gold and Seuring (2011) do not investigate about the issues affecting bioenergy supply chain or supply chain risk of bioenergy sector. Awudu and Zhang (2012) and Gold and Seuring (2011) do present some supply chain issues of the bioenergy sector however both of the studies based on literature review and look at issues which can affect the performance of individual processes and not the issues which can affect the operation of the supply chain. To put it in other words, both of the studies discuss about some potential causes which can result into supply chain risks across different processes but not the potential risks. In addition, Awudu and Zhang (2012) study was focused on biodiesel sector. Whereas Gold and Seuring (2011) studies about the potential causes that can create problems for individual processes only in the upstream supply chain, that to with an assumption of continuous availability of secure and competitively priced biomass, which can be contested as it's an important challenge for bioenergy industry (Awudu & Zhang, 2012; Palit et al., 2013). Also, other boundaries of all the individual studies from the research interest point of view are discussed above.

This review can be summed up using the statement of Iakovou et al. (2010, p. 1868), "although the vast majority of the studies in the field of biomass-to-energy production examine the system from a purely technological or ecological point of view, there is a subset of the literature body that addresses the relevant and highly critical supply chain management issues." This indicates deficiency of research in bioenergy supply chain area and specifically highlights lack of research investigating about the complete supply chain risks / issues of bioenergy sector which can impact its operations. Gold and Seuring (2011) in line with this judgment calls for "more in-depth examination using empirical investigations" (p.41). They also advocate for further empirical studies, "addressing both the whole range of supply chain actors and other relevant stakeholders" (Gold & Seuring, 2011, p. 41).

Therefore, taking research need identified in chapter 3 and research gap identified in section 7.2.1 and 7.2.2 into account, this research will address the research objective (RO3), i.e. 'to identify the supply chain (organisational sustainability) issues of the small scale bioenergy projects in India'. In the process of answering the research objective, initially supply chain issues of the bioenergy sector are synthesized from literature in the next section.

7.2.3 Supply Chain Issues of Bioenergy Sector Synthesised from Literature

The literature has been reviewed in order to identify all the relevant supply chain issues. For the purpose of synthesis of themes from literature it is not important that all the studies should be reviewed instead it is about reviewing the literature that can contribute with new themes (Thomas & Harden, 2008). Keeping this in mind through thematic synthesis approach the themes were derived from relevant literature. As most of the studies were not directly addressing supply chain issues, therefore issues were not only recognised through descriptive themes but by generating analytical themes as well (Thomas & Harden, 2008).

Whereas analytical themes are concepts or understandings generated by 'going beyond' the findings of the studies reviewed and resulted due to the inductive analysis of those findings to answer the review questions (Thomas & Harden, 2008). Therefore, in this research literature synthesis themes were developed to recognise the supply chain issues of the bioenergy sector.

These issues were then categorised according to the bioenergy supply chain processes it is related to namely, raw material, transportation, storage, pre-processing and handling, conversion and downstream, which is adopted in this study (chapter 4). In addition, there is a category named as across which represents the issues affecting the whole supply chain. The issues identified from literature and categorised according to the supply chain processes are given in Table 7.1. In total 32 issues relating to raw material (4), transportation (2), storage (5), pre-processing and handling (3), conversion (9), downstream (7) and across (2) categories were recognised from the literature. The descriptions of individual issues are not given below, in order to avoid repetition as they are discussed in findings and discussion section below.

Table 7.1: Supply Chain Issues of Bioenergy Sector - From Literature

Issues	***References***
Raw material	
Availability	(Adams et al., 2011; Allen et al., 1998; Awudu & Zhang, 2012; Carlos & Khang, 2009; Escobar et al., 2009; Gmünder et al., 2010; Hooper & Li, 1996; Jagadish, 2003; Kapur et al., 1996; Lewandowski & Faaij, 2006; McKendry, 2002a; Rao & Ravindranath, 2002; Raven et al., 2009; Ravindranath et al., 2004; Athanasios A. Rentizelas et al., 2009; Voivontas et al., 2001)
Price	(Awudu & Zhang, 2012; Palit et al., 2013)
Quality and characteristics	(Easterly & Burnham, 1996; Escobar et al., 2009; Gmünder et al., 2010; McKendry, 2002a; Ravindranath & Rao, 2011; Thornley et al., 2009a)
Multi biomass issues	(Allen et al., 1998; McKendry, 2002a; Rao & Ravindranath, 2002; Athanasios A. Rentizelas et al., 2009)
Transportation	
Cost of transportation	(Awudu & Zhang, 2012; Athanasios A. Rentizelas et al., 2009)
Poor transport infrastructure	(Gold & Seuring, 2011)
Storage	
Unavailability of	(Gold & Seuring, 2011; Athanasios A. Rentizelas et al., 2009)

Issues	References
storage space	
Cost of storage	(Athanasios A. Rentizelas et al., 2009)
Fire hazard	(Athanasios A. Rentizelas et al., 2009)
Storage technological risk	(Athanasios A. Rentizelas et al., 2009)
Loss / damage of raw material	(Gold & Seuring, 2011)
Pre-processing & handling	
Improper handling	(Ravindranath & Rao, 2011)
Manual pre-processing	(Ravindranath & Rao, 2011; Ravindranath et al., 2004)
Cost of pre-processing	(Uslu et al., 2008)
Conversion	
Public perception	(Adams et al., 2011; Rao & Ravindranath, 2002; Ravindranath & Rao, 2011)
Breakdown risk	(Ravindranath & Rao, 2011)
Technical risk	(Adams et al., 2011; Palit et al., 2013; Ravindranath & Rao, 2011; Ravindranath et al., 2004; Rösch & Kaltschmitt, 1999)
Low efficiency	(Jagadish, 2003)
Maintenance difficulties	(Carlos & Khang, 2009; Palit et al., 2013; Ravindranath & Rao, 2011; Ravindranath et al., 2004; Somashekhar et al., 2000)
Service support	(Carlos & Khang, 2009; Palit et al., 2013; Rao & Ravindranath, 2002)
Auxiliary power	(Palit et al., 2013; Ravindranath & Rao, 2011; Ravindranath et al., 2004)
Equipment quality	(Ravindranath et al., 2004)
Financial risks	(Jackson, 1992; Mitchell, 1995; Palit et al., 2013; Rao & Ravindranath, 2002; Ravindranath & Rao, 2011; Rösch & Kaltschmitt, 1999; Wright, 2006)
Downstream / Market	
Technical risk	(Ravindranath & Rao, 2011)
Infrastructure risk	(Rao & Ravindranath, 2002; Ravindranath & Rao, 2011)
Demand fluctuation	(Adams et al., 2011; Palit et al., 2013)
Market trust	Due to supply fluctuation (Ravindranath & Rao, 2011), Due to limited capacity (Palit et al., 2013)
Cost of energy	(Adams et al., 2011; Palit et al., 2013; Rao & Ravindranath, 2002; Ravindranath & Rao, 2011; Ravindranath et al., 2004)

Issues	References
Competition with other energy industries	(Adams et al., 2011; Faaij et al., 1998; Rao & Ravindranath, 2002; Raven et al., 2009; Roos et al., 1999; Rösch & Kaltschmitt, 1999)
Payment recovery	Not willing to pay and poor payment collection system (Somashekhar et al., 2000), Unviable due to poverty (Palit et al., 2013)
Across	
Labour shortages	General (Ravindranath et al., 2004), Skilled labour (Palit et al., 2013; Rao & Ravindranath, 2002; Ravindranath et al., 2004)
Regulatory risks	General (Adams et al., 2011; Ravindranath & Rao, 2011), Transportation laws (Gold & Seuring, 2011), Power production and distribution laws (Rao & Ravindranath, 2002)

7.3 Findings

Subsequent to the literature review data was collected from primary case studies, secondary case studies and external stakeholders. These data were analysed using thematic analysis approach (Braun & Clarke, 2006). Hybrid inductive and deductive theme generation approach have been used in the analysis (Fereday & Muir-Cochrane, 2008; Joffe & Yardley, 2004). While deductive themes were developed using the supply chain issues thematically synthesised from literature, which is given above. Then the information is presented using matrix data display approach, which offers quick and easy access to the analysed data and ability to draw justified conclusions (Miles & Huberman, 1994).

The analysed data from primary case studies, external stakeholders and secondary case studies are presented in Table 7.2, Table 7.3 and Table 7.4 respectively. These tables list the identified supply chain issues of bioenergy industry and the reference of case study or participant in column and row respectively. Supply chain issues from the perspective of small scale bioenergy sector in India recognised by an external stakeholder or case study company participant(s) is shown using a ✓mark in the respective cell.

In addition to the supply chain process categories recognised above, one more category namely ‘upstream’ is used to classify the empirical findings. It covers the issues common across the supply chain processes such as raw material, transportation, storage and pre-processing and handling. In total 29 supply chain issues of the small scale bioenergy sector in India relating to raw material (3), transportation (2), storage (3), pre-processing and handling (2), upstream (1), conversion (9), downstream (7) and across (2) categories were identified from the empirical evidence. The identified issues are discussed below.

Table 7.2: Matrix Display of Supply Chain Issues - Primary Case Studies

Issues	***PCS1***	***PCS2***	***PCS3***	***PCS4***	***PCS5***	***PCS6***	***PCS7***	***PCS8***	***PCS9***	***PCS10***	***PCS11***	***PCS12***	***PCS13***
Raw Material													
Availability	✓		✓			✓	✓	✓	✓		✓		✓
Price	✓	✓			✓	✓	✓			✓	✓	✓	✓
Quality and characteristics	✓	✓	✓	✓	✓		✓	✓					
Transportation													
Delivery failure	✓												
Cost of transportation					✓		✓					✓	✓
Storage													
Unavailability of storage space		✓		✓			✓	✓		✓	✓	✓	
Cost of storage		✓			✓			✓			✓	✓	✓
Fire hazard							✓					✓	
Pre-processing & Handling													
Improper handling		✓	✓				✓				✓		
Manual pre-processing		✓			✓		✓	✓		✓	✓	✓	
Upstream													
Loss / damage of raw material					✓		✓			✓		✓	
Conversion													
Public perception				✓	✓	✓							
Breakdown risk	✓	✓	✓						✓				✓
Technical risk			✓					✓	✓				

Issues	***PCS1***	***PCS2***	***PCS3***	***PCS4***	***PCS5***	***PCS6***	***PCS7***	***PCS8***	***PCS9***	***PCS10***	***PCS11***	***PCS12***	***PCS13***
Low efficiency	✓				✓	✓		✓	✓				
Maintenance difficulties		✓	✓			✓			✓				✓
Service support		✓	✓			✓							
Auxiliary power			✓			✓			✓				
Equipment quality			✓						✓				✓
Financial risks		✓	✓			✓			✓				✓
Downstream / Market													
Technical risk		✓	✓										
Infrastructure risk		✓	✓					✓	✓				
Demand fluctuation	✓		✓		✓								✓
Market trust					✓	✓							✓
Cost of energy	✓	✓	✓	✓	✓	✓			✓				✓
Competition with other energy industries		✓	✓										
Payment recovery						✓							
Across													
Labour shortages		✓			✓		✓	✓		✓	✓	✓	
Regulatory risks	✓		✓	✓	✓								✓

Table 7.3: Matrix Display of Supply Chain Issues - External Stakeholders

	Equipment Suppliers		***Government Officials***			***Bank Officials***		***NGO Officials***		***Consultants***		***Researchers***				
Issues	QSR-IN22	QSR-IN23	QSR-IN24	QSR-IN25	QSR-IN26	QSR-IN27	QSR-IN28	QSR-IN29	QSR-IN30	QSR-IN31	QSR-IN32	QSR-IN33	QSR-IN34	QSR-IN35	QSR-IN36	QSR-IN37
Raw Material																
Availability	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
Price	✓		✓			✓		✓	✓	✓	✓			✓	✓	
Quality and characteristics	✓	✓	✓							✓			✓			
Transportation																
Delivery failure														✓	✓	
Cost of transportation	✓		✓					✓		✓				✓	✓	
Storage																
Unavailability of storage space	✓							✓								
Cost of storage	✓		✓					✓		✓				✓		
Fire hazard								✓						✓		
Pre-processing & Handling																
Improper handling		✓						✓					✓			
Manual pre-processing			✓	✓				✓				✓				

	Equipment Suppliers		***Government Officials***			***Bank Officials***		***NGO Officials***		***Consultants***		***Researchers***				
Upstream																
Loss / damage of raw material	✓			✓												
Conversion																
Public perception			✓		✓	✓		✓						✓	✓	✓
Breakdown risk			✓								✓		✓	✓	✓	
Technical risk		✓		✓		✓		✓	✓	✓	✓		✓	✓	✓	
Low efficiency		✓									✓					✓
Maintenance difficulties	✓	✓	✓	✓		✓		✓		✓		✓		✓	✓	
Service support														✓		✓
Auxiliary power		✓												✓		
Equipment quality		✓				✓	✓							✓		
Financial risks	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
Downstream / Market																
Technical risk	✓		✓					✓							✓	
Infrastructure risk	✓		✓	✓		✓		✓	✓			✓	✓	✓	✓	
Demand fluctuation				✓				✓			✓			✓	✓	✓
Market trust						✓					✓			✓	✓	✓
Cost of energy	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓

	Equipment Suppliers		***Government Officials***			***Bank Officials***		***NGO Officials***		***Consultants***		***Researchers***				
Competition with other energy industries			✓	✓		✓		✓			✓		✓	✓	✓	✓
Payment recovery																✓
Across																
Labour shortages		✓	✓					✓				✓		✓		
Regulatory risks	✓					✓		✓		✓	✓	✓		✓	✓	

Table 7.4: Matrix Display of Supply Chain Issues - Secondary Case Studies

Issues	***SCS1***	***SCS2***	***SCS3***	***SCS4***	***SCS5***	***SCS6***	***SCS7***	***SCS8***	***SCS9***	***SCS10***	***SCS11***	***SCS12***	***SCS13***
Raw Material													
Availability					✓								
Price			✓		✓		✓				✓	✓	✓
Quality and characteristics	✓		✓		✓						✓	✓	
Transportation													
Delivery failure													
Cost of transportation													
Storage													
Unavailability of storage space													
Cost of storage													
Fire hazard													
Pre-processing & Handling													
Improper handling	✓		✓										
Manual pre-processing					✓		✓	✓				✓	
Upstream													
Loss / damage of raw material													
Conversion													
Public perception													
Breakdown risk		✓	✓						✓	✓	✓		
Technical risk		✓	✓							✓			

Issues	***SCS1***	***SCS2***	***SCS3***	***SCS4***	***SCS5***	***SCS6***	***SCS7***	***SCS8***	***SCS9***	***SCS10***	***SCS11***	***SCS12***	***SCS13***
Low efficiency	✓	✓	✓				✓				✓		
Maintenance difficulties	✓	✓	✓				✓			✓	✓		✓
Service support	✓										✓		
Auxiliary power	✓	✓	✓	✓			✓			✓	✓	✓	
Equipment quality	✓	✓	✓						✓		✓		
Financial risks		✓	✓	✓					✓		✓		
Downstream / Market													
Technical risk			✓					✓					✓
Infrastructure risk		✓	✓								✓		
Demand fluctuation		✓	✓			✓		✓		✓	✓		✓
Market trust		✓									✓		
Cost of energy	✓	✓	✓	✓			✓			✓	✓	✓	✓
Competition with other energy industries	✓											✓	✓
Payment recovery													
Across													
Labour shortages	✓		✓		✓		✓	✓		✓		✓	✓
Regulatory risks													

7.3.1 Raw Material

In this category issues related to raw material of bioenergy are catalogued. Three important issues namely availability, price and quality and characteristics related to the biomass for bioenergy are identified. However these three issues are closely related and interdependent on one another up to an extent. For example, the shortage of biomass will lead to increase in price and similarly poor quality biomass may cost less. These issues are discussed in detail below.

7.3.1.1 Availability

As recognised in most of the previous literature, shortage or unavailability of biomass is identified by most of the participants as an important challenge for the bio energy sector. Companies recognised this as one of the most severe issue for small scale bioenergy industry as well. Some causes identified by the participants that can impact the availability of biomass are seasonal dependence of biomass (PCS1, PCS4, PCS6, PCS9, IN22), climatic conditions and weather affects the production of biomass (PCS4, PCS6, SCS5), land unavailability (PCS3, PCS8, IN33, IN36) and water unavailability (IN36) for energy plantations, other uses for biomass (IN36) such as wood for cooking (IN26) and fodder requirements (PCS11) and competition with other industries such as paper mills (PCS11).

In addition to the above mentioned causes bioenergy supply chain and system design issues were also identified as some of the reasons influencing the biomass availability for bioenergy units. In particular, size of the bioenergy unit as it can put undue pressure on the biomass resources (IN22, IN26), location of the plant as biomass is not available in all the places (IN22), system type as it can limit the type of biomass used such as wood, which cannot utilise other biomass residues (PCS3),poor fuel linkage mechanism (IN26) and incompetent or broken biomass collection system (PCS3).

Not utilising the agro residues because of poor technical or economical viability is also a cause for biomass unavailability (PCS8, PCS11 and IN36). Some of the reasons for non-utilisation of agro residues are small size of farming land in India (PCS8, IN36), time pressure to remove the residues soon, as the land is required for next cultivation (PCS8, PCS11) and collection equipment unavailability (PCS11).

Participants articulated some suggestions to address this issue they are increasing the storage capacity of biomass (PCS1), self-owned energy plantation (PCS3, IN22), transferring the knowhow and technology (for example tissue culture) to increase the biomass production (PCS3), effective agriculture and utilization of land in the best possible way (IN37), using degraded lands for biomass plantation (IN37), using multiple type of biomass (PCS6, PCS9), small scale plants (IN36), proper planning of upstream linkages (IN37),introducing fuel supply contract system in India which is currently not in practice (IN22) and improving the arrangement for agro residues collection (PCS3, PCS11). One group of farmers (PCS11) consulted suggested sponsored biomass collection, by giving an example of a paper mill in their locality which uses their own or rented machineries to collect agro residues from all the small farmers in that region, this helps the farmers to clear their land quickly and confirmed biomass availability for the company, which is a win-win situation for both parties.

7.3.1.2 Price

The report prepared for PCS3(2005) based on the case studies (i.e. secondary case studies in this thesis) conclude the following about the biomass price.

> *The [biomass] cost is inclusive of (a) processing the wood either at site or at source, (b) loading and unloading, (c) labour charges and (d) moisture content in wood. Of the points mentioned above from (a) to (d) even if one changes it has a direct impact on the cost of biomass. If the cost escalates in an unrealistic manner, then the feasibility of the project would be at stake.*

The permanent increase or short term fluctuation in the cost of biomass is a huge risk for the bioenergy company impacting its economical viability. As stated above, the price is significantly influenced by other two issues in this category namely availability and quality and characteristics of biomass. Increase in demand for biomass in the region (PCS1), competition with other industries (PCS2) and other application of biomass (IN36) are some of the causes recognised which affects the price of biomass through its impact on availability. Monopoly supplier (IN22) can also be a reason for the price rise. Short term fluctuations on the price can occur due to no fixed price contract arrangement (IN22), opportunity cost charged by suppliers (PCS6) and market fluctuations (IN36). However, it is argued that local collection of biomass can reduce the cost of raw material (SCS5).

7.3.1.3 Quality and Characteristics

Poor quality and inappropriate characteristics of biomass is an issue for efficient and successful bioenergy operation. Moisture content (PCS1, PCS2, PCS3, PCS4, PCS8, SCS1, SCS11, IN22), calorific value (PCS1, SCS1, SCS5), type of feedstock (PCS3), density of raw material (PCS8), sizing of biomass (SCS3) and chemical properties (PCS4) are some of the specific concerns about the quality and characteristics of biomass used. Poor quality raw material not only impact on performance of the system but lead to other issues (PCS4). For example, the case study company PCS4 faced local public opposition due to local air pollution and flying of ash formed by burning of rice husk, which they were using as their feedstock (Eswarlal et al., 2013). An additional example is extra cost incurred due to the requirement of drying the biomass which is with high moisture content (PCS1, PCS2). Proper technology selection and better system design can minimise the effect of this issue (PCS2, PCS3). For instance, case study company PCS2, have designed their exhaust flu gas to be used for drying the wet biomass, saving the energy requirements.

7.3.2 Transportation

The issues related to the biomass transportation process are categorised under this category, which is discussed below.

7.3.2.1 Delivery Failure

The failure to deliver biomass in required place at required time can impact the day to day operation of the plant (PCS1, IN36). For instance, case study PCS1 holds raw material stock sufficient for two days only due to the limited storage space availability. They had to stop their complete production multiple times when the biomass was not delivered on time because of the lorry break down or strike. The breakdown of transport vehicles can also be attributed to the poor transport road networks in rural areas (IN36).

7.3.2.2 Cost of transportation

Increase in the cost of biomass transportation is an issue impacting economics of the production. The rising price of diesel (due to subsidy reduction by government), poor transport infrastructure leading to increased vehicle maintenance in India and low density of the biomass are some of the reasons for increasing the cost of biomass transportation (IN22, IN36).

7.3.3 Storage

In this category issues related to storage of biomass are catalogued. The issues identified are unavailability of storage space, cost of storage and fire hazard, which is discussed below.

7.3.3.1 Unavailability of storage space

Unavailability of space to store the biomass is an issue in bioenergy supply chain. It can increase the risk of the chain by increasing the exposure to degradation or loss of raw material (IN22), market price fluctuation (IN36), dependence on the supplier and unexpected delays to deliver (PCS1). Storage space required can be open or closed depending on the type of raw material, location of the plant among other factors. However, closed storage is preferred to store biomass in rainy season to avoid the high moisture content in biomass and in very hot weather conditions to avoid any fire hazards (PCS4, PCS12). Storage is also important for agro residues which need to be cleared from agricultural lands of the small farmers as they don't have much space to store them (PCS8, PCS11, PCS12).

7.3.3.2 Cost of Storage

Increase in the cost of storing the biomass is an issue recognised by many participants. Some of the participants believe that cost of storage is increasing as they evaluate the space used in terms of productive land unutilised and cost of setting up the storage (IN22, PCS11 and PCS12). Especially the small land farmers see it as big loss to use the space to store biomass, as it can significantly reduce their land available to cultivate (PCS11, PCS12). However it is important to consider the value lost by degradation or loss of raw material and operational cost of not having enough biomass in stock by not storing properly as well (IN22). Therefore, it is suggested to design storage with optimum storage limit by taking both the cost savings and spending into account (IN22).

7.3.3.3 Fire hazard

Fire accident due to improper storage of biomass can lead to significant damage to material and a concern for health and safety of the people (PCS12). Therefore, it is important to take preventive steps to avoid any fire hazard.

7.3.4 Pre-processing & Handling

The issues related to the biomass pre-processing and handling are categorised under this category, which is discussed below.

7.3.4.1 Improper handling

Inappropriate handling of biomass affects the bioenergy supply chain operation. Poor handling of the biomass can increase or mix the debris or sand with the agro residues affecting the quality of biomass, especially in farm lands (PCS11). It can generate operational risks for the plant such as conveyor belt jam because of the dust (PCS7). Unsuitable sizing of biomass can lead to poor performance of boilers (PCS3). In addition poor handling of residues can impact workers health through inhalation of residue particles (PCS7).

7.3.4.2 Manual pre-processing

Pre-processing the biomass manually is an issue for small scale bioenergy sector in India, as it can increase cost of production (PCS2, SCS5, SCS7, SCS8), minimise rate of pre-processing (PCS2), increase risk due to high dependence on the workforce (PCS7) and increase biomass wastage if it's not properly processed (PCS3). In addition other factors associated with workers such as increasing reluctance among the workers to work for loading and unloading of biomass (PCS2), health hazard to workers (PCS7) and unavailability of labour (PCS7, PCS11, PCS12, SCS7) also contribute as challenge for a system with manual pre-processing. Automation of the biomass pre-processing is a suggested solution to address it, however the financial requirements to automate seems to be a hindrance for small scale industries (PCS2, PCS8, PCS11, PCS12, IN33, SCS8).

7.3.5 Upstream

This category covers the issues common across the supply chain processes such as raw material, transportation, storage and pre-processing and handling.

7.3.5.1 Loss / damage of raw material

Loss or spoiling of biomass is an upstream supply chain issue of the small scale bioenergy sector as it can increase the production cost (PCS5, PCS7, PCS12, IN22). The biomass can be lost or damaged during transportation because of open truck transport (IN22), in storage because of open storage system or poor flooring (IN22) and in pre-processing and handling stage because of improper handling (PCS12). In addition, biomass can be stolen during transport or from storage (PCS7).

7.3.6 Conversion

Issues related to conversion unit in the bioenergy supply chain are discussed under this category.

7.3.6.1 Public Perception

Negative (mainly local) public opinion about the bioenergy unit is an issue for the bioenergy company as the opposition can impact its operation (PCS4, PCS5, PCS6, IN26, IN36 and IN37). The impact of negative public perception on case study companies such as PCS4, PCS5 and PCS6 are discussed in (Eswarlal et al., 2013). Some of the factors which lead to the local opposition for bioenergy in India were local air pollution, poor waste disposal and local politics (Eswarlal et al., 2013). However, local public concerns about bioenergy in

India is very limited when compared to other developed nations (IN36), this is because of the energy poverty and socio-economic circumstances in India (Eswarlal et al., 2013). The positive public perception can be built by closely engaging with and contributing to the community (IN26, IN37).

7.3.6.2 Breakdown Risk

Energy production system breakdown is an important risk for the bioenergy units as it can make the “operation of this [bioenergy] power plant an un-economical proposition” (PCS9). Frequent breakdowns can lead to the increased cost of operation (PCS9, SCS2) through more operator intervention (SCS2), downtime production loss, increased consumption of biomass (SCS3), affecting other associated production systems (for example choking of ash removal screw conveyor) (SCS2) and repair expenses. Unplanned shutdowns due to the breakdowns are also expensive because of the production loss in downstream industries (PCS1). The breakdown can be due to the failure of any individual or multiple system components (for example boiler, gasifier, engine and turbine). Some of the causes leading to this risk occurrence are poor maintenance (PCS1), un-optimised system (PCS9), unsuitable technology (PCS9), poor equipment or parts (SCS2, SCS9, SCS10), poor output from boilers / gasifiers (for example bad quality producer gas from gasifier) (SCS2).

7.3.6.3 Technical Risk (Conversion)

Technical risks affect performance of the bioenergy system. This issue is related to system integration issues and technological risk of any system components not only the conversion unit. For example,

> *Although technical feasibility is available for the gasifier-based systems, the operational problems are found especially in gas cleaning and cooling system (Report prepared for PCS3, 2005).*

Technological feasibility and maturity of conversion technology (PCS3, PCS8, IN36), system design and integration of whole system (SCS2), technological feasibility of cleaning and cooling systems (SCS10) and system flexibility (PCS9) are some of the specific technical risks recognised from the data. In bioenergy technical risk can also be caused because of the different feedstock type and feedstock size (PCS3).

7.3.6.4 Low efficiency

Low conversion and transmission efficiency can impact on energy production cost. Some of the causes for low efficiency are heat transfer loss (PCS1), electricity transmission loss (PCS8), low demand (SCS1, SCS3), fluctuating demand (SCS2) and conversion efficiency of the overall system (SCS3, PCS9). Conversion efficiency of the overall system can be influenced by poor system optimisation leading to higher fuel consumption (PCS9), performance of cooling (SCS1, SCS2, SCS11) and cleaning (SCS1, SCS11) system, problems with the filters (SCS1), engine operating performance (SCS11) and moisture content of biomass (SCS11). In addition to addressing the above causes the efficiency can also be increased by converting the electricity only system into a combined heat and power system (IN37), adopting decentralized energy production and supply approach (PCS8) and using the exhaust heat (PCS6, SCS7).

7.3.6.5 Maintenance Difficulties

Difficulties in carrying out maintenance of bioenergy conversion unit are considered as one of the important issue affecting supply chain operation (PCS2, PCS3, PCS6, PCS9, IN22 and IN33). Availability of spare parts and machinery consumables in rural areas is one of the challenges, which also leads to the time delay in fixing them (PCS2). While, stocking the machinery consumables (for example grease and oil) and spare parts sometimes do lead to wastages (PCS2). Maintenance cost also influence economics of the operation up to an extent (PCS2), for example, “repairs and maintenance cost is considered at 3% of the production cost” (SCS2 -Report prepared for PCS3, 2005). This involves cost of spare parts (PCS2) and cost of production downtime (PCS6, SCS13). Therefore, it is important to consider the issue of maintenance when selecting and designing the system (PCS9, SCS1, and SCS7).

7.3.6.6 Service Support

Unavailability of service support is an issue for small scale bioenergy industries in India because of skilled technicians’ shortage and unavailability of spare parts in the rural areas where most of these industries are located (PCS2, PCS3 and PCS6). In order to address this better engagement with the suppliers and having annual maintenance contract is suggested (PCS6, SCS1). However, case study companies such as PCS2 and PCS3 stated that in spite of their contract with the suppliers, the machine suppliers failed to provide required support and satisfy the agreement.

7.3.6.7 Auxiliary Power

The cost of alternate/hybrid fuel and high auxiliary power consumption can impact on cost of bioenergy and its operations (PCS3, PCS6, and PCS9). Alternate / hybrid fuel (Auxiliary energy source) is used in starting up of the unit or as a mixture fuel in duel fuel mode. Auxiliary energy sources used in the case studies are diesel in duel fuel mode (PCS9, SCS1, SCS3, SCS4, SCS7, SCS10 and SCS11) and LPG to start up (PCS6). Cost of diesel and LPG impacted the cost of bioenergy significantly and any increase in them lead to increase in the price of unit energy (PCS6, PCS9, SCS1, SCS3, SCS4, SCS7, SCS10 and SCS11). For example,

> *Though the reported average power generation cost per kWh is 3.25, the actual power generation cost estimated during the above operating period [study period] is Rs.4.6/kWh and this mainly because of diesel price (SCS4 - Report prepared for PCS3, 2005).*

In particular, in duel fuel mode the cost of diesel plays a vital role in power generation cost, as in some cases it contributes as high as 86 % (SCS11) and 65% (SCS1) of the average power generation cost.

Auxiliary power can be consumed for associated preparatory processes as well. Auxiliary consumption in some cases was nearly 43% (SCS3) and 20% (SCS10) of total power generation because of the low operating load. Therefore, it is important to minimise auxiliary power consumption and minimise auxiliary energy source used to produce the energy.

7.3.6.8 Equipment Quality

The poor quality of equipment / system is an important issue as it impacts the performance of the system (PCS3, PCS9, SCS1, SCS2, SCS3 and SCS9). Vibration and noise levels of the installation (SCS1 and SCS2), need for modifications immediately after the installations (PCS3), low actual operational performance and poor environmental performance when compared to the specifications (SCS2), and unspecified technological constraints (SCS3) were some of the challenges faced, which are related to the quality of the equipment's. In order to ensure the quality of the system it is important to procure from a dependable supplier, even if the price is slightly higher (PCS9).

7.3.6.9 Financial risks

Economical viability of the bioenergy organisation is very important for its continued existence. In the Indian context most of the electricity producing bioenergy companies gets some sort of subsidy from government (PCS2, PCS3, SCS4, SCS9 and SCS11) to make the bioenergy power production a profitable venture. This is because the companies have to compete with the heavily subsidised fossil fuel energy market in India (IN36).

> *Many units currently has adopted gasifier based energy generation system not only on the basis of adopting renewable energy technology but for availing subsidies and soft loans from Government to generate energy at a cheaper rate. If the delay in disbursement persists it might lead to a closure of the parent company itself (Report prepared for PCS3, 2005).*

However, low power purchase tariff (PCS3, IN26), low loading (SCS3), delay to pay subsidy affecting the cash flow (SCS4) and increased cost of raw material (PCS6) are some of the factors resulting into poor profit margin (IN33, IN37) leading to an unattractive rate of return for investors (IN36). This impacts the continuous operation of bioenergy units and new investments in bioenergy projects. Offering a profitable power purchase tariff (PCS3), increasing the subsidy available (PCS2) and avoiding delays to pay subsidy and tariff payments are some of the suggestions to minimise financial risks of a bioenergy company.

7.3.7 Downstream / Market

In this category the issues related to the downstream (transmission, distribution and market) supply chain of the bioenergy are discussed.

7.3.7.1 Technical Risk (Downstream)

This issue is related to the technological risks and integration issues of transmission and distribution systems for both heat and electricity. These risks impact on the transmission and distribution system performance and continuous operation of the bioenergy unit at its full capacity (PCS3). For instance,

> *The college [SCS8] observed that, due to changing loads, it would not be possible for the system to be synchronized with the grid, due to changing frequency (SCS8- Report prepared for PCS3, 2005).*

The electricity produced is unable to synchronise with grid because of the existing load (IN36), restriction on minimum load that can be connected to the grid (IN36), poor quality of grid infrastructure (IN36), voltage difference (SCS3) and regularly changing load (SCS3). Some other important technical risk concerns raised are low reliability of grid supply lines in rural areas (for example frequent load shedding and high transmission losses) (PCS2, PCS3, IN22), overloading (SCS3) and inefficient heat transfer infrastructure (IN36).

7.3.7.2 Infrastructure Risk

Technical risks of the existing infrastructure that impact transmission and distribution of the energy produced are discussed above. However, in many rural areas of India energy transmission and distribution infrastructure is unavailable, which is an issue for the bioenergy sector as most of the plants are situated in rural areas (PCS2, PCS3, PCS8, IN22, IN33, and IN36). For example,

> *The power plant though, has an installed capacity of 4 x 125 kW, but presently one system is operated, due to the non-completion of grid extension network (SCS2 - Report prepared for PCS3, 2005).*

Not only the electricity grid availability but heating / cooling grid availability is also an issue as utilisation of the heat produced can help to increase energy generation efficiency and its economics (IN36). Unavailability of the infrastructure limits production capacity, full capacity utilisation and requires additional capital expenditure on supply grid (PCS2, PCS3). This makes it unattractive for the investors.

7.3.7.3 Demand Fluctuation

> *Loading plays an important role in the viability of the system (SCS3 - Report prepared for PCS3, 2005).*

Fluctuating energy demand (PCS1, PCS3, IN37,IN36, SCS2, SCS3, SCS8, SCS10, SCS11) is an important issue for the bioenergy systems as it increases the cost of operation (SCS3) and lead to poor performance of the system (SCS2, SCS10, SCS11). For a grid connected plant load acceptance by the grid (IN36) is one of the factors influencing the demand. While, for the plants which supply to customer / downstream directly, varying electricity and heat demand from them (PCS1, PCS3, SCS8, IN36 and IN37) is a cause for fluctuation. For the industrial consumers the load fluctuation is dependent on their process requirement (SCS10).

7.3.7.4 Market Trust

Low market trust on bioenergy unit's ability to supply the required energy continuously is an issue for attracting the customers (IN37, IN36, and SCS11). Supply ability is particularly an issue for the small scale non-grid connected units as the customers buying from them would like to be sure about the energy supply ability (electricity and heat) and backup supply arrangement when the bioenergy system is down (IN37).

7.3.7.5 Cost of Energy

Cost of unit energy is very important for bioenergy industries survival, its market acceptance and attaining energy access for all (PCS1, PCS2, PCS3, PCS4, PCS6, PCS9, IN22, IN26, IN36, IN37, SCS1, SCS3, SCS4, SCS7 and SCS11). The cost of procurement is low for grid connected plants as they are fixed by the government (IN22 and IN36). In some cases, cost of production is higher than the price offered by government to supply into grid. This is because they consider bioenergy mostly in contest with the large scale coal fired thermal plants (PCS3). Government should in light of country's energy poverty, energy dependence and in the interest of promoting all type of renewable energies, should consider the production price of bioenergy and procure at a profitable rate for the company (PCS3 and IN36).

While situation in un-electrified areas are different because bioenergy units their need to be competitive with other energy industries in that market (for example diesel generator) (PCS1, PCS2, PCS3, PCS4 and PCS6). In addition to this energy affordability by the poor segment of population need to be carefully considered while pricing the energy, because the energy access can offer lot of socio-economic benefits to those people (PCS3 and PCS6).

7.3.7.6 Competition with other energy industries

Bioenergy industry need to be competitive with other energy industries on its investment requirements (PCS3), price of energy (PCS1, PCS2,PCS3, IN36, IN37, SCS1), reliability (IN37, IN36, and SCS11) and flexibility (PCS1, PCS3, SCS8, IN36, IN37) for it to gain access to the market. Investment wise small scale bioenergy industries are nearly competitive with other fossil fuel technologies (PCS3). Competing with grid cost of electricity is difficult as its heavily subsidised by the government (PCS2, IN37, and SCS1). However, cost of electricity is cheaper when it is compared to the diesel generators (PCS2, PCS3, and IN36). Whereas, for producing heat energy in India, bioenergy is already economical when compared to the diesel (PCS2), furnace oil and even grid supply (PCS1).

7.3.7.7 Payment recovery

Unable or delay to recover the payments for the energy supplied is an issue affecting the small scale bioenergy company seriously by impacting its cash flow and profit (PCS6, IN37). The payment for the energy supplied to the grid, get severely delayed because of the sluggish bureaucratic process followed in the state electricity boards (IN37). While, in one of the case study company namely PCS6, direct monthly payments from residential customers were delayed as they were reluctant to pay as there was not any penalty for not paying such as disconnecting the line. Due to this company faced severe financial challenges in first few months. In order to address this they introduced a community based fee collection system with the support of community leaders, resulting in an improved payment collection system.

7.3.8 Across

In this category issues affecting all across the supply chain processes are classified. Labour shortages and regulatory risks are the two issues found in this category and this is discussed below.

7.3.8.1 Labour Shortages

Unavailability of labour to work in bioenergy supply chain is an issue that affects the operation of supply chain. There is a shortage of skilled workers required for both pre-processing of biomass and operation, repair and maintenance of the bioenergy units (PCS2, SCS3, SCS7, SCS8 and IN33). In addition to that there is also shortage of unskilled workers to work in the bioenergy field for harvesting and collecting biomass (PCS11) and handling the biomass (PCS7, PCS8). This can be due to little equipment availability to support the workers, low wages, and health concerns (for example breathing of residue dust) (PCS7). These labour shortages impact operations of bioenergy supply chain and contribute to increase in cost of production due to increased labour cost (SCS5, SCS8).

7.3.8.2 Regulatory Risks

Red tape procedures and slow bureaucratic process is one of the major challenges in decision making and execution, especially for small scale players. Environmental clearance from the pollution control board is considered to be one of the toughest regulatory hurdles (PCS1, PCS3, IN22 and IN33). These regulatory risks lead to action time delays, which result into associated cost (PCS4).

7.4 Discussion

In this chapter, supply chain issues of the small scale bioenergy sector in India are explored in response to the research objective RO3. In the process of addressing the research objective, at first supply chain issues of the bioenergy sector were synthesised by analysing the relevant literature. In total 32 issues of the bioenergy supply chain were identified from the literature. They were then classified according to the supply chain processes it is related to namely raw material (4), transportation (2), storage (5), pre-processing and handling (3), conversion (9), downstream (7) and across (2). The number of issues identified related to the individual processes are mentioned within brackets above. This step offered foundation to address the research objective through its list of bioenergy supply chain issues, based on the literature review.

Following that empirical data was collected from organisations and individuals involved in bioenergy supply chain processes, relevant external stakeholders and secondary case studies report to identify supply chain issue of the small scale bioenergy sector in India. Through data analysis 29 supply chain issues of the small scale bioenergy sector in India were found, which were classified based on the relevant supply chain processes. Supply chain issues and their short description are presented in

Table 7.5. It presents 33 issues in total by collating issues identified both from empirical evidence and literature review. They are classified under categories namely raw material (4), transportation (3), storage (4), pre-processing and handling (3), upstream (1), conversion (9), downstream (7) and across (2).

Table 7.5: Description of Bioenergy Supply Chain Issues

Issues	***Description***
Raw Material	
Availability	Shortage or unavailability of biomass for bioenergy.
Price	Increase in the cost of biomass (both the permanent rise and short term fluctuation).
Quality and characteristics	Biomass which is of poor quality and / or with unsuitable characteristics.
Multi feed issues	Issues related to use of multiple type of raw material.
Transportation	
Delivery failure	Failure to deliver biomass in required place at the required time.
Cost of transportation	Increase in the cost of biomass transportation.
Poor transport infrastructure	Poor transport infrastructure to transfer biomass.
Storage	
Unavailability of storage space	Unavailability of space to store the biomass (open or closed storage space).
Cost of storage	Increase in the cost of biomass storage.
Fire hazard	Accidental fire of improperly stored biomass.
Storage technological risk	Risks related to particular biomass storage system.
Pre-processing & Handling	
Improper handling	Inappropriate handling of biomass.
Manual pre-processing	Pre-processing the biomass manually.
Cost of pre-processing	Increase in the cost of biomass pre-processing.
Upstream	
Loss / damage of raw material	Loss or spoiling of biomass.
Conversion	
Public perception	Negative (mainly local) public opinion about the bioenergy unit.
Breakdown risk	Energy production system breakdown.
Technical risk	Technological risks of system components or issues related to integration of the system.
Low efficiency	Low conversion and transmission efficiency.
Maintenance difficulties	Bioenergy conversion unit maintenance difficulties.
Service support	Unavailability of service support.

Issues	***Description***
Auxiliary power	Cost of alternate / hybrid fuel and auxiliary power consumption.
Equipment quality	Poor quality of equipment / system.
Financial risks	Economic viability of the bioenergy organisation.
Downstream / Market	
Technical risk	Technological risks and integration challenges of transmission and distribution systems.
Infrastructure risk	Unavailability of energy transmission and distribution infrastructure.
Demand fluctuation	Varying demand for energy.
Market trust	Low market trust on the ability to supply required energy continuously.
Cost of energy	Affordable, competitive and profitable cost of energy.
Competition with other energy industries	Competitive with other energy industries based on the investment, price, reliability and flexibility.
Payment recovery	Unable / delay to recover the payment for bills from customers.
Across	
Labour shortages	Unavailability of labour to work in bioenergy supply chain.
Regulatory risks	Red tape regulation and slow bureaucratic process.

‘Cost of energy’ is recognised as an important issue for bioenergy supply chain by maximum number of participants in this study. This can be due to the peculiar situation of small scale bioenergy sector in India, which need to compete with either government subsidised grid electricity in India or large scale thermal power plants production cost or subsidised diesel or kerosene based energy cost in rural areas. In addition to that for captive plants also the price is important, as normally captive energy is used in companies which are energy intensive and cost of energy is a significant for their economics of operation. Similarly, cost of transportation, cost of storage and manual pre-processing were widely echoed as well due to its impact on the cost of production. Financial risk for the organisation was also recognised as another important issue, which is closely related to the energy cost and price as it impact on the economical sustainability of the bioenergy organisations. In relation to the bioenergy companies studied by the researcher, it can be commented that apart from commercial captive heat plants the financial propositions of all other type of small scale bioenergy plants are weak without the government subsidy.

As recognised in most of other literatures in this study also the issues related to raw material of bioenergy such as availability, price and quality and characteristics are vastly recognised by all the different group of participants. All these three issues are closely related and the price is influenced by the availability and quality of the biomass. Even when most of the small scale bioenergy plants in India are dependent on residues (agro / industrial) or wood waste still the above mentioned issues are predominant challenge for the companies. This can be because of their use in other industries, poor collection and utilisation of the biomass due to technological or economical constraints or poor decision making (for example location and size).

Maintenance issues and labour shortages were widely echoed by the participants as an important issue for bioenergy supply chain. Especially, in rural area as the skilled technician and spare parts availability are limited there. Delivery failure is identified as a problem only by one case study organisation which doesn't had enough storage space. This brings attention on 'unavailability of storage space', which was recognised as a limitation by many supply chain organisations. As storage space limits the biomass stock, which can make it more prone to be affected by market price fluctuations of biomass. Whereas bigger biomass storage also have consequences such as increased storage cost and increased wastage of biomass. Therefore the storage space need to be planned and designed to balance all of these aspects.

Public perception and regulatory risk are external factors which can impact on functioning of bioenergy, as happened in some of the case studies. All the conversion issues are recognised as significant internal challenges by most of the conversion units. Downstream issues such as infrastructure and technical risk were matter of concern for most of the bioenergy conversion units, as it limits their market choice and potential. Some of the participants recognised low confidence about continuous supply of energy by the customers such as industries which need uninterrupted energy supply is an important issue for its market acceptance and adoption. Issues related to the transportation and storage processes were not at all recognised in secondary case studies, due to the limited scope of that study.

Four issues which were not found in the empirical data when compared to the themes from literature synthesis namely multi-feed issues, poor transport infrastructure, storage technological risk and cost of pre-processing. Transportation delivery failure was identified in the empirical data but not found in the literature synthesis.

Multiple feedstock challenges were not raised by any participants of the study may be because most of the case studies used only one type of biomass and similar phenomena is widespread across small scale bioenergy sector in India.

Storage technological risks are not identified in small scale bioenergy sector in India may be because it's not very common to use properly designed storage systems for biomass (for example silos) in this sector.

Poor transport infrastructure is not identified directly in the empirical data; however it is recognised as one of the causes for delivery failure and increased cost of transportation. Similarly, even if the cost of pre-processing is not directly recognised as an issue as they are considered as a necessary step in the production process, but it is recognised to be affected by the manual pre-processing.

Delivery failure is recognised as an issue in the empirical data which was not previously identified in the literature. This can be because all the bioenergy companies in India do not have enough space to have adequate biomass storage. Therefore, they depend on just in time delivery approach, which leads 'delivery failure' to be a significant risk for the industries with less storage capacity.

Awudu and Zhang (2012) and Gold and Seuring (2011) were the two studies which have looked at the bioenergy issues from supply chain perspective. These studies inappropriateness to address the research objective are individually reviewed and discussed with reasons above. However in order to observe consistency of the findings they are compared with those studies below.

Availability, price and cost of transportation were the supply chain issues recognised in the study by Awudu and Zhang (2012). Poor transport infrastructure, unavailability of storage space, loss of raw material in storage, transportation regulations were the issues identified in the study by Gold and Seuring (2011). When compared to those studies, in current study wide range of issues across bioenergy supply chain processes are identified through empirical investigation. The current study findings confirm those findings except for poor transport infrastructure and it advances the awareness about the relevant issues further. However as stated above even if transport infrastructure is not directly recognised it was identified as one of the causes affecting other issues related to the transportation process.

The studies looking at the bioenergy sector from supply chain perspective in Indian or developing country context are scant. However other studies which are close are reviewed to evaluate the current findings. They have done techno-economic and policy analysis or looked at the barriers of bioenergy industry in Indian context (Palit et al., 2013; Rao & Ravindranath, 2002; Ravindranath & Rao, 2011; Ravindranath et al., 2004). These studies are individually reviewed and discussed above from the perspective of addressing the research objective and their limitations. Among these studies, work of Palit et al. (2013) and Ravindranath et al. (2004) are based on case studies and the other two studies are based on literature review.

Table 7.6 presents reference of the relevant studies compared along with respective study number, which is used in Table 7.7. In Table 7.7, using the compiled list of supply chain issues described in

Table 7.5 as foundation, the current study findings are compared with other relevant studies (Palit et al., 2013; Rao & Ravindranath, 2002; Ravindranath & Rao, 2011; Ravindranath et al., 2004). If an issue is recognised in a study, then it is shown using a ✓mark in the respective cell. It is important to note that most of the issues shown as stated in other relevant studies (in Table 7.7) are not directly recognized in these studies. Instead they have been identified by the researcher through analysis of those study findings and developing relevant analytical themes.

In the current study all the issues recognized in other four studies are identified except multiple feedstock challenges issue recognized by Rao and Ravindranath (2002). This can be because most of the case studies considered in this study used single feedstock (which is also very common in this sector in India). Besides that as stated above, it might be also because work of Rao and Ravindranath (2002) is based on literature review and not based on empirical evidence in India.

None of the other studies compared in Table 7.7, documented any issues related to the transportation and storage supply chain processes, which are identified in this study. In addition, loss / damage of raw material and low efficiency were recognised in this study, which was not identified by other studies compared. These variations can be mainly due to the limited scope of those other studies. Also, it is important to consider that none of the other studies have recognized in any one study, all the issues. Instead each of the study compared has recognized only some of the issues. Again this can because of the research focus and scope of those studies.

Table 7.6: Relevant Studies Compared

Study Number	***Reference***
1	Current study
2	Palit et al. (2013)
3	Ravindranath and Rao (2011)
4	Ravindranath et al. (2004)
5	Rao and Ravindranath (2002)

Table 7.7: Comparison of the Findings

Issues / Study Number	***1***	***2***	***3***	***4***	***5***
Raw Material					
Availability	✓			✓	✓
Price	✓	✓			
Quality and characteristics	✓		✓		
Multi feed issues					✓
Transportation					
Delivery failure	✓				
Cost of transportation	✓				
Poor transport infrastructure					
Storage					
Unavailability of storage space	✓				
Cost of storage	✓				
Fire hazard	✓				
Storage technological risk					
Pre-processing & Handling					
Improper handling	✓		✓		
Manual pre-processing	✓		✓	✓	
Cost of pre-processing					
Upstream					
Loss / damage of raw material	✓				
Conversion					
Public perception	✓		✓		✓
Breakdown risk	✓		✓		
Technical risk	✓	✓	✓	✓	
Low efficiency	✓				
Maintenance difficulties	✓	✓	✓	✓	
Service support	✓	✓			✓
Auxiliary power	✓	✓	✓	✓	
Equipment quality	✓			✓	
Financial risks	✓	✓	✓		✓
Downstream / Market					
Technical risk	✓		✓		
Infrastructure risk	✓		✓		✓
Demand fluctuation	✓	✓			

Issues / Study Number	*1*	*2*	*3*	*4*	*5*
Market trust	✓	✓	✓		
Cost of energy	✓	✓	✓	✓	✓
Competition with other energy industries	✓				✓
Payment recovery	✓	✓			
Across					
Labour shortages	✓	✓		✓	✓
Regulatory risks	✓		✓		✓

The above mentioned findings addressing the research objective, RO3 makes twofold contributions to the literature. First, through the list of supply chain issues synthesised and compiled from literature. This contributes to the knowledge by recognising the wide range of issues affecting the whole supply chain (including the downstream) of bioenergy, which is scant in the literature. The next contribution is the identification of the supply chain issues of the small scale bioenergy sector in India. The empirical data collected in this work, adds specific knowledge about the bioenergy supply chain from small scale and Indian perspective, existing literature on which is inadequate. The findings present issues from multiple stakeholders' viewpoint, which provides further value from utilisation point of view. In addition the findings substantiate the issues recognised through literature synthesis.

These findings in addition to the contributions to the existing knowledge in the field have significant practical implications. These findings inform policy makers and practitioners about the issues affecting supply chain of the bioenergy, based on that they can take necessary steps to address them through change in policies or other efforts. Taking the issues identified into account can help the practitioners to design resilient supply chain and increase its performance.

As with any other studies, this study does have some limitations that also offer interesting future research opportunities, which are discussed below. As the intention behind this thesis is to provide business supportive solutions to bioenergy plants, in this study supply chain issues for the bioenergy sector are investigated from the perspective of conversion plant to achieve organisational sustainability. Despite the discussion about some of the causes of supply chain issues, further work looking at challenges for different supply chain members to carry out their processes effectively and how it get affected can answer about the exact causes for the issues identified in this study, which can help to develop a right response.

As the intention of the study was to explore and identify all the potential issues, and not to prioritise the issues, so findings of this study are not prioritised based on their importance. Therefore, future studies should test the identified propositions through a large scale survey which can both prioritize and generalize the findings further.

It is important take into account that these findings are based on case studies and stakeholder inputs representing the bioenergy sector with particular characteristics (for example size, raw material, output, application of the output and technology) and context (for example developing country). Therefore, future research is encouraged for generalising or contesting these findings in other settings.

7.5 Chapter Summary

In this chapter third research objective to identify supply chain issues affecting the organisational sustainability of the small scale bioenergy industry in India is addressed. Following the recognition of research need and research gap, literature is reviewed and synthesised with relevant themes of supply chain issues. Then the empirical data collected were analysed through thematic analysis approach with support of the synthesised themes. Then the findings were categorised according to the appropriate supply chain processes and presented above. The findings were then critically analysed and discussed by comparing with the pertinent literature. Finally this study's contribution, limitations and suggestions for interesting future research are presented.

Chapter Eight: Application of the Framework

8.1 Introduction

Sustainable supply chain was identified as an important requisite for the bioenergy sector, in Chapter 3. Hence to support the decision makers in making the right choices to develop a sustainable supply chain, a risk based framework was proposed in Chapter 5 (RO1). In this chapter application and evaluation of that sustainable supply chain risk analysis framework is presented (RO4). The framework was applied in a real time action research case study namely, ARC (which is part of science bridge project). The findings from other research objectives in this study such as RO2 (i.e. sustainability objectives and issues) and RO3 (i.e. supply chain issues), discussed in Chapter 6 and Chapter 7 respectively, provided valuable inputs that helped to apply this framework. Following the application of the framework, feedback from the user expert group was collected to evaluate the framework for its functionality and usability. In addition to that a focus group was also convened to evaluate the framework for future applications (generalizability). The steps taken to apply and evaluate the framework are depicted in the Figure 8.1.

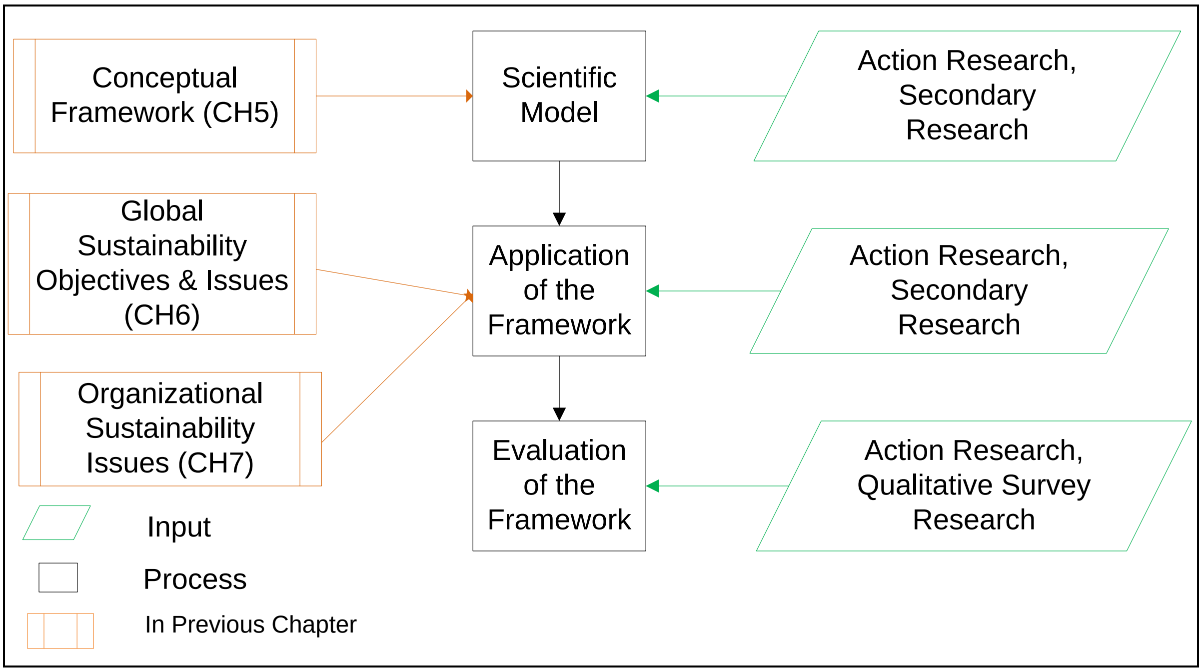

Figure 8.1: Approach for Applying and Evaluating the Framework

The next section explains the modelling of the conceptual framework for the purpose of application in the ARC project. Section 8.3 presents, the application of the modelled framework in the ARC project, including a brief overview of the case, discussion and verification of the results and their practical outcomes. Then the discussion on evaluation and contribution of the framework follow.

8.2 Scientific Model

The systems view of problem solving presented by Mitroff et al. (1974) has reported a practically applicable 'scientific model' as a step before solving the real problem. The 'scientific model' derived from the conceptual framework (Chapter 5), is discussed in this section. Figure 8.10 portrays the steps taken to apply the framework in practice. Discussion on individual stages of the model follows.

8.2.1 Risk Identification Group

Stakeholder opinion and involvement are very important for a sustainable bioenergy project (Buchholz et al., 2009b; Joudre, 2012; Painuly, 2001; Ravindranath & Balachandra, 2009). As different supply chain activities in the bioenergy industry interact with the wider society, it is vital that the stakeholders' views taken into account for make the industry sustainable. In Chapter 6 and Chapter 7, global and organisational sustainability issues of the 'bioenergy supply chain' identified respectively. Researcher have engaged with variety of important stakeholders relevant to bioenergy (in the Indian context) to identify their views on those issues.

The findings of the objectives RO2 and RO3 are vital source of information for this project. However, the (global and organisational) sustainability issues are contextual and project specific. Therefore, it is important to get stakeholders' views from that perspective. Hence, in ARC project, the project owners had multiple consultations with stakeholders such as local community, government agencies, local NGO, suppliers and customers during the planning stage. The researcher attended a few of those meetings but due to the practical limitations could not attend all of those consultations. ARC project being a research project and the project owners being experienced researchers have taken the views of those stakeholders into account and reflected them during the application of the framework. Yet, to strengthen the outcomes of the framework and to avoid any bias about the issues relevant for the project, the data collected from a variety of experts with experience in bioenergy from different backgrounds and disciplines. Therefore, in risk identification both the project owners and experts were involved. Data from the group of project owners and experts' collected separately through focus groups ARC-FG2 and ARC-FG3 respectively.

8.2.2 Defining Sustainability Objectives and Risk Identification

Adoption of the framework required to identify organisational and global sustainability objectives and the related risks for the upcoming project. As stated above this information collected from the risk identification groups, that comprised of three project relevant participants and nine experts. Out of the nine experts, three experts also had very good contextual understanding of the project. Initially the project details collected from the project owners through interviews (ARC - IN1, IN2 & IN3) and then the information compiled from supply chain perspective. Then the compiled project information and the findings of the research objectives RO2 and RO3, presented in the starting of the focus groups. Then the discussions to identify the objectives and risks relevant for the project followed.

8.2.3 Risk Assessment Group

After identification of the sustainable objectives and risks it was important to assess the sustainable supply chain risks, so that they can be used in decision making. In order to obtain such an analytical output, a relevant expert risk assessment group comprising 3 project relevant participants and 2 experts with contextual understanding of the project were selected, who were also part of the risk identification group. Inputs were collected from them A focus group (ARC - FG4) was convened to collect input from them in order, to select the appropriate analytical methodology, to develop measurement and output scales, to obtain risk and objective assessment values, to discuss the outputs and to identify the recommendations for the ARC project and to evaluate the framework. The experts are classified into project relevant experts (EG1) and outside experts (EG2) group and named as Et1, Et2, Et3, Et4 and Et5.Their description is given in the Table 8.1.Even though all the participants had expertise relevant to the project, still different experts views had different impacts on the final decision (Zeng et al., 2007). Therefore expert contribution factor (CF) is introduced into the risk assessment model, to differentiate experts' level of influence and competence. This value will be allocated to individual experts based on their influence, experience and expertise. However, when the situation change it is important to re-evaluate the CFs of the experts (Zeng et al., 2007). The two mathematical relationship of the CF's defined by the Zeng et al. (2007) is adopted to calculate the CF's. They are,

If there are 'n' number of experts in the group then,

E_k*'s (K^{th} Expert) Contribution Factor =*C_k*, where* $C_k \in [0,1]$

$C_1 + C_2 + \ldots + C_k = 1$--- *Equation 1*

Table 8.1: Risk Assessment Expert Group

Expert Group	***Expert***	***Description***
EG1	Et1	Co-principal investigator of the project and head of the work package related to the upcoming bioenergy plant. He is a senior professor in the engineering department of a renowned Indian institution. 30+ years, of experience in teaching and research.
	Et2	Deputy in charge of the work package related to the upcoming bioenergy plant. She is a senior professor in the rural development department of a renowned Indian institution. 30+ years, of experience in teaching and research.
	Et3	Partner in charge for the installation and operation of the upcoming bioenergy plant. He is the administrative head of a NGO working in various projects related to the social and rural development. 20+ years, of experience in NGO and rural development.
EG2	Et4	Associate Professor of Sustainable Rural Development in a central government institution in Punjab, India. Have a 15+ years of teaching and research experience. Have done research on bioenergy projects and worked in the region of the upcoming plant as well, therefore have good understanding of the context.
	Et5	Professor of Mechanical Engineering in a central government institution in Punjab, India. Have a 20+ years of teaching and research experience. Have a good knowledge about the local context of the upcoming project and have experience in the bioenergy project implementations.

8.2.4 Measurement Techniques

The appropriate risk assessment and analysis methods were selected to execute the conceptual framework in the practical circumstances of the project. The inputs from the experts along with literature review helped to select the suitable techniques. Initially the conceptual framework was presented to the experts, which was then followed by the discussion of different suitable techniques that led to the selection of the appropriate risk analysis techniques by the experts. These techniques and their suitability for the purpose are discussed below.

8.2.4.1 Fuzzy sets

Uncertainty in decision making due to imprecise and vague data can be dealt using fuzzy set theory (Kahraman et al., 2006; Zheng et al., 2012), which is introduced by Zadeh (1965). Chan and Kumar (2007) states that fuzzy set is easy to understand as it classify and group the data, however the boundaries of the groups are fuzzy, i.e. it's not sharply defined (Zheng et al., 2012). Kahraman et al. (2003) argues that fuzzy set theory can be applied in different type of problems where the information available is imprecise because it was designed to represent these type of vague data mathematically. Due to this, fuzzy set theory has been widely used in risk management for risk evaluation and analysis (Carr & Tah, 2001; Gürcanli & Müngen, 2009; Tam et al., 2002; Zeng et al., 2007). Some of the studies also have used fuzzy set theory to assess the sustainable development of the systems(Acosta-Michlik et al., 2011; Cornelissen et al., 2001). While, Acosta-Michlik et al. (2011) argues that fuzzy system is very useful to model the sustainability concepts because of its advantages such as,

- the easy conversion between linguistic and numerical form of the data,
- potential of the model to generate multi-valued outputs,
- capability to use both qualitative and quantitative data together in the model
- ability to include expert opinions,
- inference rules making the model assumptions very transparent and
- potential to represent the non-linearity between the related data.

Most of the data to be collected for the risk analysis will have degree of uncertainty and subjectivity. Therefore, by taking the vagueness of the data, potential to use linguistic form of data and to include multiple expert opinions and the non-linear relationship of the interrelated data into account, fuzzy set theory approach was adopted in this study.

"Decision makers usually feel more confident to give linguistic variables rather than expressing their judgments in the form of exact numeric values" (Zheng et al., 2012, p. 229). Zadeh (1975, p. 199) states that linguistic variable is "a variable whose values are words or sentences in a natural or artificial language". Linguistic variables can be appropriately expressed using fuzzy numbers, which is not exact like 'ordinary' numbers but imprecise. They are expressed using a fuzzy set that suits the conditions of normality and convexity (Zheng et al., 2012). Triangular, trapezoidal and s-shaped membership functions (MF) are some of the most widely adopted geometric mapping functions to represent fuzzy membership functions. However, trapezoidal or triangular fuzzy membership functions are the ones mostly used in risk analysis (Zeng et al., 2007) and in particular to convey perception of group members in group decision making, triangular or trapezoidal fuzzy number approaches are usually adopted (Guha & Chakraborty, 2011; Zheng et al., 2012).

Whereas, a triangular fuzzy number is a type of a trapezoidal fuzzy number (Zheng et al., 2012, p. 230) and trapezoidal fuzzy number is a more general representation that includes triangular fuzzy number as well (Sadi-Nezhad & Khalili Damghani, 2010). Therefore, linguistic variables which were preferred by the expert group were represented using the trapezoidal fuzzy number approach in the action research project.

The mathematical definitions and the relevant operational laws of standardized trapezoidal fuzzy number (STFN) provided in the literature (Acosta-Michlik et al., 2011; Sadi-Nezhad & Khalili Damghani, 2010; Zeng et al., 2007; Zheng et al., 2012) are given below.

A STFN can be defined as $\tilde{T} = (a, b, c, d)$ *--- Equation 2*

Membership function (MF) specifies the degree of preference and for STFN it can be defined as ,

$$\mu_{\tilde{T}}(x) = \begin{cases} (x-a)/(b-a) & (a \leq x \leq b) \\ 1 & (b \leq x \leq c) \\ (d-x)/(d-c) & (c \leq x \leq d) \\ 0 & \text{for otherwise} \end{cases}$$ *--- Equation 3*

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Figure 8.2: Standardized Trapezoidal Fuzzy Number

(Adopted from: Zeng et al., 2007)

Figure 8.2 shows the graphical representation of a STFN. When in a STFN, a=b=c=d, then it represents a numerical value. If a=b, and c=d, in a STFN then it represent a range of numerical values. When b=c, in a STFN, then it is a triangular fuzzy number.

Defuzzification needed to transform the fuzzy number back into a crisp number. If STFN$\tilde{T} = (a, b, c, d)$ then the crisp value (i.e. T) of it can be obtained by using the equation below,

$T = \frac{(a+2(b+c)+d)}{6}$--- *Equation 4*

If $\tilde{T_1} = (a_1, b_1, c_1, d_1)$and $\tilde{T_2} = (a_2, b_2, c_2, d_2)$are two STFN's then the mathematical functions between them are:

$\tilde{T_1}(+)\tilde{T_2} = (a_1, b_1, c_1, d_1) + (a_2, b_2, c_2, d_2) = (a_1 + a_2, b_1 + b_2, c_1 + c_2, d_1 + d_2)$- Equation 5

$\tilde{T_1}\ (-)\ \tilde{T_2} = (a_1, b_1, c_1, d_1) - (a_2, b_2, c_2, d_2) = (a_1 - d_2, b_1 - c_2, c_1 - b_2, d_1 - a_2)$ - Equation 6

$\tilde{T_1}(*)\tilde{T_2} = (a_1, b_1, c_1, d_1) * (a_2, b_2, c_2, d_2) = (a_1 a_2, b_1 b_2, c_1 c_2, d_1 d_2)$--- Equation 7

$\tilde{T_1}\ (\div)\ \tilde{T_2} = (a_1, b_1, c_1, d_1) \div (a_2, b_2, c_2, d_2) = \left(\frac{a_1}{d_2}, \frac{b_1}{c_2}, \frac{c_1}{b_2}, \frac{d_1}{a_2}\right)$--- Equation 8

$k * \tilde{T_1} = k * (a_1, b_1, c_1, d_1) = (ka_1, kb_1, kc_1, kd_1)$(Where k is a numeric value) --- Equation 9

$(\tilde{T_1})^{-1} = (\frac{1}{d_1}, \frac{1}{c_1}, \frac{1}{b_1}, \frac{1}{a_1})$ --- Equation 10

The sections below describe how these different equations were used within the risk analysis framework for mathematical calculations.

8.2.4.2 Fuzzy AHP

Prioritizing the important global sustainability objectives which are influenced by the bioenergy supply chain using the simple rating scale was found difficult due to the ambiguity and complexity involved in understanding and responding to the individual objectives. Therefore, well-accepted multi criteria decision making tool analytic hierarchy process (AHP) was selected to identify the weightage of different objectives (Zeng et al., 2007). This is because, "AHP can consider each factor in a manner that is flexible and easily understood, and allows consideration of both subjective and objective factors" (Dey, 2006, p. 92). Other methods such as Preference Ranking Organization Method for Enrichment Evaluations

(PROMETHEE) (Behzadian et al., 2010; Brans et al., 1986), Multi-Attribute Utility Theory (MAUT) (Ishizaka & Nemery, 2013) or Elimination and Choice Expressing Reality (ELECTRE) (Roy, 1991) approaches can also be used for this purpose. However, AHP provides an easy way to structure the problem when compared to these other methods (Ishizaka, 2013; Macharis et al., 2004; Papadopoulos & Konidar, 2011).

AHP technique was established by Saaty (1977), and decomposition, relative opinion, and combining the priorities are the three fundamental principle of it (Dey, 2006; Dey & Ramcharan, 2008). In reality, AHP uses definite scale which is one of its drawbacks (Zeng et al., 2007), whereas for uncertain environment and subjective opinions, fuzzy numbers are the best to evaluate (Kabir & Hasin, 2011). Therefore, a modified fuzzy AHP has been adopted in this study.

Van Laarhoven and Pedrycz (1983) first introduced the fuzzy AHP (FAHP) based on the AHP (Saaty, 1977) and fuzzy set theory (Zadeh, 1965). It has been widely used in different real world risk analysis and pair wise comparison problems (Dağdeviren & Yüksel, 2008; Gumus, 2009; Zeng et al., 2007; Zheng et al., 2012). Kabir and Hasin (2011) compared AHP and FAHP and concluded that FAHP method is more convenient to deal with practical decision making problems. Weck et al. (1997) argues that it is one of the best assessment methods among many. FAHP is a simple process which handles the problem in a structured manner that can capture uncertain and imprecise judgment of experts and handle both qualitative and quantitative data (Zheng et al., 2012). Therefore based on the benefits mentioned above, FAHP is adopted to evaluate the influence on the objectives.

8.2.4.3 Fuzzy System

Fuzzy system which is based on the fuzzy set theory and fuzzy logic (Lee, 1990) was selected in consultation with experts to calculate objective index (OI) and risk magnitude (RM) in ARC project. The ease of use, knowledge representation, providing meaningful logic and ease of structuring to include prior knowledge (expert knowledge) are some of the important reasons to select a fuzzy system (Lee, 1990; Lee & Wessel, 1993; Zadeh, 1983). These calculations are done by using the Fuzzy logic toolbox in the Matlab software.

There are five major components of a fuzzy system (Chen, 1989 cited in Lee & Wessel, 1993), they are fuzzy set database, fuzzification interface, fuzzy rule base, fuzzy inference engine, defuzzification interface which is shown in the Figure 8.3 (Source: Lee & Wessel, 1993).

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Figure 8.3: Fuzzy System

(Source: Lee & Wessel, 1993)

Fuzzy Set Database: In this part the fuzzy sets for the respective linguistic variables (both input and output) used in the fuzzy system are defined (Lee & Wessel, 1993). This will be defined by the risk assessment experts.

Fuzzification Interface: During this process crisp input values are transformed into respective linguistic variables based on the fuzzy set database (Lee & Wessel, 1993).

Fuzzy Rule Base: This are fuzzy IF-THEN rules (Lee & Wessel, 1993) which is constructed based on the expert knowledge.

Fuzzy Inference Engine: This is a "reasoning mechanism to do computations given a fuzzy rule base and input values" (Lee & Wessel, 1993). Mamdani and Sugeno are the two types of inference systems, in this Mamdani is the most commonly adopted method, which is used in this research. Fuzzy inference process computes the output in two steps and they are explained below.

Rule Inference: In this stage, rule firing strength is obtained by firing all the rules in the rule base. Depending on the problem 'AND' or 'OR' operators are used to combine different input variables (Lee & Wessel, 1993). Combination operator (AND) is used for the calculation of both OI and RM.

Composition: An output fuzzy membership value is computed based on the consequence of all the rules fired and its rule strength (Lee & Wessel, 1993), where there is a reasoning scheme underlying the compositions (Yu, 2002). Max-Min reasoning scheme is used in this research, which is the commonly used approach for composition. The process of max-min composition is shown in the Figure 8.4.

Figure 8.4: Fuzzy Reasoning Scheme

(Source: Yu, 2002)

Defuzzification Interface: In this stage the fuzzy output is converted into a crisp value. Centroid of area method is used for defuzzification in this research as shown in the Figure 8.5 (Yu, 2002).

Figure 8.5: Defuzzification

(Source: Yu, 2002)

8.2.5 Implementation Procedure

The measurement techniques mentioned above were selected keeping the implementation of them in the ARC project in mind. This section discuss about the modus operandi and calculation steps to implement the above discussed techniques in the ARC project.

8.2.5.1 Measurement of Objective Index

From the conceptual framework, it can be derived that assessing the importance of both organisational and global sustainable objectives is an important step, from the corporate sustainability point of view (phase 3). So, that risk can be mapped onto a corporate sustainability risk magnitude scale and to prioritize those risks. Therefore, organisational and global sustainable objectives need to be evaluated from the corporate sustainability perspective.

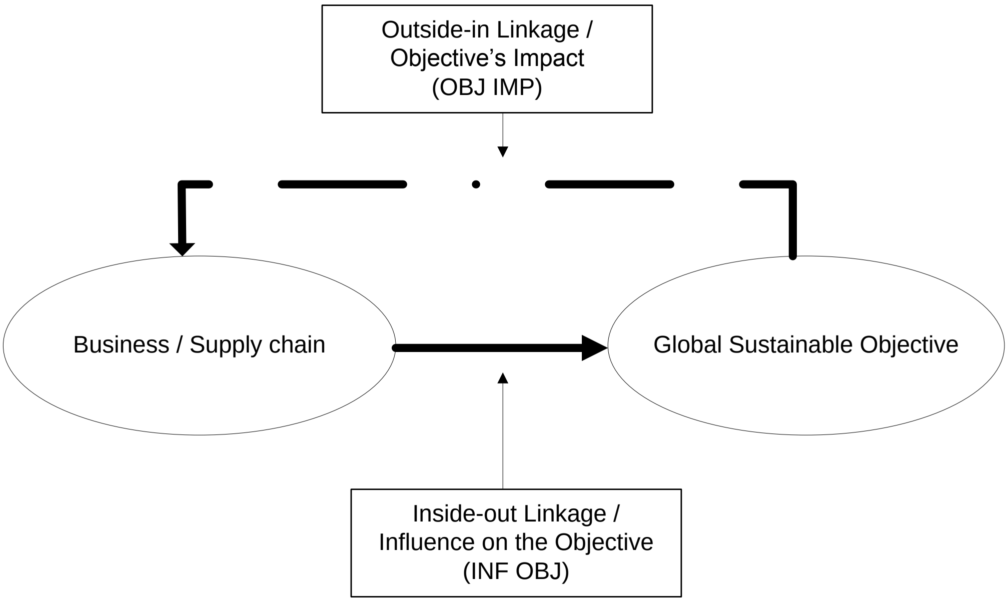

Figure 8.6: Sustainable Objective from Corporate Sustainability Perspective

In the ARC project, the experts selected 'business continuity' as the prime umbrella objective which covered the breadth of all the aspects related to the organisational sustainability. As the experts could relate the organisational sustainability risks (i.e. risks to supply chain operations) directly to the impact on corporate sustainability, they preferred the simple and regular supply chain risk assessment (based on the risk likelihood and risk severity) for the organisational sustainability part of the analysis. Whereas, for the global sustainability the individual objectives need to be assessed, in order to prioritize the risks of those objectives and map it onto the (common) risk magnitude scale accordingly. This assessment of global sustainability objective from a corporate sustainability perspective is labelled as objective index (OI). It have been agreed that in order to judge the global sustainability objectives from a corporate sustainability perspective (OI) both the inside-out and outside-in linkages proposed by Porter and Kramer (2006) need to be taken into account. The inside-out linkages relates to the business or supply chain influence on those objectives (INF OBJ) and the outside-in linkages refer to the relevant impact of the objective's on the business / supply chain (OBJ IMP). This relationship is portrayed in Figure 8.6. Therefore to identify the relevant objective's, objective index (OI), influence on the objective (INF OBJ) and objective's impact (OBJ IMP) need to be measured, which is described in the next section.

8.2.5.1.1 Influence on the Objectives

As stated above in section 8.2.4.2, influence on the objectives of the ARC project was evaluated using fuzzy AHP approach. It was applied by following the steps explained below, which is adopted from literature (Dey, 2006; Saaty, 1977; Zeng et al., 2007; Zheng et al., 2012).

Step1: Construct an Objectives Hierarchy

The objectives need to be organized in such a way that it can be easily assessed. Therefore the objectives should be classified onto relevant themes by the risk assessment group through brainstorming technique (Zeng et al., 2007).

Step 2: Pair-wise Comparison of Objectives

Individual objectives need to be compared pair-wise with all the objectives in the corresponding pre-arranged section in the objectives hierarchy. The expert risk assessment group does the pair-wise comparison and standardizes them using the pre-determined Fuzzy AHP scale. In AHP, 1-9 scale and its inverse is used for pair-wise comparison (Dey, 2006). In this FAHP instead of the crisp value, a STFN value for their preference is used which is predetermined by experts. Therefore, the comparative preferences provided by the experts are converted into respective STFN, for it to be used for the further calculations. From individual expert's inputs respective pair wise comparison matrix X_{Ea} can be constructed, as shown below for A^{th} Expert (Ea) (Zheng et al., 2012).

$$\tilde{X}_{Ea} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \cdots & \ddots & \vdots \\ \tilde{x}_{n1} & \tilde{x}_{n2} & \cdots & \tilde{x}_{nn} \end{bmatrix} \text{ --- Equation 11}$$

Whereas $X_{12}$is the value of comparing the objective 'O_1'with 'O_2'. While the value of comparing the objective'O_2' with 'O_1', is X_{21}. The relationships between them are:

If $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij}, d_{ij})$ *--- Equation 12*

Then $\tilde{x}_{ji} = (\tilde{x}_{ij})^{-1} = \left(\frac{1}{d_{ij}}, \frac{1}{c_{ij}}, \frac{1}{b_{ij}}, \frac{1}{a_{ij}}\right)$ *--- Equation 13*

Step 3: Check for Consistency

The consistency of individual expert inputs needs to be checked in AHP before aggregating the individual STFN's into a group STFN and calculating the weights of the objectives. If the crisp value comparison matrix is consistent, then the fuzzy comparison matrix is also consistent (Zheng et al., 2012). Therefore, in order to check the consistency of the comparison matrix firstly the STFN need to be converted into a crisp value using the defuzzification equation (Equation 4). After the defuzzification the STFN comparison matrix is converted to X, which is given below.

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \cdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nn} \end{bmatrix}$$ --- *Equation 14*

Once the fuzzy comparison matrix is converted into a crisp value comparison matrix then the consistency can be checked using the Eigen value method proposed by (Saaty, 1977). In which the consistency ration (CR) is calculated using the formula,

$$CR = \frac{CI}{RI}$$ --- *Equation 15*

Where,

Consistency Index, $CI = \frac{(\lambda_{max} - n)}{(n-1)}$ --- *Equation 16*

λ_{max} = Largest Eigen value of the matrix

RI = Random Index, which is calculated and provided by the Saaty (1977), given in the Table 8.2. In the table n is the matrix size.

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Table 8.2: Random Index (RI)

(Source: Saaty, 1977)

As a thumb rule Saaty (1977) suggests that if the CR is less than 0.10 (or 10 %) then it can be considered as consistent and acceptable. If not, the pair-wise comparison matrix should be revised (Zheng et al., 2012).

Step 4: Converting Individual Preferences into Group Preferences

In this step, the individual expert's pair-wise comparison preference, which is a STFN, is aggregated into a group STFN using the STFN mathematical calculation equations mentioned above (Equation 5 to Equation 10). If the aggregation of the STFN scales comparing the objective O_i with O_j is denoted as $\tilde{x}_{ij_{agg}}$ then it can be defined as (Zeng et al., 2007):

$$\tilde{x}_{ij_{agg}} = \left(\tilde{x}_{ij_{E1}} \boxast C_1\right) \boxplus \left(\tilde{x}_{ij_{E2}} \boxast C_2\right) \boxplus \ldots \ldots . \boxplus \left(\tilde{x}_{ij_{Ek}} \boxast C_k\right)$$ --- Equation 17

Where,

$\tilde{x}_{ij_{E1}}, \tilde{x}_{ij_{E2}}, \ldots . \tilde{x}_{ij_{Ek}}$ - STFN scales of O_i comparing with O_j measured by experts E1, E2, ...,Ek respectively.

$C_1, C_2, \ldots C_k$ - Contribution factors of the experts E1, E2,... ,Ek respectively.

i, j - 1,2,3,... n are the numbers of objective O_1, O_2, ... , O_n respectively.

$\boxast$ - STFN multiplication operator

$\boxplus$ - STFN Addition operator

This will lead to the aggregated STFN pair wise comparison matrix as shown below.

$$\tilde{X}_{agg} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \cdots & \ddots & \vdots \\ \tilde{x}_{n1} & \tilde{x}_{n2} & \cdots & \tilde{x}_{nn} \end{bmatrix}$$ --- *Equation 18*

Step 5: Defuzzify the STFN Scale

The aggregated STFN then need to be transformed into crisp value using the defuzzification equation (Equation 4), this will lead to the transformation of $\tilde{x}_{ij_{agg}}$ into crisp scales X_{ij} which is within the range of (0,9). This will result into a crisp value comparison matrix as shown below.

$$X_{agg} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \cdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nn} \end{bmatrix}$$ --- *Equation 19*

Step 6: Calculate the Priority Weights of the Objectives

Arithmetic averaging method is used to calculate the priority weights of objectives in the matrix W_i (Zeng et al., 2007), the equation for calculation is

$$w_{i(subsection)} = \frac{1}{n} \sum_{j=1}^{n} \frac{x_{ij}}{\sum_{k=1}^{n} x_{kj}}$$ --- *Equation 20*

Where,

$w_{i(subsection)}$ - is the priority weight of the objective O_i within the sub section (lower level) of the hierarchy

i, j - 1, 2, 3,... n

If the objective O_i has 't' upper sections in different levels in the objectives hierarchy, then the final weight of the objective w_i can be calculated using the formula below.

$$w_i = w_{i(subsection)} * \prod_{i=1}^{t} w_{section}^{(i)}$$ --- *Equation 21*

Where,

w_i - Final weight of the Objective O_i

$w_{section}^{(i)}$ - Weights of individual upper sections, it can be derived using the Equation 20, within the corresponding cluster of the hierarchy.

Step 7: Calculate the INF OBJ

The priority weights need to be converted into a rating scale for its easy usability in the fuzzy inference stage. Therefore, the experts suggested at first to equate the maximum priority weight with the maximum rating in the rating scale using a multipliable conversion constant (CC) in the equation.

$$r_{max} = w_{max} * CC$$ --- *Equation 22*

Where,

r_{max} - Maximum rating in the scale

w_{max} - Weight of the Objective O_{max}, which have the maximum priority weight among all the objectives

CC- Conversion Constant

Therefore the CC can be found using the equation

$$CC = \frac{r_{max}}{w_{max}}$$ --- *Equation 23*

The INF OBJ of individual objectives (i.e. Influence on the Objectives in a rating scale) can be found by multiplying the respective objective weights with the 'CC'. This can be defined as,

$$INF\ OBJ_i = w_i * CC$$ --- *Equation 24*

Where,

$INF\ OBJ_i$ - Influence on the Objective O_i

i = 1,2,3, … n.

w_i - Final priority weight of the Objective O_i

8.2.5.1.2 Objectives Impact

The experts selected linguistic rating scale linked with STFN to measure global sustainability objectives impact on the supply chain (OBJ IMP). The individual experts provide their linguistic preferences for the individual objectives; the corresponding STFN is then aggregated into a group STFN using the equation below.

$$\widetilde{OBJ\,IMP^{\iota}}_{agg} = (\widetilde{OBJ\,IMP^{\iota}}_{E1} \boxed{*} C_1) \boxplus (\widetilde{OBJ\,IMP^{\iota}}_{E2} \boxed{*} C_2) \boxplus \ldots \ldots \boxplus (\widetilde{OBJ\,IMP^{\iota}}_{Ek} \boxed{*} C_k)$$

--- Equation 25

Where,

$\widetilde{OBJ\,IMP^{\iota}}_{E1}, \widetilde{OBJ\,IMP^{\iota}}_{E2}, \ldots. \widetilde{OBJ\,IMP^{\iota}}_{Ek}$ - STFN values of the objective's impact for objectiveO_i measured by experts E1, E2, ...,Ek respectively.

$C_1, C_2, \ldots C_k$ - Contribution factors of the experts E1, E2,... ,Ek respectively.

i- 1, 2, 3,... n are the numbers of objective O_1, O_2, ... , O_n respectively.

$\boxed{*}$ - STFN multiplication operator

$\boxplus$ - STFN Addition operator

The aggregated STFN is then defuzzified into crisp value 'OBJ IMP' using the defuzzification equation (Equation 4), which is the final objective's impact for objective .

8.2.5.1.3 Objective Index

As discussed in the section 8.2.5.1 the objective index (OI) is the measurement proposed to consider global sustainability objectives from a corporate sustainability perspective. It is calculated using the fuzzy rule based system with two constructs "INF OBJ" and "OBJ IMP" which is discussed above. That can be defined as

$OI = f(INF\ OBJ, OBJ\ IMP)$ --- *Equation 26*

Figure 8.7 shows the objective index fuzzy system with its inputs and outputs. The experts give the rule base and fuzzy sets for the inputs and output.

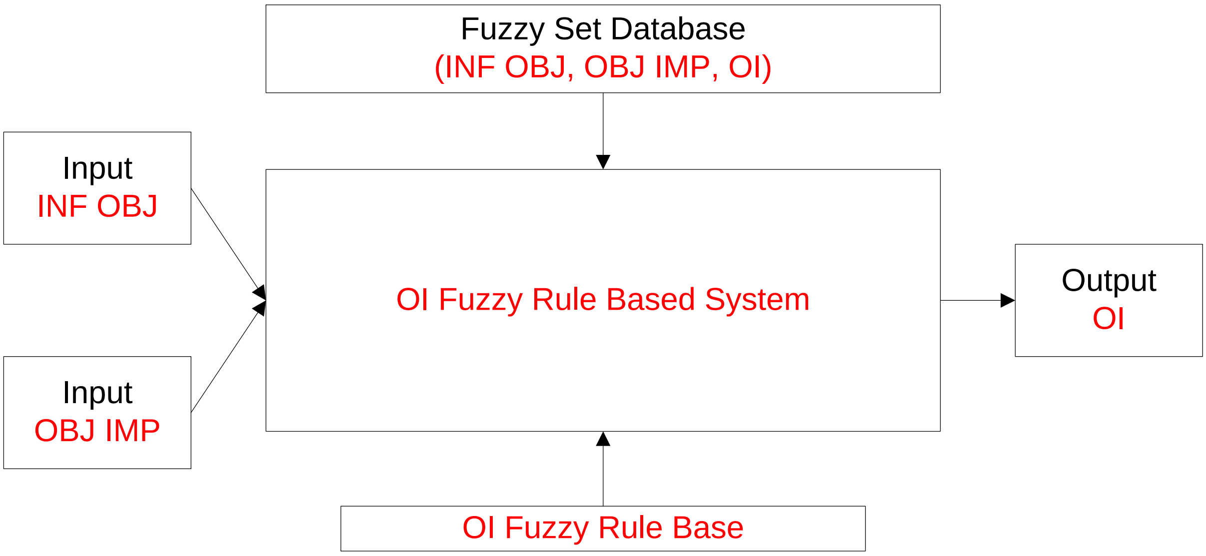

Figure 8.7: Objective Index Fuzzy System

8.2.5.2 Risk Severity& Risk Likelihood

Both the global sustainability risks (SUSR) and organisational sustainability risks (SCR) identified by the risk identification group are assessed using the two dimensions of the standard risk assessment approach namely, risk severity (RS) and risk likelihood (RL) (Waters, 2007). For the SUSR, the assessment was considered from the perspective of effect on the respective global sustainability objectives. For the SCR, it was assessed for the consequence to the organisational sustainability. SUSR and SCR both are measured by the individual experts using the linguistic variables associated with the fuzzy sets. Then they are aggregated using the following formula for risk severity (RS) and risk likelihood (RL) respectively, which is then defuzzified using the STFN defuzzification equation (Equation 4).

$\widetilde{RS}^{i}_{agg} = \left(\widetilde{RS}^{i}_{E1} \circledast C_1\right) \boxplus \left(\widetilde{RS}^{i}_{E2} \circledast C_2\right) \boxplus \ldots \ldots \boxplus \left(\widetilde{RS}^{i}_{Ek} \circledast C_k\right)$--- Equation 27

$\widetilde{RL}^{i}_{agg} = \left(\widetilde{RL}^{i}_{E1} \circledast C_1\right) \boxplus \left(\widetilde{RL}^{i}_{E2} \circledast C_2\right) \boxplus \ldots \ldots \boxplus \left(\widetilde{RL}^{i}_{Ek} \circledast C_k\right)$--- Equation 28

Where,

$\widetilde{RS}^{i}_{E1}, \widetilde{RS}^{i}_{E2}, \ldots$- STFN values of the risk severity for the risk measured by experts E1, E2...Ek respectively.

$\widetilde{RL}^{i}_{E1}, \widetilde{RL}^{i}_{E2}, \ldots$- STFN values of the risk likelihood for the risk measured by experts E1, E2... Ek respectively.

C_1, C_2, ... C_k- Contribution factors of the experts E1, E2 ...Ek respectively.

i- 1, 2, 3 ... n are the numbers of risk respectively.

8.2.5.3 Risk Magnitude

As discussed in the chapter 5, risk magnitude is the construct proposed to provide a value of significance for the risks (both organisational and global) from corporate sustainability perspective. As the experts preferred two different logical approaches for global sustainability and organisational sustainability, the risk magnitude is calculated using two separate fuzzy rule based systems for the respective risks. However, the final outputs of both the systems are mapped onto a common scale (i.e. risk magnitude) from corporate sustainability perspective.

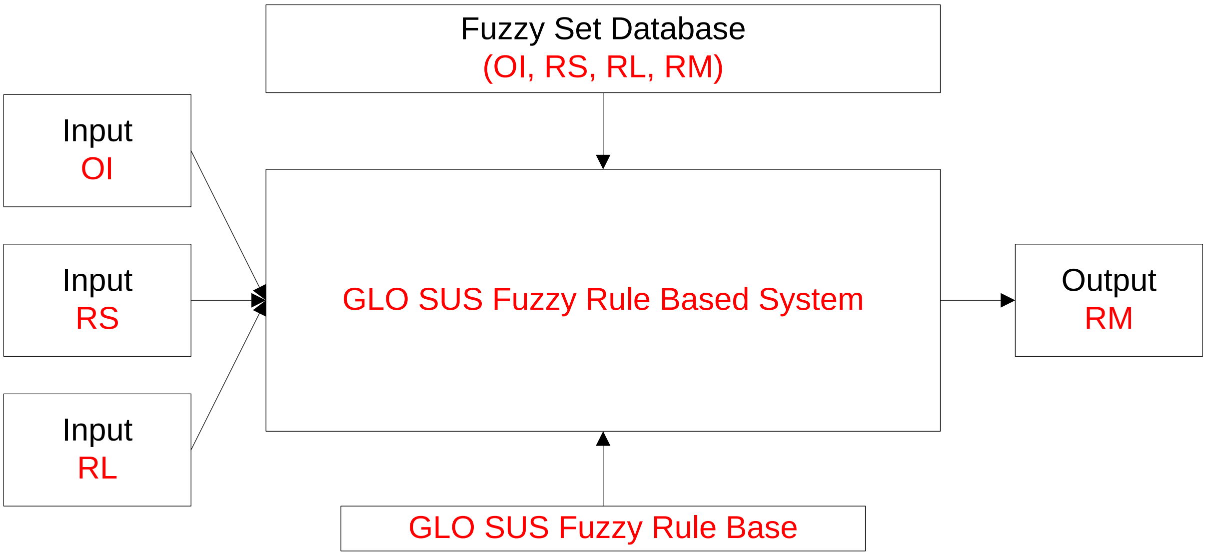

Figure 8.8: Global Sustainability - Risk Magnitude Fuzzy System

The assessment of global sustainability risks are mapped onto the risk magnitude scale using the fuzzy rule based system with three constructs they are global sustainability risks (SUSR) RS and RL and respective global sustainability objectives OI. Figure 8.8 shows the “global sustainability - risk magnitude fuzzy system” with its inputs and outputs. Experts gave the input and output “fuzzy sets” and its “rule base”. This fuzzy system function can be defined as

$RM^{susr} = f(SUSR - RS,\ SUSR - RL,\ SUSR - OI)$ --- *Equation 29*

Experts preferred a two construct fuzzy rule based system for measuring the risk magnitude for the organisational sustainability risks (SCR). The two input constructs are risk severity (RS) and risk likelihood (RL) of the organisational sustainability risks (SCR). Figure 8.9 represents the fuzzy rule based systems for organisational sustainability risks. Experts provided the rule base and fuzzy sets for the inputs and outputs. It can be represented in an equation form as below.

$RM^{scr} = f(SCR - RS, SCR - RL)$ --- *Equation 30*

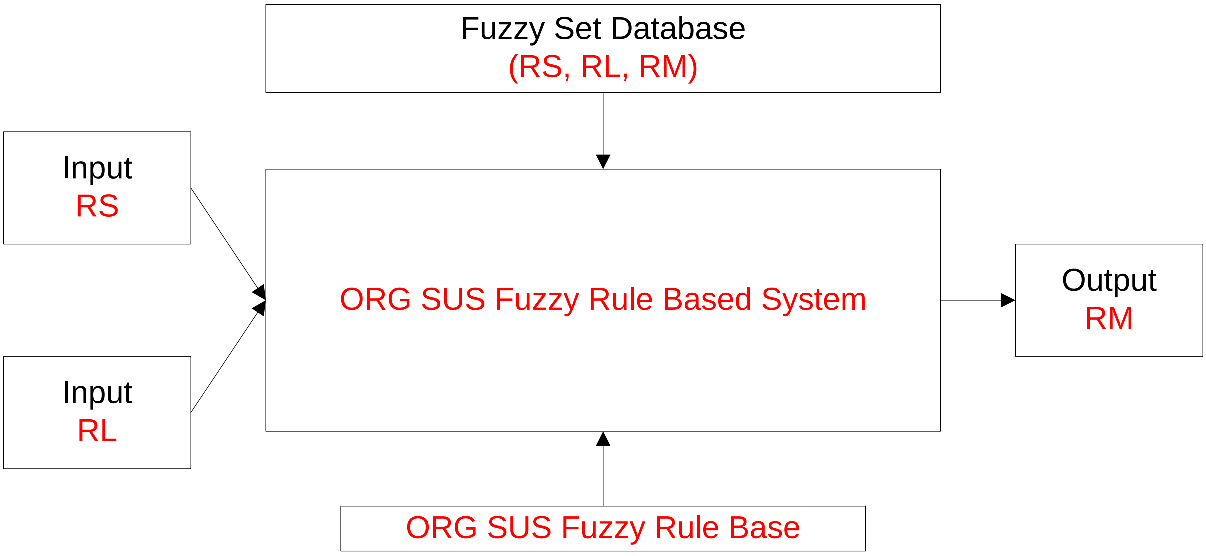

Figure 8.9: Organisational Sustainability - Risk Magnitude Fuzzy System

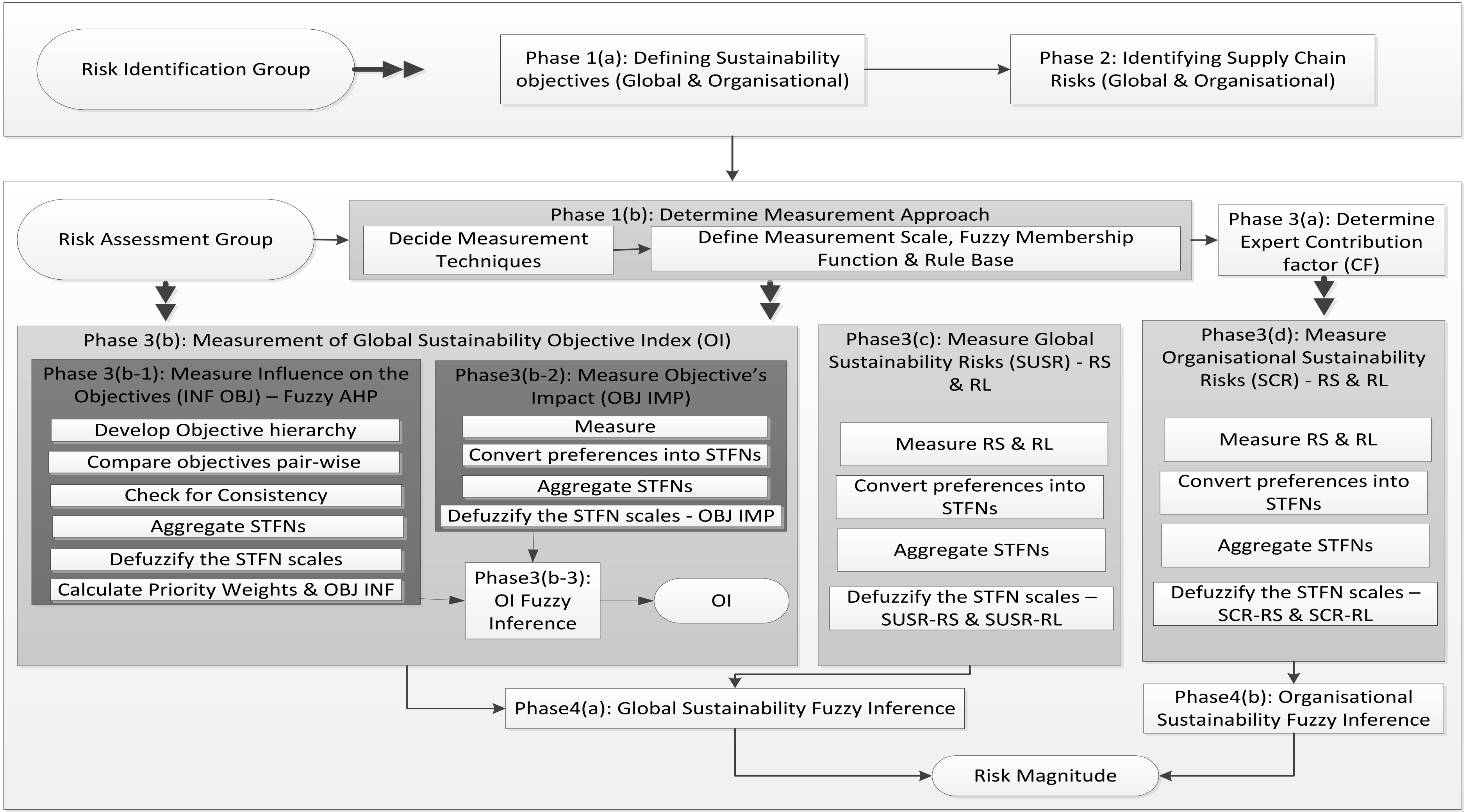

Figure 8.10: Scientific Model - Application of Framework in Practice

8.3 Application in ARC Project

The above-discussed model, based on the conceptual framework in Chapter 5, applied in the ARC project. This section describes firstly the case in detail, followed by the steps taken to apply the above-discussed ‘scientific model’, finding of the model in the real time project, verification of the results and finally implication of the findings on the project.

8.3.1 Project Description

Indian Institute of Technology, (IIT) Delhi, in India is the principal institution responsible for implementation of the ARC project, which is one of the work packages of the Science Bridge project. While School of Desert Science in Jodhpur, India a nongovernmental organisation (NGO) were selected as the partner responsible for operation and management of the project. Both the partners take strategic and tactical decisions of the business jointly. After careful analysis, Maloonga - a village in Western state of Rajasthan in India, selected as the location for the bioenergy plant. Keeping, the research interest to establish a tri-generation (i.e. electricity, heat and cold generating) plant, available budget for the plant and local market needs in mind, the initial system for the project was designed by the project owners. This initial design was analysed using the “sustainable supply chain risk analysis framework” for any sustainability risk. Based on that necessary changes made to the design of the system to avoid or mitigate the risks.

Figure 8.11 shows the initial design of the system. Prosopis Juliflora selected as the biomass feedstock for the bioenergy conversion system. The plan was to procure this raw material from the wood suppliers in Jodhpur (who purchase from farmers in the nearby districts). Then the plan was to transport and store it in the factory site, they have planned for an open storage system for biomass. Cutting and sizing are the pre-processing steps planned for the selected raw material. The plan was to carry out pre-processing and handling processes within the factory site manually. To get a grid electricity connection for auxiliary power requirements and for the use during plant maintenance, planned. Ground water was the planned source of water for all the operation in the factory. Bioenergy conversion system was planned with a boiler of approximately 2 MW thermal and 125 kVA turbine capacity. During the energy conversion process, the input water will be transformed into high-pressure steam in the boiler. Then the high-pressure steam will be utilized in the turbine to produce electricity and output low pressure steam is then supplied to the downstream industries for process heating and cooling. The electricity generated also planned to supply to the downstream industries.

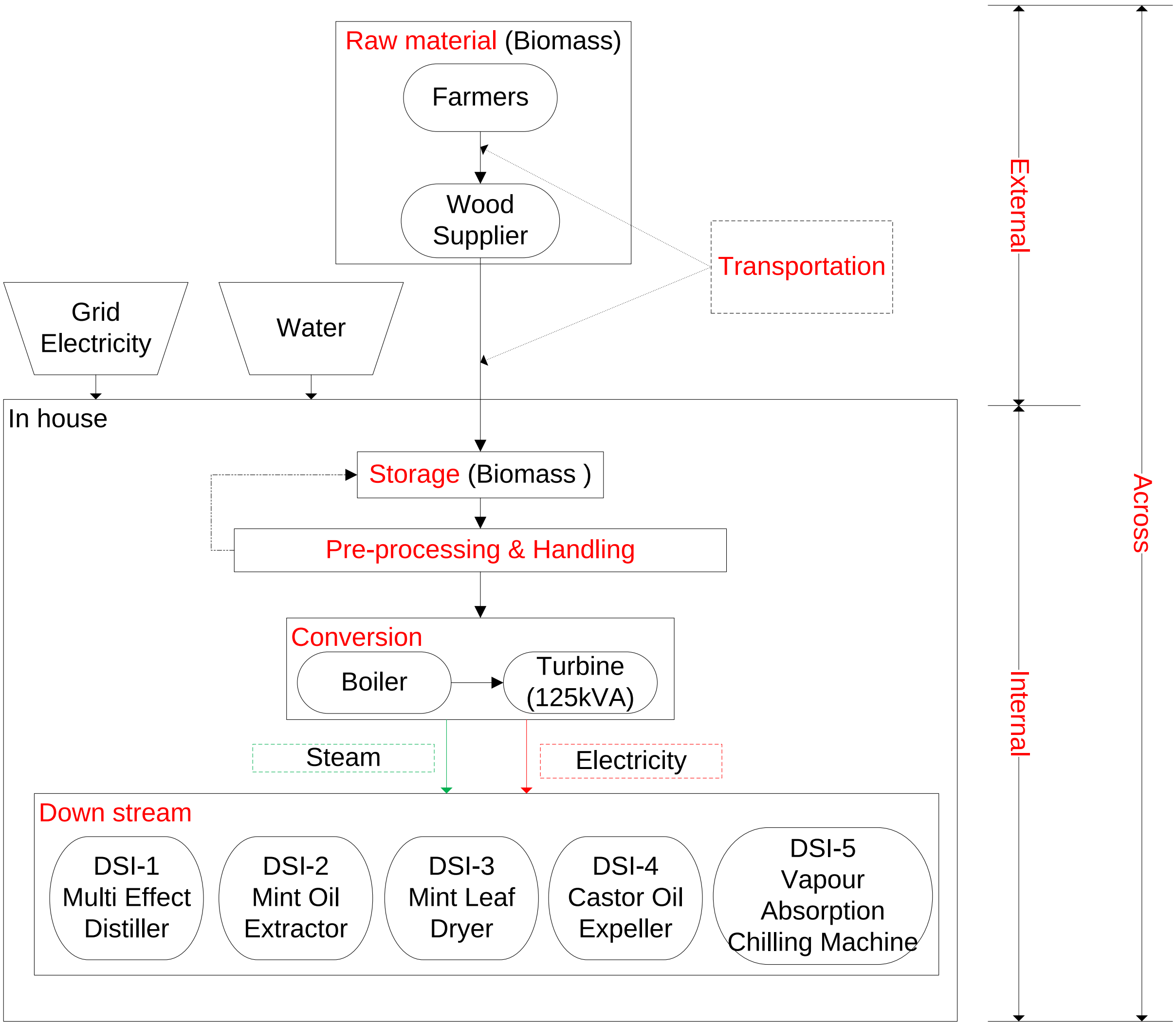

Figure 8.11: ARC Project - Initial System Design

Plan was to setup five downstream industries as a part of this project, which will use the electricity and steam produced in the conversion plant. The planned industries were multi effect distiller (DSI-1) to produce mineral water, mint oil extractor (DSI-2) to produce mint oil, mint leaf dryer (DSI-3) to produce mint leaf powder, castor oil expeller (DSI-4) to produce castor oil and vapour absorption chilling machine (DSI-5) for cold storage of fruits and vegetables. Most of the steam used in the production process of DSI-1, DSI-5 and DSI-4 industries.

The six important supply chain components of the bioenergy supply chain mentioned in chapter 4, namely raw material, transportation, storage, pre-processing & handling, conversion and downstream were used as the categorise of processes within the supply chain to identify the risks. In addition to that internal, external and across are also used as categorise within which the risk fall, where they represent all the processes in house (storage, pre-processing & handling, conversion and downstream), processes carried out by external supply chain members (raw material, transportation) and all the supply chain processes respectively. All of these categories of supply chain processes used for supply chain risk identification and classification depicted in red colour in the Figure 8.11.

8.3.2 Details of the Project Location

Understanding about the local context of the project is important to make the right decisions for the corporate sustainability, especially from global sustainability perspective. Therefore, this section describes some of the important information about the village, where the bioenergy plant is constructed. This information were collected through interviews with project stakeholders and gathered from census of India 2001 (Government of Rajasthan, 2012) and other government reports. This information provided to both the risk identification and risk assessment group of experts for them to make informed choices.

Maloonga, a rural village in Osian tehsil of Jodhpur district (which is a desert city) in the state of Rajasthan in India, was selected as a suitable location for the ARC project by the project owners in consultation with their partners. Availability of land, local socio-economic situation, proximity to a major city (37 km from Jodhpur city), established connections for the operating partner NGO (i.e. home advantage for the project partner) and downstream industries business opportunity are some of the important reasons for selecting the particular location. A government secondary school, a public health centre, a centrally located point base water supply, public transport system connected to district headquarter and power supply to the households are some of the facilities available in the village. The economy of the area is dependent on the mixed farming-cultivation plus animal husbandry, better known as subsistence economy. Most of the people in the village are involved in agriculture sector as either landowners or labours. The demographic information of the Maloonga village from 2001 census (Government of Rajasthan, 2012) is given in the Table 8.3.

Table 8.3: Demographic Information of the Maloonga Village

Detail	***Information***
Total Population	1661
Male	881
Female	780
Total Workforce Population	726
Main Workforce	488
Marginal Workforce	238
Total Village Land (in hectare)	2049
Irrigated (in hectare)	73
Un-irrigated (in hectare)	819

Detail	Information
Not for cultivation (in hectare)	985
Other (in hectare)	172
Number of Households	271
Percentage of Literacy (%)	26.37

8.3.3 Implementation

In this section, implementation of the framework in the ARC project is given.

8.3.3.1 Phase 1(a)

As discussed in the sections 8.2.1and 8.2.2 above the risk identification group identified relevant sustainability objectives for the action research project. Business continuity is the only prime organisational sustainability objective identified for the project by the experts. The expert group also identified seven environmental and five socio-economic objectives as the related global sustainability objectives for the project. The objectives identified for the project and their description is given in Table 8.4.

Table 8.4: Sustainability Objectives of the ARC Project

Objective Name	*Objective Description*	*Objective Number*
Global Sustainability - Environmental Objectives		
Atmosphere	Protect the atmosphere	E1
Water	Conserve the quality and quantity of water	E2
Soil	Conserve and improve the quality of soil	E3
Biodiversity	Conserve the biodiversity	E4
Land use change	Conserve the typical landscape elements	E5
Natural resource & Energy efficiency	Increase the efficient use of natural resources & energy	E6
Waste Management	Minimize the waste and support proper handling	E7
Global Sustainability - Socio-Economic Objectives		
Food security	Maintaining food security	S1
Labour working conditions	Improving labour working conditions	S2
Human rights	Protecting and promoting human rights	S3
Local prosperity & Social	Supporting local prosperity & social wellbeing	S4

Objective Name	Objective Description	Objective Number
wellbeing		
Employment generation	Creating employment	S5
Organisational Sustainability Objective		
Business continuity	Continuity of business operations	OSO

8.3.3.2 Phase 2

As shown in Figure 8.10, the risks that hinder attainment of the objectives is the sequential next step following the identification of relevant objectives. However, for some global sustainability risks initially the groups discussed about them as a risky event related to the project. Then the group considered if the objective related to that particular risk need to be taken into account or not. Following that, they identified other risks in connection with the objective across the supply chain. Therefore, the identification of the objectives and risks carried out simultaneously rather than sequentially in the ARC project. The experts identified the risks across various supply chain processes of the bioenergy industry as stated in section 8.3.1. The supply chain process where the risk can occur, risk event, related sustainable objective and the risk number, given in Table 8.5. The possible causes and consequences of the 'organisational sustainability risks' and 'global sustainability risks' identified by the expert group given in Appendix 1 and Appendix 2 respectively.

Table 8.5: Sustainable Supply Chain Risks

Sustainability Objective	Risk Event	Risk Number
Raw material		
Business continuity	Unavailability or shortage of the raw material	SCR01
Business continuity	Poor quality of the raw material	SCR02
Business continuity	Increase in the price of raw material	SCR03
Biodiversity	Allelopathic effect	SUSR01
Land use change	Land use conversion	SUSR02
Natural resource & Energy efficiency	Low Yield	SUSR03
Food security	Indirect effect on food security	SUSR04
Local prosperity & Social wellbeing	Fuel wood requirement for cooking	SUSR05
Local prosperity & Social wellbeing	Change in occupational pattern change	SUSR06

Sustainability Objective	***Risk Event***	***Risk Number***
Employment Generation	Potential indirect job loss	SUSR07
Transportation		
Business continuity	Delivery Failure	SCR04
Business continuity	Increase in the transportation cost of raw material	SCR05
Biodiversity	Spread of the seeds	SUSR08
Storage		
Business continuity	Unavailability of the storage space	SCR06
Business continuity	Storage imperfection	SCR07
Labour working conditions	Fire risk	SUSR09
Pre-Processing & Handling		
Business continuity	Pre-processing & Handling weakness	SCR08
Business continuity	Increase in the cost of pre-processing	SCR09
Conversion		
Business continuity	Community Objection	SCR10
Business continuity	Breakdown risk	SCR11
Business continuity	Low variation flexibility of heat & electricity mix ratio	SCR12
Business continuity	Low efficiency	SCR13
Business continuity	Risk from competition	SCR14
Business continuity	Increased Cost of operation	SCR15
Atmosphere	Untreated / poorly designed exhaust	SUSR10
Atmosphere	Greenhouse gas emissions	SUSR11
Water	Water availability & quality	SUSR12
Natural resource & Energy efficiency	Low conversion ratio	SUSR13
Waste management	Ash Disposal	SUSR14
Waste management	Dumping the heat in atmosphere	SUSR15
Consumer		
Business continuity	Technical risk	SCR16
Business continuity	Requirement fluctuation	SCR17
Business continuity	Demand risk	SCR18
Business continuity	Marketability risk	SCR19
Natural resource &	Transmission Losses	SUSR16

Sustainability Objective	Risk Event	Risk Number
Energy efficiency		
	Internal	
Business continuity	Regulatory risk	SCR20
Business continuity	Labour shortages (skilled)	SCR21
Human rights	Equal opportunity for women	SUSR17
	External	
Atmosphere	Indirect Greenhouse gas emissions	SUSR18
	Across	
Business continuity	Natural Disaster	SCR22
Natural resource & Energy efficiency	Increased energy consumption	SUSR19
Labour working conditions	Occupational Hazard	SUSR20

8.3.3.3 Phase 1 (b)

The appropriate measurement and mathematical techniques to apply the conceptual framework in ARC project selected in consultation with the 'risk assessment expert group' discussed in section 8.2.5. As discussed above in section 8.2.5 INF OBJ, OBJ IMP, RS, RL, OI and RM are the parameters used for the measurement in the risk analysis. The standards for these criteria that provided a basis for measurement discussed and agreed by the expert group members. The parameters INF OBJ, OBJ IMP, RS, RL, OI and RM are defined using trapezoidal MFs. Fuzzy AHP method is selected by the experts to evaluate the influence on the objectives (INF OBJ). The scale of relative importance used in the Fuzzy AHP method to calculate influence on the objectives is given in Table 8.6.

Table 8.6: Fuzzy AHP Scale of Relative Importance

Description	Regular	Fuzzy number	Inverse	Fuzzy number
Equal importance	1	(1,1,1,1)	1	(1,1,1,1)
	2	(1,2,2,3)	1/2	(1/3,1/2,1/2,1)
Moderate importance	3	(2,3,3,4)	1/3	(1/4,1/3,1/3,1/2)
	4	(3,4,4,5)	1/4	(1/5,1/4,1/4,1/3)
Strong Importance	5	(4,5,5,6)	1/5	(1/6,1/5,1/5,1/4)
	6	(5,6,6,7)	1/6	(1/7,1/6,1/6,1/5)
Very strong importance	7	(6,7,7,8)	1/7	(1/8,1/7,1/7,1/6)
	8	(7,8,8,9)	1/8	(1/9,1/8,1/8,1/7)
Extreme importance	9	(8,9,9,9)	1/9	(1/9,1/9,1/9,1/8)

Table 8.7: Fuzzy Measurement Scale

Description	***Regular***	***Fuzzy number***
Influence on the Objective (INF OBJ)		
Very Low (VL)	1	(0,1,1,2)
Low (L)	2	(1,2,2,3)
Medium (M)	3	(2,3,3,4)
High (H)	4	(3,4,4,5)
Very High (VH)	5	(4,5,5,5)
Impact of the Objective (OBJ IMP)		
No Impact (NI)	0	(0,0,0,1)
Very Low (VL)	1	(0,1,1,2)
Low (L)	2	(1,2,2,3)
Medium (M)	3	(2,3,3,4)
High (H)	4	(3,4,4,5)
Very High (VH)	5	(4,5,5,5)
Risk Severity (RS)		
Insignificant (VL)	1	(0,1,1,2)
Minor (L)	2	(1,2,2,3)
Moderate (M)	3	(2,3,3,4)
Major (H)	4	(3,4,4,5)
Catastrophic (VH)	5	(4,5,5,5)
Risk Likelihood (RL)		
Rare (VL)	1	(0,1,1,2)
Unlikely (L)	2	(1,2,2,3)
Possible (M)	3	(2,3,3,4)
Likely (H)	4	(3,4,4,5)
Almost certain (VH)	5	(4,5,5,5)
Objective Index (OI)		
Low (L)	1	(0, 0.5,1,1.5)
Medium (M)	2	(1,1.5,2,2.5)
High (H)	3	(2,2.5,3,3)
Risk Magnitude (RM)		
Very Low (VL)	1	(0,1,1,2)
Low (L)	2	(1,2,2,3)
Medium (M)	3	(2,3,3,4)

Description	Regular	Fuzzy number
High (H)	4	(3,4,4,5)
Very High (VH)	5	(4,5,5,5)

The linguistic terms and standard trapezoidal fuzzy number (STFN) of parameters INF OBJ, OBJ IMP, RS, RL, OI and RM agreed by the experts shown in

Table 8.7. The knowledge base of the rules to calculate the OI and RM (both RM^{susr}andRM^{scr}) are defined using the linguistic terms with the if- then rules by the experts.

For example:

- SUSR-OI rules - If OBJ IMP is **VH** and INF OBJ is **VH** then OI is **H**
- RM^{susr} rules - If OI is **M** and RS is **VH** and RL is **VH** then RM is **VH**
- RM^{scr} rules - If RS is **L** and RL is **M** then RM is **L**

The rule base to calculate the Global Sustainability Objective Index (SUSR-OI), Global Sustainability Risks (RM^{susr}) and Organisational Sustainability Risks (RM^{scr}) are given in Appendix 3, Appendix 4 and Appendix 5 respectively.

8.3.3.4 Phase 3 (a)

Five experts with vast experience and subject knowledge in the field selected to assess the risks. However, as discussed in section 8.2.3, different experts have different impact on the final decision. Therefore, a value of influence namely, contribution factors (CF) allocated to individual experts. CF assigned to the experts using an AHP based on the experts experience and influence on the outcome (Appendix 6). Table 8.8 shows the calculated CF values of the individual experts. However, the experts Et1, Et2 and Et3 discussed the issues as a group (EG1) and agreed a common value for individual factors. Therefore, all of them provided same assessment values for factors as inputs.

Table 8.8: Experts Contribution Factor

Expert	CF value
Et1	0.30
Et2	0.30
Et3	0.17
Et4	0.09
Et5	0.14

8.3.3.5 Phase 3 (b)

In this stage the Objective Index (OI) for the sustainability-objectives are calculated. As there is only one organisational sustainability objective identified for the ARC project and experts can relate those risks directly to the corporate sustainability, the OI calculated only for global sustainability. The OI calculated through three stages discussed below.

8.3.3.5.1 Measure Influence on the Objectives

The influence on the objectives (INF OBJ) is calculated by following the steps mentioned in section 8.2.5.1.1, which given below.

Step 1: Construct an Objectives Hierarchy

The risk assessment group have constructed an OI hierarchy. They have categorised global sustainability objectives into two group's namely environmental sustainability and socio-economic sustainability as shown in Figure 8.12.

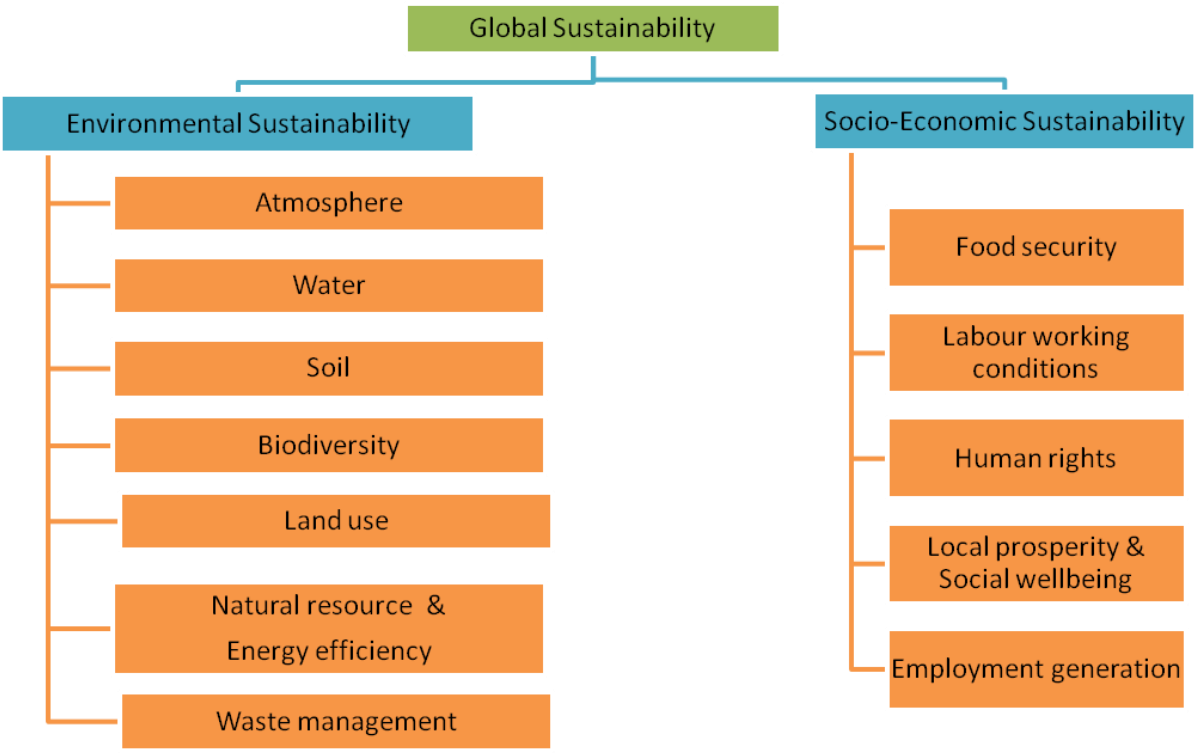

Figure 8.12: Objective Index Hierarchy

Step 2: Pair-wise Comparison of Objectives

Individual experts compared objectives pair-wise within the branches of the hierarchy using the 1-9 and inverse AHP scale. This then converted into FAHP matrix by using the agreed STFN values for the corresponding crisp values. Experts also compared environmental and social sustainability in the first level of hierarchy and provided their inputs. For example, crisp value AHP input for the environmental sustainability objectives and the corresponding FAHP with STFN values given by expert group EG1 given in Table 8.9 and Table 8.10 respectively.

Table 8.9: Environmental Sustainability Objectives AHP Input from EG1

Matrix	***E1***	***E2***	***E3***	***E4***	***E5***	***E6***	***E7***
E1	1	1	3	5	5	5	1
E2	1	1	3	5	5	5	3
E3	1/3	1/3	1	3	5	1/2	1/3
E4	1/5	1/5	1/3	1	3	1/3	1/5
E5	1/5	1/5	1/5	1/3	1	1/3	1/5
E6	1/5	1/5	2	3	3	1	1/3
E7	1	1/3	3	5	5	3	1

Table 8.10: Environmental Sustainability Objectives FAHP Input from EG1

Matrix	***E1***	***E2***	***E3***	***E4***	***E5***	***E6***	***E7***
E1	(1,1,1,1)	(1,1,1,1)	(2,3,3,4)	(4,5,5,6)	(4,5,5,6)	(4,5,5,6)	(1,1,1,1)
E2	(1,1,1,1)	(1,1,1,1)	(2,3,3,4)	(4,5,5,6)	(4,5,5,6)	(4,5,5,6)	(2,3,3,4)
E3	(1/4,1/3,1/3,1/2)	(1/4,1/3,1/3,1/2)	(1,1,1,1)	(2,3,3,4)	(4,5,5,6)	(1/3,1/2,1/2,1)	(1/4,1/3,1/3,1/2)
E4	(1/6,1/5,1/5,1/4)	(1/6,1/5,1/5,1/4)	(1/4,1/3,1/3,1/2)	(1,1,1,1)	(2,3,3,4)	(1/4,1/3,1/3,1/2)	(1/6,1/5,1/5,1/4)
E5	(1/6,1/5,1/5,1/4)	(1/6,1/5,1/5,1/4)	(1/6,1/5,1/5,1/4)	(1/4,1/3,1/3,1/2)	(1,1,1,1)	(1/4,1/3,1/3,1/2)	(1/6,1/5,1/5,1/4)
E6	(1/6,1/5,1/5,1/4)	(1/6,1/5,1/5,1/4)	(1,2,2,3)	(2,3,3,4)	(2,3,3,4)	(1,1,1,1)	(1/4,1/3,1/3,1/2)
E7	(1,1,1,1)	(1/4,1/3,1/3,1/2)	(2,3,3,4)	(4,5,5,6)	(4,5,5,6)	(2,3,3,4)	(1,1,1,1)

Step 3: Check for Consistency

The consistencies for individual expert inputs checked using Equation 15 and 16 given in section 8.2.5.1.1. The consistency ratio of different expert inputs on both environmental and socio-economic sustainability AHP's given in Table 8.11. Consistency ratio's less than 10% considered consistent. High inconsistencies found in one of the expert's inputs (Et5) shown in brackets within the table. Therefore, the expert asked to reassess their inputs and then the new values provided by him were consistent.

Table 8.11: Consistency Ratio

Experts	***Environmental Sustainability Consistency Ratio (CR)***	***Socio-economic Sustainability Consistency Ratio (CR)***
EG1	6.5 %	8.8 %
Et4	8.9 %	9.4 %
Et5	9.9% (38.6 %)	7.9% (18.5 %)

Step 4: Converting Individual Preferences into Group Preferences

The individual preferences converted into group preferences using the Equation 17, given in section 8.2.5.1.1. For example, the aggregation of objective E1 compared with E3 in FAHP, attained as shown below.

E1-E3' = (2,3,3,4)*0.30+ (2,3,3,4)*0.30+ (2,3,3,4)*0.17+ (1/6,1/5,1/5,1/4)*0.09+ (6,7,7,8)*0.14 = (2.4, 3.3, 3.3, 4.2)

Similarly, all the inputs are aggregated to form respective aggregated STFN pair wise comparison matrix.

Step 5: Defuzzify the STFN Scale

Following the aggregations, those aggregated STFN values are defuzzified using the Equation 4, which transform the STFN values into crisp values. For example, the aggregated value of E1 compared with E3 transformed into crisp value as shown below.

E1-E3 = (2.4+ (2*(3.3+3.3)) +4.2) /6 = 3.31

Similarly, all the inputs transformed to form respective crisp value pair wise comparison matrix. The environmental sustainability objectives defuzzified FAHP and socio-economic sustainability objectives defuzzified FAHP given in Table 8.12 and Table 8.13 respectively.

Table 8.12: Environmental Sustainability Objectives Defuzzified FAHP

	E1	***E2***	***E3***	***E4***	***E5***	***E6***	***E7***
E1	1.00	1.00	3.31	4.86	3.93	4.01	0.87
E2	1.00	1.00	3.38	4.64	4.31	4.36	2.54
E3	0.30	0.30	1.00	2.54	4.11	0.53	0.31
E4	0.21	0.22	0.39	1.00	2.48	0.38	0.19
E5	0.25	0.23	0.24	0.40	1.00	0.78	0.28
E6	0.25	0.23	1.89	2.63	1.28	1.00	0.37
E7	1.15	0.39	3.23	5.26	3.57	2.70	1.00

Table 8.13: Socio-Economic Sustainability Objectives Defuzzified FAHP

	S1	***S2***	***S3***	***S4***	***S5***
S1	1.00	3.60	3.60	4.40	1.40
S2	0.28	1.00	2.31	2.20	0.27
S3	0.28	0.43	1.00	1.25	0.26
S4	0.23	0.45	0.80	1.00	0.43
S5	0.71	3.70	3.85	2.33	1.00

Step 6: Calculate the Priority Weights of the Objectives

Priority weights of the objectives, calculated using the Equation 20. Then these priority weights as given in Equation 21 are multiplied with the priority weights (importance) of the upper hierarchy (objective group), namely environmental and socio-economic sustainability respectively to find the final priority weight of the objectives. Following the Step 4 and Step 5, the weights of environmental and socio-economic sustainability calculated which is 0.45 and 0.55 respectively.

Table 8.14 shows the initial and final 'priority weights of the objectives'.

Table 8.14: Priority Weights

Objective	***Priority weight***	***Objective Group Importance (E/S)***	***Final Priority weight***
E1	0.24	0.45	0.11
E2	0.28	0.45	0.13
E3	0.09	0.45	0.04
E4	0.05	0.45	0.02
E5	0.05	0.45	0.02
E6	0.08	0.45	0.04
E7	0.20	0.45	0.09
S1	0.37	0.55	0.20
S2	0.14	0.55	0.08
S3	0.07	0.55	0.04
S4	0.09	0.55	0.05
S5	0.33	0.55	0.18

Step 7: Calculate the INF OBJ

The conversion constant (CC) value is 24.64, calculated by using the Equation 23, where 'Food security' identified as the objective with utmost priority. Then from the 'final priority weight', the 'influence of objectives' (INF OBJ) calculated using Equation 24, as shown in Table 8.15.

Table 8.15: Influence on the Objective

Objective No	Objective	INF OBJ
E1	Atmosphere	2.60
E2	Water	3.13
E3	Soil	1.02
E4	Biodiversity	0.59
E5	Land use change	0.51
E6	Natural resource & Energy efficiency	0.93
E7	Waste Management	2.25
S1	Food security	5.00
S2	Labour working conditions	1.94
S3	Human rights	1.01
S4	Local prosperity & Social wellbeing	1.16
S5	Employment generation	4.49

8.3.3.5.2 Measure Impact of the Objective (OBJ IMP)

The experts provided their choice of linguistic term from the scale given in

Table 8.7 as a measurement of individual objective's impact on the corporate sustainability (OBJ IMP). These linguistic measurement values converted into appropriate STFN values. These individual STFN values then aggregated using Equation 25 and defuzzified using Equation 4 to get the final impact of the individual objectives, this given in Table 8.16.

For example, the aggregation and defuzzification of STFN values in order to calculate the OBJ IMP for E1 as given below.

OBJ IMP - E1' = (1,2,2,3)*0.30+ (1,2,2,3)*0.30+ (1,2,2,3)*0.17+ (1,2,2,3)*0.09+ (2,3,3,4)*0.14 = (1.14, 2.14, 2.14, 3.14)

OBJ IMP - E1 = (1.14+ (2*(2.14+2.14)) +3.14)/6 = 2.14

Table 8.16: Impact of the Objective

Objective No	Objective	OBJ IMP
E1	Atmosphere	2.14
E2	Water	2.40
E3	Soil	2.05
E4	Biodiversity	1.37

Objective No	Objective	OBJ IMP
E5	Land use change	0.68
E6	Natural resource & Energy efficiency	1.37
E7	Waste Management	3.14
S1	Food security	0.64
S2	Labour working conditions	0.64
S3	Human rights	0.73
S4	Local prosperity & Social wellbeing	1.69
S5	Employment generation	0.91

8.3.3.5.3 Objective Index Fuzzy Inference

The objective index (OI) of the global sustainability objectives are calculated using the two constructs namely Influence on the Objective (INF OBJ) and Impact of the Objective (OBJ IMP) using a fuzzy rule based system in Matlab software. The fuzzy rule base for OI is defined by the experts this is given in Appendix 3. Firstly, the fuzzy system created in Matlab with two inputs and one output, as shown in Figure 8.13. Secondly, the membership functions of the variables defined using the defined STFN values. The membership functions of the output OI shown in Figure 8.14. Then the expert defined rules serve as input for the rule base. 'Surface view of the OI rule base' shown in Figure 8.15. Based on the rules and input from INF OBJ and OBJ IMP the OI of the objectives are calculated, this given in Table 8.17.

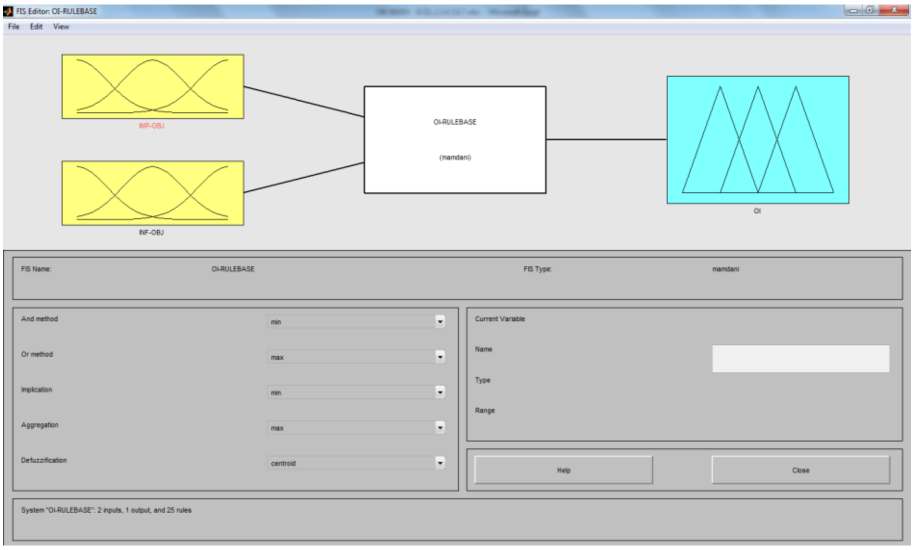

Figure 8.13: OI Fuzzy Rule Based System

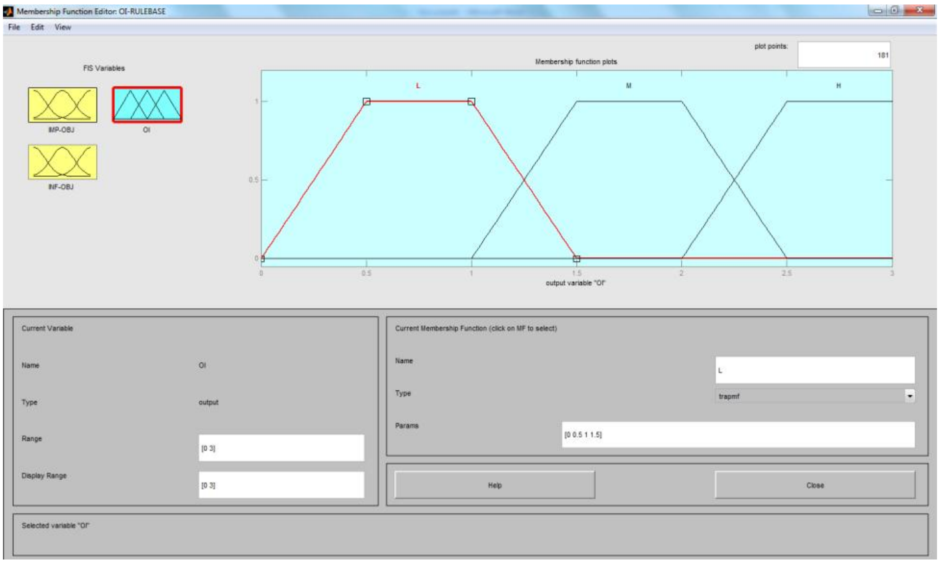

Figure 8.14: OI Membership Functions

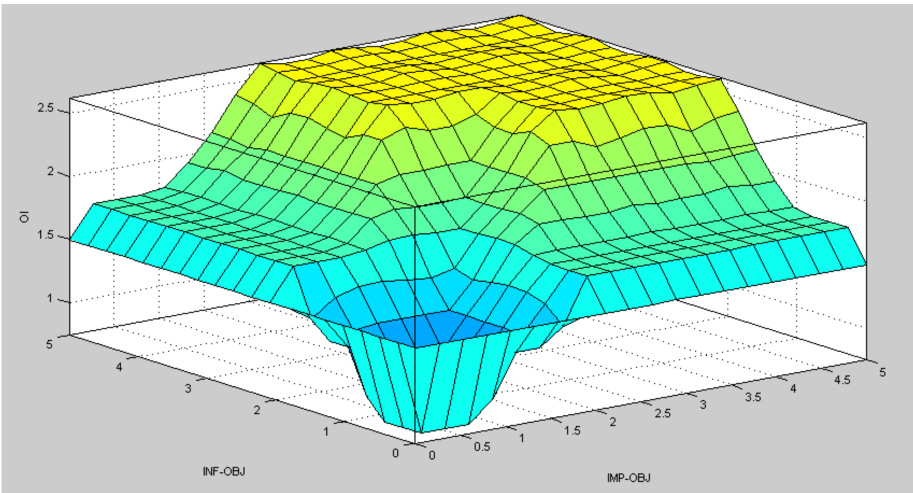

Figure 8.15: OI Rule Base Surface View

Table 8.17: Objective Index

Objective No	**Objective**	**OI**
E1	Atmosphere	2.15
E2	Water	2.58
E3	Soil	1.76
E4	Biodiversity	1.15
E5	Land use change	0.75
E6	Natural resource & Energy efficiency	1.13
E7	Waste Management	2.59
S1	Food security	1.75

Objective No	**Objective**	**OI**
S2	Labour working conditions	1.66
S3	Human rights	0.77
S4	Local prosperity & Social wellbeing	1.42
S5	Employment generation	1.75

8.3.3.6 Phase 3(c)

Experts provided the risk severity (RS) and risk likelihood (RL) values as linguistic terms for the different risks that can affect the global sustainability objectives. Group preference is obtained by aggregating the STFN's corresponding to the linguistic terms using Equation 27 and Equation 28 respectively for RS and RL. Then they are defuzzified using Equation 4. For example, the risk event "Allelopathic effect's" (SUSR01) RS and RL aggregated and defuzzified as shown below.

SUSR01-RS' = (2,3,3,4)*0.30+ (2,3,3,4)*0.30+ (2,3,3,4)*0.17+ (3,4,4,5)*0.09+ (2,3,34)*0.14 = (2.09,3.09,3.09,4.09)

SUSR01-RS = (2.09+ (2*(3.09+3.09)) +4.09)/6 =3.09

SUSR01-RL' = (2,3,3,4)*0.30+ (2,3,3,4)*0.30+ (2,3,3,4)*0.17+ (2,3,3,4)*0.09+ (2,3,34)*0.14 = (2,3,3,4)

SUSR01-RL = (2+ (2*(3+3)) +4)/6 =3

The global sustainability risks severity and likelihood given in Table 8.18.

Table 8.18: Global Sustainability Risks Severity and Likelihood

Risk Event	*RISK NUMBER*	*RS*	*RL*
Allelopathic effect	SUSR01	3.09	3.00
Land use conversion	SUSR02	2.86	3.00
Low Yield	SUSR03	2.91	2.68
Indirect effect on food security	SUSR04	1.18	1.91
Fuel wood requirement for cooking	SUSR05	1.32	2.00
Change in occupational pattern change	SUSR06	1.18	2.18
Potential indirect job loss	SUSR07	1.09	1.32
Spread of the seeds	SUSR08	2.04	2.09
Fire risk	SUSR09	1.60	2.14
Untreated / poorly designed exhaust	SUSR10	2.46	1.51
Greenhouse gas emissions	SUSR11	1.46	1.60
Water availability & quality	SUSR12	3.31	3.00
Low conversion ratio	SUSR13	1.51	1.60

Risk Event	***RISK NUMBER***	***RS***	***RL***
Ash Disposal	SUSR14	2.46	2.49
Dumping the heat in atmosphere	SUSR15	2.96	3.00
Transmission Losses	SUSR16	1.51	1.46
Equal opportunity for women	SUSR17	2.37	1.51
Indirect Greenhouse gas emissions	SUSR18	1.60	1.60
Increased energy consumption	SUSR19	1.46	1.46
Occupational Hazard	SUSR20	3.23	3.05

8.3.3.7 Phase 3(d)

In a similar way the risk severity (RS) and risk likelihood (RL) values for organisational sustainability risks are calculated, this given in Table 8.19.

Table 8.19: Organisational Sustainability Risks Severity and Likelihood

Risk Event	***RISK Number***	***Severity***	***Likelihood***
Unavailability or shortage of the raw material	SCR01	3.86	3.77
Poor quality of the raw material	SCR02	2.05	2.05
Increase in the price of raw material	SCR03	3.23	3.23
Delivery Failure	SCR04	2.77	2.68
Increase in the transportation cost of raw material	SCR05	2.81	2.72
Unavailability of the storage space	SCR06	1.23	2.09
Storage imperfection	SCR07	2.28	2.37
Pre-processing & Handling weakness	SCR08	2.28	2.37
Increase in the cost of pre-processing	SCR09	2.37	1.60
Community Objection	SCR10	1.46	1.46
Breakdown risk	SCR11	3.00	2.23
Low variation flexibility of heat & electricity mix ratio	SCR12	2.04	1.95
Low efficiency	SCR13	2.37	1.60
Risk from competition	SCR14	1.32	1.23
Increased Cost of operation	SCR15	1.37	1.46
Technical risk	SCR16	1.60	1.60

Risk Event	*RISK Number*	*Severity*	*Likelihood*
Requirement fluctuation	SCR17	1.86	1.95
Demand risk	SCR18	2.09	1.32
Marketability risk	SCR19	2.28	2.37
Regulatory risk	SCR20	3.05	3.05
Labour shortages (skilled)	SCR21	3.17	3.26
Natural Disaster	SCR22	2.63	1.86

8.3.3.8 Phase 4(a)

The risk magnitude of the global sustainability risks are calculated using a fuzzy rule based system in Matlab with 3 input variables namely OI, RS and RL, this is shown in Figure 8.16. The OI, RS and RL values for individual risks serve as inputs to find out the corresponding risk magnitude (RM) based on the rules defined by the experts, given in Appendix 4. Risk magnitude of all the 'global sustainability risks' given in Table 8.20.

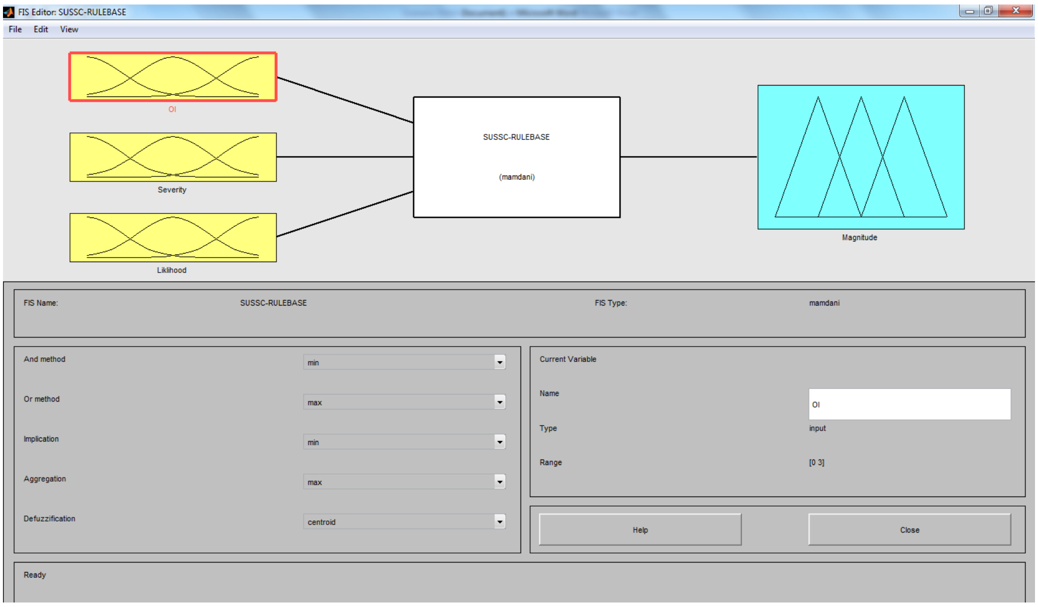

Figure 8.16: Global Sustainability Risks Fuzzy Rule Based System

Table 8.20: Global Sustainability Risks - Risk Magnitude

Risk Event	*Risk Number*	*OI*	*Severity*	*Likelihood*	*Magnitude*
Allelopathic effect	SUSR01	1.15	3.09	3.00	1.72
Land use conversion	SUSR02	0.75	2.86	3.00	1.00
Low Yield	SUSR03	1.13	2.91	2.68	1.69
Indirect effect on food security	SUSR04	1.75	1.18	1.91	1.00
Fuel wood requirement for cooking	SUSR05	1.42	1.32	2.00	1.00
Change in occupational pattern change	SUSR06	1.42	1.18	2.18	1.00
Potential indirect job loss	SUSR07	1.75	1.09	1.32	1.00
Spread of the seeds	SUSR08	1.15	2.04	2.09	1.16
Fire risk	SUSR09	1.66	1.60	2.14	1.00
Untreated / poorly designed exhaust	SUSR10	2.15	2.46	1.51	1.85
Greenhouse gas emissions	SUSR11	2.15	1.46	1.60	1.80
Water availability & quality	SUSR12	2.58	3.31	3.00	4.05
Low conversion ratio	SUSR13	1.13	1.51	1.60	1.00
Ash Disposal	SUSR14	2.59	2.46	2.49	3.48
Dumping the heat in atmosphere	SUSR15	2.59	2.96	3.00	3.94
Transmission Losses	SUSR16	1.13	1.51	1.46	1.00
Equal opportunity for women	SUSR17	0.77	2.37	1.51	1.00
Indirect Greenhouse gas emissions	SUSR18	2.15	1.60	1.60	1.77
Increased energy consumption	SUSR19	1.13	1.46	1.46	1.00
Occupational Hazard	SUSR20	1.66	3.23	3.05	3.07

8.3.3.9 Phase 4(b)

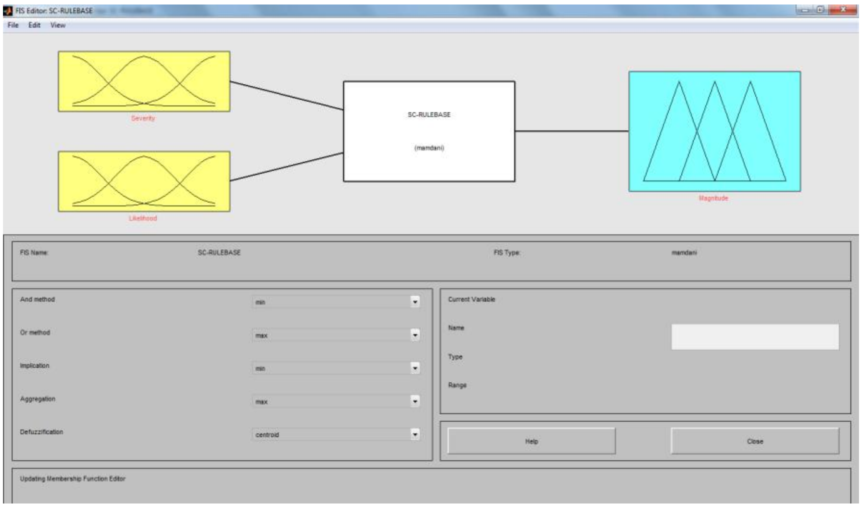

Figure 8.17: Organisational Sustainability Risks Fuzzy Rule Based System

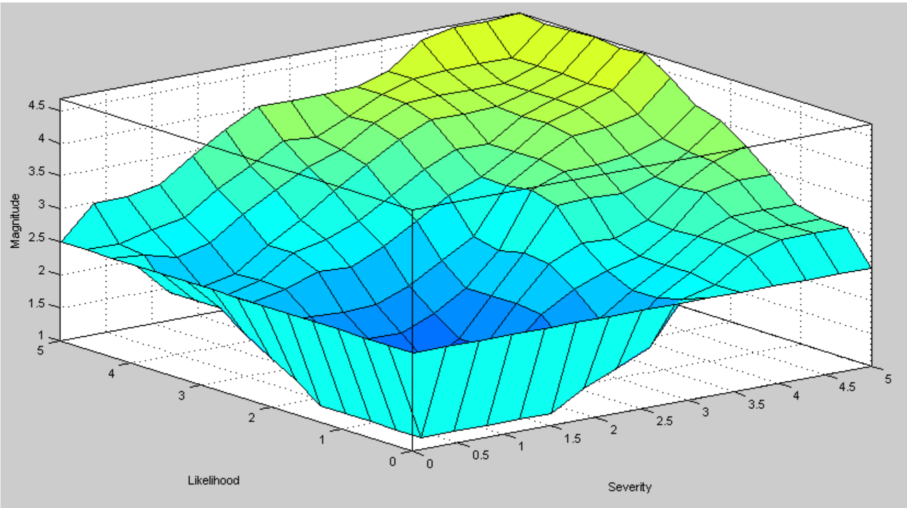

Figure 8.18: Organisational Sustainability Risks - Rule Base Surface View

For the organisational sustainability risks, two input variables namely RS and RL based fuzzy rule based system used to calculate risk magnitudes of individual risks in Matlab software, as shown in Figure 8.17. The rules defined by experts given in Appendix 5and the surface view of the rules shown in Figure 8.18. Risk magnitude of the 'organisational sustainability risks' given in Table 8.21.

Table 8.21: Organisational Sustainability Risks - Risk Magnitude

Risk Event	*RISK Number*	*Severity*	*Likelihood*	*Magnitude*
Unavailability or shortage of the raw material	SCR01	3.86	3.77	3.82
Poor quality of the raw material	SCR02	2.05	2.05	2.07
Increase in the price of raw material	SCR03	3.23	3.23	3.27
Delivery Failure	SCR04	2.77	2.68	2.72
Increase in the transportation cost of raw material	SCR05	2.81	2.72	2.76
Unavailability of the storage space	SCR06	1.23	2.09	1.27
Storage imperfection	SCR07	2.28	2.37	2.33
Pre-processing & Handling weakness	SCR08	2.28	2.37	2.33
Increase in the cost of pre-processing	SCR09	2.37	1.60	2.40
Community Objection	SCR10	1.46	1.46	1.47
Breakdown risk	SCR11	3.00	2.23	3.00
Low variation flexibility of heat & electricity mix ratio	SCR12	2.04	1.95	2.06
Low efficiency	SCR13	2.37	1.60	2.40
Risk from competition	SCR14	1.32	1.23	1.35
Increased Cost of operation	SCR15	1.37	1.46	1.42
Technical risk	SCR16	1.60	1.60	1.58
Requirement fluctuation	SCR17	1.86	1.95	1.82
Demand risk	SCR18	2.09	1.32	2.13
Marketability risk	SCR19	2.28	2.37	2.33
Regulatory risk	SCR20	3.05	3.05	3.07
Labour shortages (skilled)	SCR21	3.17	3.26	3.30
Natural Disaster	SCR22	2.63	1.86	2.61

8.3.3.10 Risk Magnitude

Risk magnitude of all the organisational and global sustainability risks given in Table 8.22. It also provides information about the supply chain process, where the risk event can occur.

Table 8.22: Risk Magnitude

Supply chain process	***Risk Event***	***RISK Number***	***RM***
Raw material	Unavailability or shortage of the raw material	SCR01	3.82
Raw material	Poor quality of the raw material	SCR02	2.07
Raw material	Increase in the price of raw material	SCR03	3.27
Raw material	Allelopathic effect	SUSR01	1.72
Raw material	Land use conversion	SUSR02	1
Raw material	Low Yield	SUSR03	1.69
Raw material	Indirect effect on food security	SUSR04	1
Raw material	Fuel wood requirement for cooking	SUSR05	1
Raw material	Change in occupational pattern change	SUSR06	1
Raw material	Potential indirect job loss	SUSR07	1
Transportation	Delivery Failure	SCR04	2.72
Transportation	Increase in the transportation cost of raw material	SCR05	2.76
Transportation	Spread of the seeds	SUSR08	1.16
Storage	Unavailability of the storage space	SCR06	1.27
Storage	Storage imperfection	SCR07	2.33
Storage	Fire risk	SUSR09	1
Pre-Processing & Handling	Pre-processing & Handling weakness	SCR08	2.33
Pre-Processing & Handling	Increase in the cost of pre-processing	SCR09	2.4
Conversion	Community Objection	SCR10	1.47
Conversion	Breakdown risk	SCR11	3
Conversion	Low variation flexibility of heat & electricity mix ratio	SCR12	2.06
Conversion	Low efficiency	SCR13	2.4
Conversion	Risk from competition	SCR14	1.35
Conversion	Increased Cost of operation	SCR15	1.42
Conversion	Untreated / poorly designed exhaust	SUSR10	1.85
Conversion	Greenhouse gas emissions	SUSR11	1.8
Conversion	Water availability & quality	SUSR12	4.05
Conversion	Low conversion ratio	SUSR13	1
Conversion	Ash Disposal	SUSR14	3.48
Conversion	Dumping the heat in atmosphere	SUSR15	3.94
Consumer	Technical risk	SCR16	1.58
Consumer	Requirement fluctuation	SCR17	1.82
Consumer	Demand risk	SCR18	2.13
Consumer	Marketability risk	SCR19	2.33
Consumer	Transmission Losses	SUSR16	1
Internal	Regulatory risk	SCR20	3.07
Internal	Labour shortages (skilled)	SCR21	3.3
Internal	Equal opportunity for women	SUSR17	1
External	Indirect Greenhouse gas emissions	SUSR18	1.77
Across	Natural Disaster	SCR22	2.61

Supply chain process	***Risk Event***	***RISK Number***	***RM***
Across	Increased energy consumption	SUSR19	1
Across	Occupational Hazard	SUSR20	3.07

8.3.4 Verification of Results

The obtained results substantiated further by testing the impact on results by varying some of the important parameters of the model. The verification part has six scenarios in total, in addition to the main results scenario. Three main methods of testing were used namely, Range Sensitivity Analysis, Expert Importance and Individual Experts. The details of the different scenarios to verify the results given in Table 8.23, which is further explained in sections below.

Table 8.23: Scenarios to Verify the Results

Method of Testing	***Scenario Number***	***Expert Contribution factor (CF)***	***Sensitivity***
Main	Sce1	AHP	-
Range Sensitivity Analysis	Sce2	AHP	Positive Delta 0.5
	Sce3	AHP	Negative Delta 0.5
Expert Importance	Sce4	Equal Importance	-
Individual Experts	Sce5	EG1	-
	Sce6	Et4	-
	Sce7	Et5	-

8.3.4.1 Range Sensitivity Analysis

"Sensitivity analysis is concerned with understanding how changes in the inputs x influence the output y" (Oakley & O'Hagan, 2004, p. 751). In range sensitivity analysis, the ranges of the input variables altered to see the impact on the output. In this method, the ranges of fuzzy input variables changed to see the impact on the outcome. This helps to verify the strength of the fuzzy input range selected in this case. This verification process conducted using two scenarios namely Sce2 and Sce3. In Sce2, the fuzzy input range increased by moving both upper and lower limits outside by 0.5. In Sce3, the fuzzy range decreased by moving both upper and lower limits inside by 0.5. Input range of both of these scenarios shown in Figure 8.19. For example, the regular, positive and negative input fuzzy value for the linguistic term 'Minor' to measure risk severity given in Table 8.24.

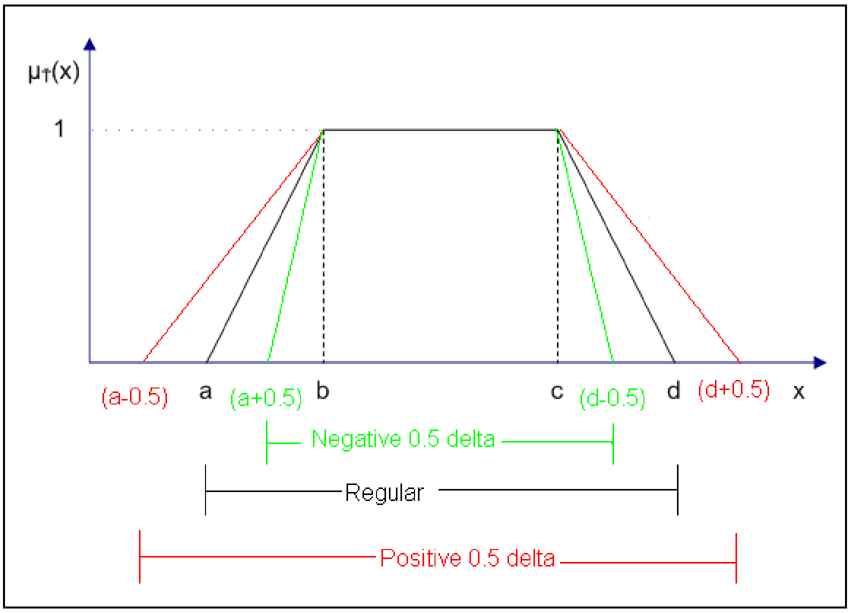

Figure 8.19: Fuzzy Input Range

Table 8.24: Fuzzy Range Sensitivity Input Values - Example

Input	***Regular Fuzzy***	***Positive Delta 0.5***	***Negative Delta 0.5***
Risk Severity - Minor (L)	(1,2,2,3)	(0.5,2,2,3.5)	(1.5,2,2,2.5)

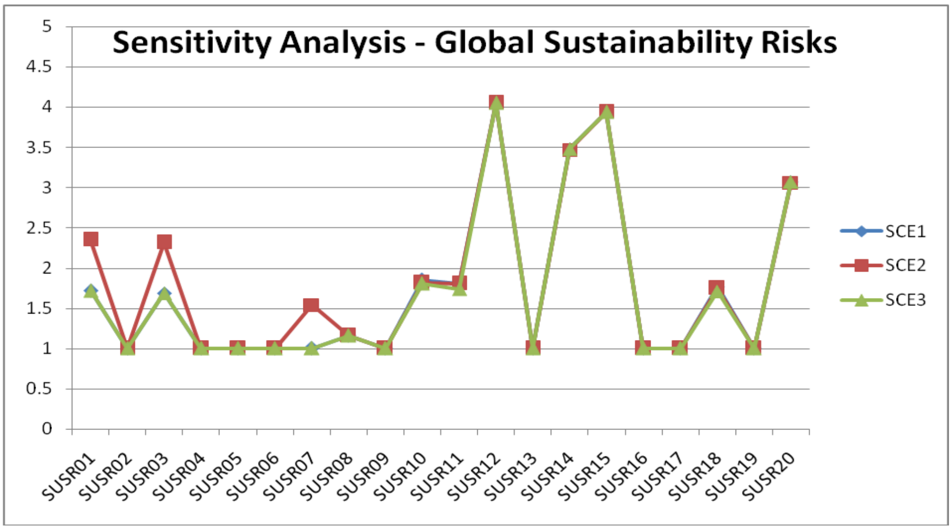

Figure 8.20: Range Sensitivity Analysis - Global Sustainability Risks

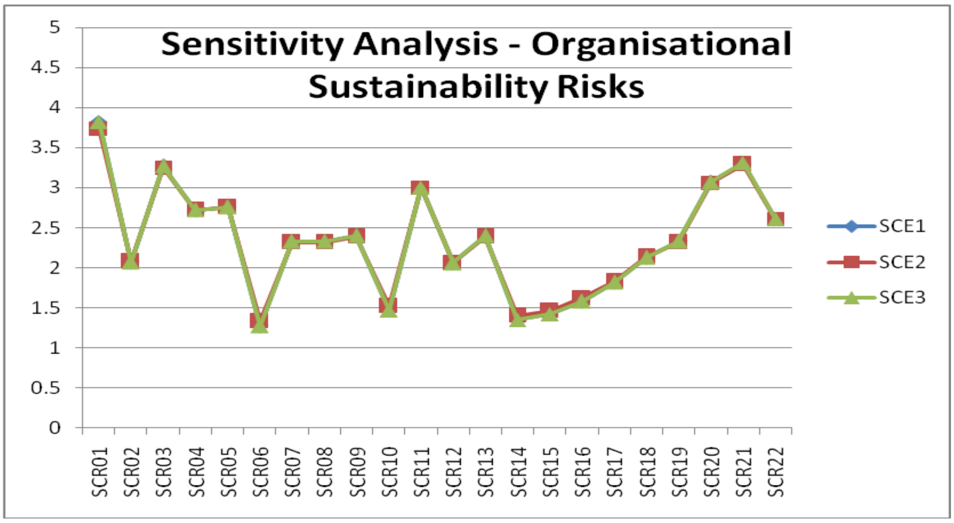

Figure 8.21: Range Sensitivity Analysis - Organisational Sustainability Risks

The main (Sce1), Sce2 and Sce3 risk magnitude outputs of global and organisational sustainability risks plotted graphically in Figure 8.20 and Figure 8.21 respectively. In both of the graphs, it can be seen that Sce3 outputs very closely coincide with Sce1 results and except 3 global sustainability risks all Sce2 outputs also coincide with Sce1 results. Overall, the variance of outputs when comparing Sce1 with Sce2 and Sce3 is very small and does not show any significant change in the results. This confirms the rigidity of the fuzzy input range used in the model and its appropriateness for the model.

8.3.4.2 Expert Importance

In this method of verification, expert's contribution factor (CF) has been varied to see the impact on the outcomes. In the main scenario (Sce1), individual expert's contribution factor is decided using an AHP based on their experience and influence on the project. While, in Sce4 all the expert's considered to be equal and all the expert's given equal contribution factor.

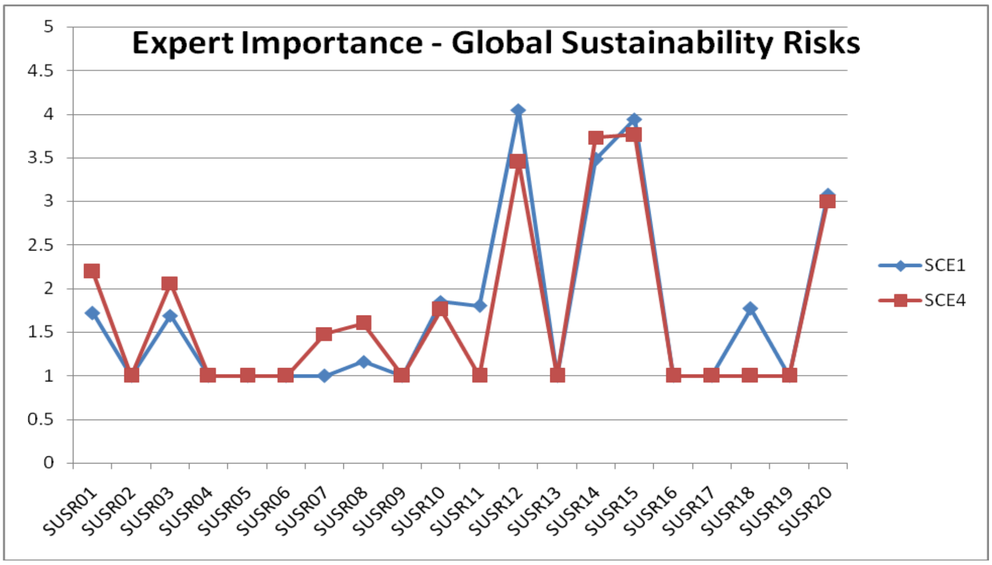

Figure 8.22: Expert Importance - Global Sustainability Risks

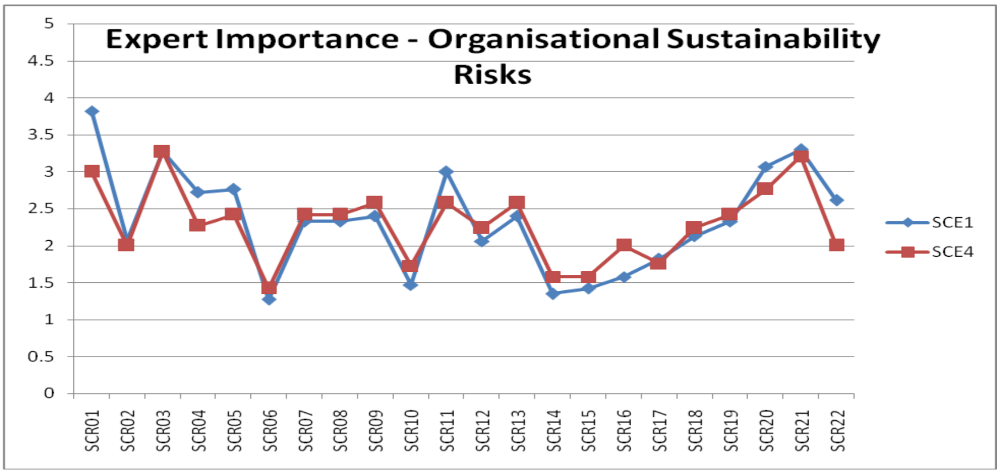

Figure 8.23: Expert Importance - Organisational Sustainability Risks

Figure 8.22 and Figure 8.23 shows the risk magnitudes of global and organisational sustainability risks respectively. The figures show the scenarios Sce1 and Sce4 outputs. There is a small variation in outputs in both the scenarios, which is due to the change in expert's importance where they have different estimation for input parameters. This shows the significance of the 'expert's contribution factor' in the model. However, the choice of Sce1 in this model is justified, because of the following two reasons.

- Most of the variations are very small. None of the risks final magnitude value difference is more than one between these two scenarios.
- In the ARC project, 'expert importance' based on their experience and influence on the project provides the outcomes of the model, which are more practical and reflects the real view of the organisation.

8.3.4.3 Individual Experts

In this step, the outputs calculated separately based on individual expert's preferences namely EG1, Et4 and Et5 in Sce5, Sce6 and Sce7 respectively. These three scenarios global and organisational sustainability risks outputs plotted along with the main scenario (Sce1) outputs to compare in Figure 8.24and Figure 8.25 respectively.

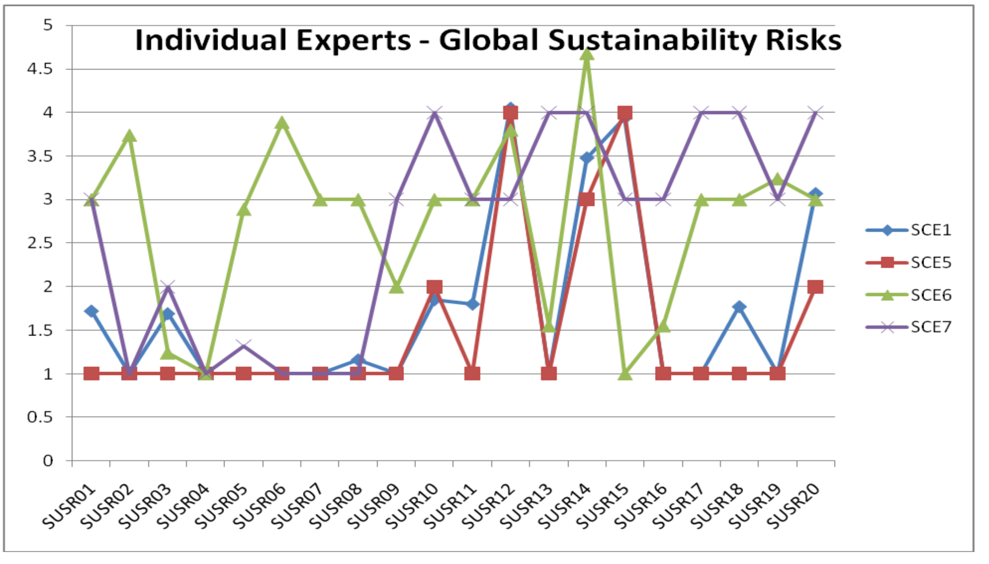

Figure 8.24: Individual Experts - Global Sustainability Risks

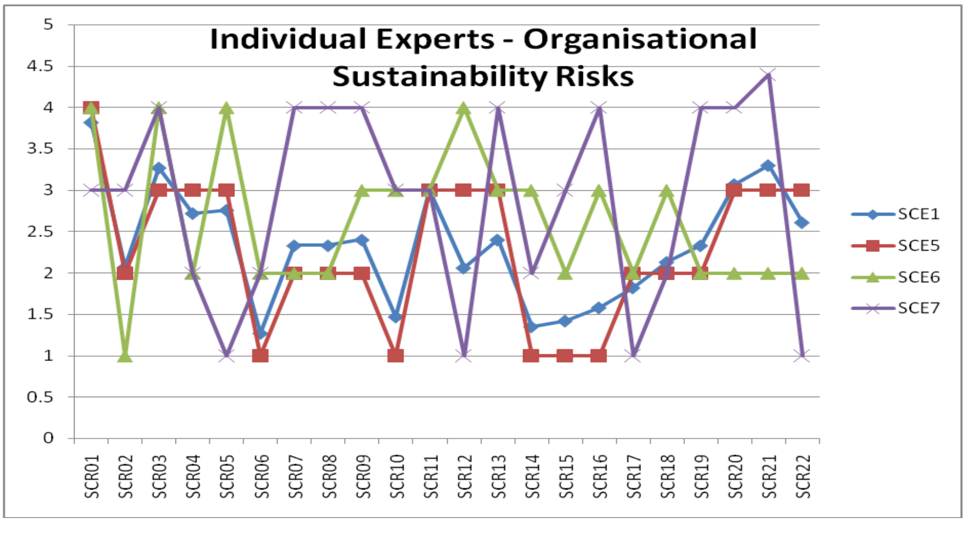

Figure 8.25: Individual Experts - Organisational Sustainability Risks

The global sustainability risks outputs based on project relevant experts group (EG1) shows that they see most of the risks as very low when compared to the experts who are not project stakeholders. This shows that even within the research led projects, the owners /

stakeholders perceptions of global sustainability risks are different compared to outsiders. This signifies the need for inputs from external experts as well to get a balanced opinion. A certain degree of variance in outputs from different experts can be attributable to difference in their expertise and experience.

Both the graphs above clearly shows the advantage of the compiled group inputs when compared to the individual choices, which shows huge variance of outputs. The compiled group inputs approach allows taking the different views proportionally into account based on their properties, which can help in making better decisions.

8.3.5 Findings and Practical Outcomes

The above section 8.3.4have established the appropriateness of the fuzzy input range used, use of collective group inputs and applying expert's importance based on their experience and influence on the project. This has justified the approach selected to obtain results for the action research project and results obtained in Sce1. Hence, outcome of scenario Sce1was presented to the expert group in second segment of focus group ARC-FG4 to identify suitable mitigation measures, this discussed below.

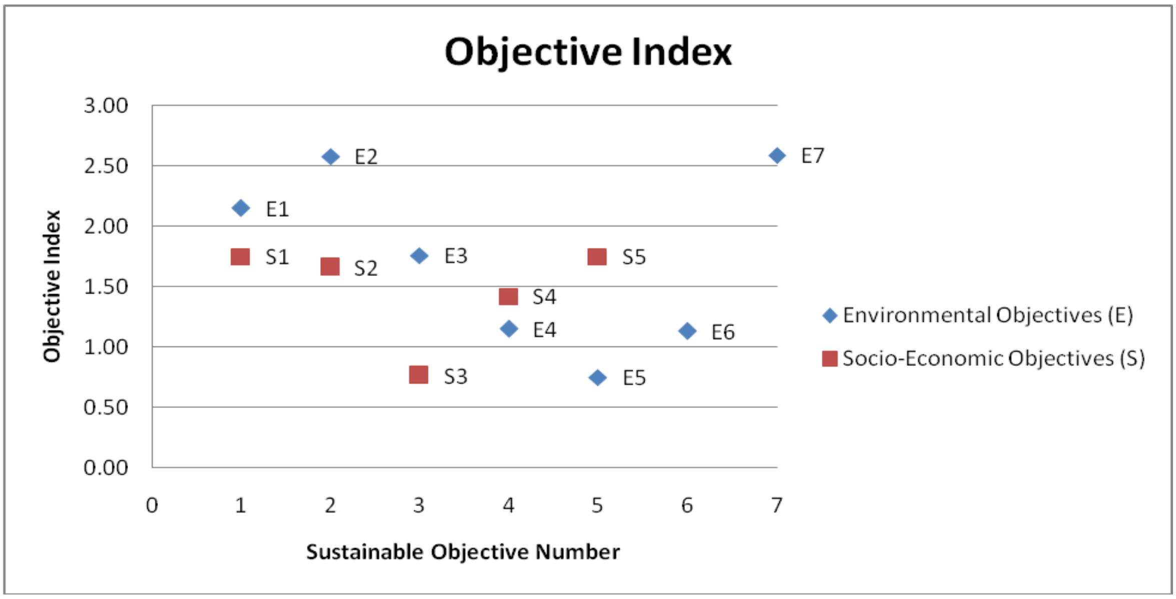

Figure 8.26: Objective Index

The objective index (OI) values of the global sustainability objectives given in Table 8.17. It has also shown graphically in Figure 8.26. Waste management (E7), water (E2) and atmosphere (E1) are the top three objectives in the index respectively. The priority for 'Atmosphere' is not surprising as it is commonly one of the sustainability objective expected with high importance for energy projects. As it has considerable influence on the project and vice versa. However, waste management and water not very commonly identified as sustainable objectives with high priority, but they have emerged as very important objectives in ARC project.

Waste management objective has identified with less significant influence from the ARC project (INF OBJ) when compared to other top objectives but it have been identified as an objective which have highest impact on the project (OBJ IMP) thus making it an objective with highest priority. This is in line with the findings of another study related to the science bridge project (Eswarlal et al., 2013). In which, the waste disposal by the bioenergy projects in India has been identified as one of the important concern of the community. The study concludes that improper waste management can hinder the community acceptance of the bioenergy projects; this can in turn create huge impact on the project (OBJ IMP). This is probably due to the poor state of municipal solid waste (MSW) management in India, where the report by Ministry of urban development in Government of India (2011, p. 11) describe the current situation in most part of the country as, "... authorities are unable to implement and sustain separate and independent projects to enable scientific collection, management, processing and disposal of MSW."

The water availability can hamper, due to the operation of the plant. This can in turn have significant impact on the project. This importance to the sustainability objective to conserve the quality and quantity of water is also due to the location of the project. The project implemented in the desert region of Rajasthan state, which normally has low rainfall, leading to the low availability of water. In addition, the proposed plan to have a mineral water plant and to sell the water to other regions, instead of recycling the water within the bioenergy plant is another important reason for the priority to this objective in the project.

Socio-economic sustainability objectives such as food security (S1), employment generation (S5) and labour working conditions (S2) identified as some of the medium priority objectives. These objectives found to have significant influence from the project, for instance the highest influential objective by the project (INF OBJ) found to be food security objective. However, these socio-economic objectives have low impact on the project (OBJ IMP); this can be due to the difficulty in easily relating the connections between project and the impact on socio-economic situations, poor visibility of the immediate damage and impact time lag.

The risk magnitude of different sustainability risks for ARC project shown in Figure 8.27. The risk magnitude values with the supply chain process where the risk might occur given in Table 8.22. Conversion process of the supply chain seems to be most vulnerable to risks with higher magnitudes followed by the raw material part. Upstream supply chain processes (before conversion) are the most exposed to the significant organisational sustainability risks, in particular raw material procurement. This echoes the findings from other case studies in Chapter 7 and literature, where raw material considered being one of the very weakest links in bioenergy supply chain. This has highlighted the need for better procurement management for the success of business, which the project stakeholders accepted and agreed to take necessary steps to address it immediately. Conversion process exposed to considerable risks affecting both global and organisational sustainability equally. As conversion is the central process of operation in supply chain, considerable dependency of the organisational sustainability on it is expected. In addition, this process is also vulnerable due to the global sustainability risks with huge risk magnitudes, relating to the design of the particular process, its inputs and outputs. Besides the risks relating to the individual processes there are significant global and organisational sustainability risks affecting multiple processes this are categorised using the classification of internal processes (in house processes), external processes and across (all the processes). Some of the important risks identified, explained below with their practical mitigation measures.

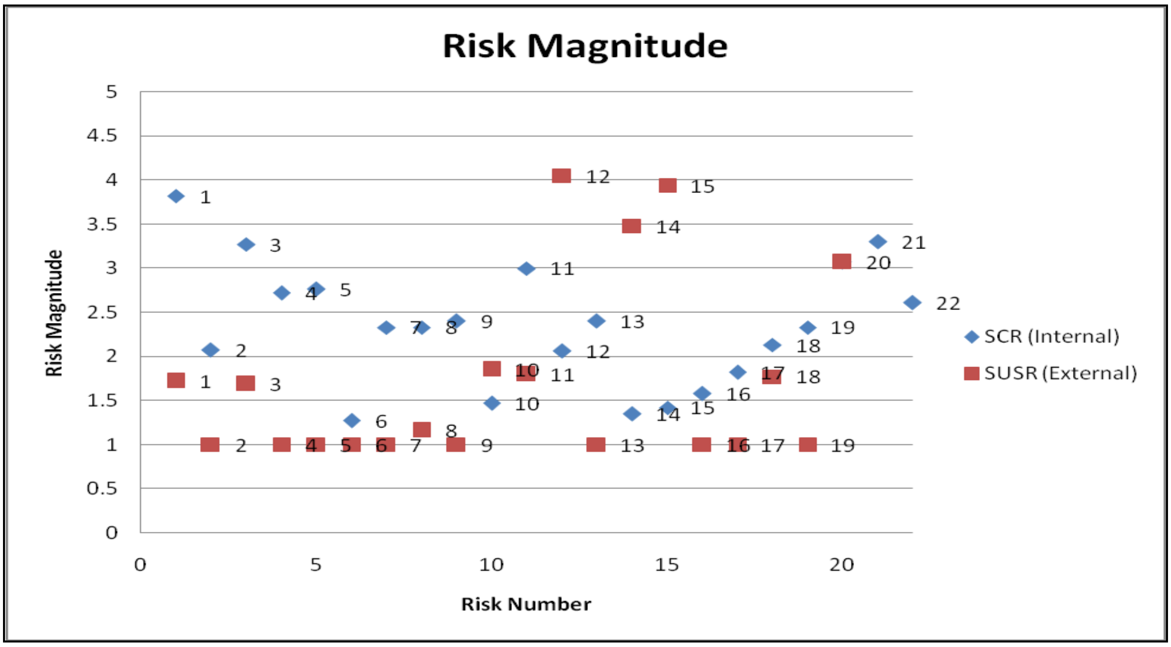

Figure 8.27: Risk Magnitude

Water availability & quality (SUSR12) was found to be the risk with top most risk magnitude to affect the corporate sustainability of the ARC project. All the experts agreed that, this is a significant risk. This may be due to the plant location in desert region with low water availability and the proposed plan to have a mineral water plant as one of the downstream industries. In addition to that, as water scarcity affecting the people’s life in that region to sell the water across the state, found to be unjustifiable. Project stakeholders agreed that it’s an important issue and can create challenges such as community objection or political interference. In order to mitigate the risk they have decided to take two practical steps, they are given below. These steps in addition to mitigating the risks also provides further benefits to the local communities, which can increase the acceptance of the project by the community (Eswarlal et al., 2013).

- One of the partners of ARC project namely, School of Desert Science (a NGO) is already involved in projects to save water in the region by conservation and harvesting. So, the project stakeholders decided to build up on this existing lead by allocating a budget to the NGO to save more water annually than it will be used by the business every year in addition to their current program as a corporate social responsibility measure.
- Another action planned to mitigate the risk is to supply part of the clean drinking water processed in the mineral water plant to the local residents at a very minimal cost. It can solve the problem of availability of drinking water in the village.

The current system design is to produce less electricity than technically possible from a 2MW (thermal) bioenergy plant in order to produce more heat that can be used in DSI. Hence, there are concerns about dumping the heat in atmosphere (SUSR15) when one or more of the DSI is not working, this make this risk related to the demand risk (SCR18) from the DSI. While in the other end of the spectrum the marketability risk (SCR19) exist, where the DSI can face problem to operate when the bioenergy plant is not operating or down for maintenance. This can lead to enormous business challenges to operate, as machines such as VAM (cold storage for fruits and vegetables) are completely dependent on boiler heat and problem with that can lead to huge wastage of fruits and vegetables. In order to address these risks the following action points are planned.

- To add a "heat only" auxiliary biomass boiler that can supply DSI as and when required.
- As there are very frequent electricity disruptions in rural areas of Rajasthan, it is planned to add an auxiliary diesel electricity generator that can supply electricity to the industries, as and when required if the main boiler and grid electricity is down.
- To develop a plan to use the single or combined systems between main boiler, supplementary boiler, grid electricity or diesel generator based on the requirements, which can optimize the efficiency, cost and wastage.
- Also, to develop a timing strategy for different downstream industries to operate taking the heat and electricity demand into account.

Unavailability or shortage of the raw material (SCR01) and increase in the price of raw material (SCR03) are the two organisational sustainability risks recognized to have high risk magnitudes. Having discussed the importance of the procurement management in bio-energy industry, the stakeholders, following the risk analysis to address the weakness of upstream supply chain processes, have penned down some action points. They are as follows:

- To have contracts for raw material supply, this is unusual in small-scale bioenergy industries in India.
- To have multiple suppliers of raw material instead of one as planned before.
- To increase the storage capacity by building storage sheds for biomass. This step will also address other risks related to the storage process (SCR06 &SCR07).
- To use caster residue, by-product of downstream castor oil expeller (DSI-4), as one of the biomass source for boiler. As it is, being in-house can avoid the fluctuation of price and availability.
- To lease land near to the plant and to have energy plantation that can supply to the plant.

The last two steps above in addition to mitigating the risk SCR01 and SCR02, can also minimise other risks such as poor quality of the raw material (SCR02), transportation process risks (SCR04, SCR05 &SUSR08), Allelopathic effect (SUSR01), low yield (SUSR03), fuel wood requirement for cooking (SUSR05), change in occupational pattern change (SUSR06), and potential indirect job loss (SUSR07).

Ash disposal (SUSR14) is found as one of the risks with high risk magnitude. Eswarlal et al. (2013), found ‘ash disposal’ as one of those issue, that created community objection for a bioenergy plant in India. During the discussion all the experts agreed that the ash can be a valuable by-product with commercial value that can be used in other sectors. Therefore it was planned to build storage for the ash that can be then sold periodically.

Skilled labour shortages (SCR21) are identified as important challenge to perform skilled jobs internally (in house). This is in line with the findings from other case studies in Chapter 7. The project stakeholders discussed this with their machine suppliers and found a solution that the machine suppliers will provide skilled work force required for the project in a contract basis for 6 months. During that time the contract workers will also train new employees of the company, so that they can be trained and take over the operations after 6 months.

Regulatory risk (SCR20) is found as a significant risk for the project as the project stakeholders have not considered and planned properly to address the regulatory requirements. The project stakeholders during the discussion did agree with the findings and stated that it will be a complex bureaucratic process, so that they need to act on it quickly. The risk analysis output has given them a clear caution about this and they planned to immediately identify all the required licenses and work towards getting the appropriate permissions as soon as possible.

Occupational hazard (SUSR20) has been found as a risk with high risk magnitude this may be because of the limited explicit consideration about the health and safety of people during the system design process and severe consequences if the hazard occurs due to poor medical facility availability in the village. For example, the nearest hospital is one hour drive from the village and the emergency transport availability is very limited. Project stakeholders agreed that safety of the people is of paramount importance to them and they have planned following action points to reduce the risk occurrence and its impact.

- To take health and safety into account and make necessary changes in the floor plan (for example to have fire exits and proper storage for biomass to avoid any fire hazard) and provide necessary facilities to avoid any potential harms (for example to provide helmets, gloves and fire extinguishers). This action plan on top of addressing the occupational hazard risk also addresses fire risk (SUSR09) by minimizing the chance of fire risk.
- In addition to providing facilities to increase the safety, they planned to buy some automatic machinery that can ease the pre-processing of biomass. Furthermore this action plan addresses pre-processing & handling weakness risk (SCR08).
- To have first aid facilities onsite and as a company's corporate social responsibility measure to buy an ambulance for the village and surroundings. This can minimize the severity of the consequence significantly as medical treatment availability can be fast.

Breakdown risk (SCR11) was measured to be highly risky mainly because of the low availability of spare parts and technician (location) to do service if the machineries crash. Following the risk analysis findings to minimize this risk the project stakeholders included a 5 years' service clause for machines within minimum time in the contract during procurement from suppliers.

Some of the important practical outcomes due to the findings of risk analysis discussed above. There are other changes which the project stakeholders have made to the system because of the risk analysis process carried out which is not discussed here due to the practical constraint of providing all those information within a thesis. The final system design of the ARC project that influenced by the mitigation measures following the 'sustainable supply chain risk analysis' is given in Figure 8.28.

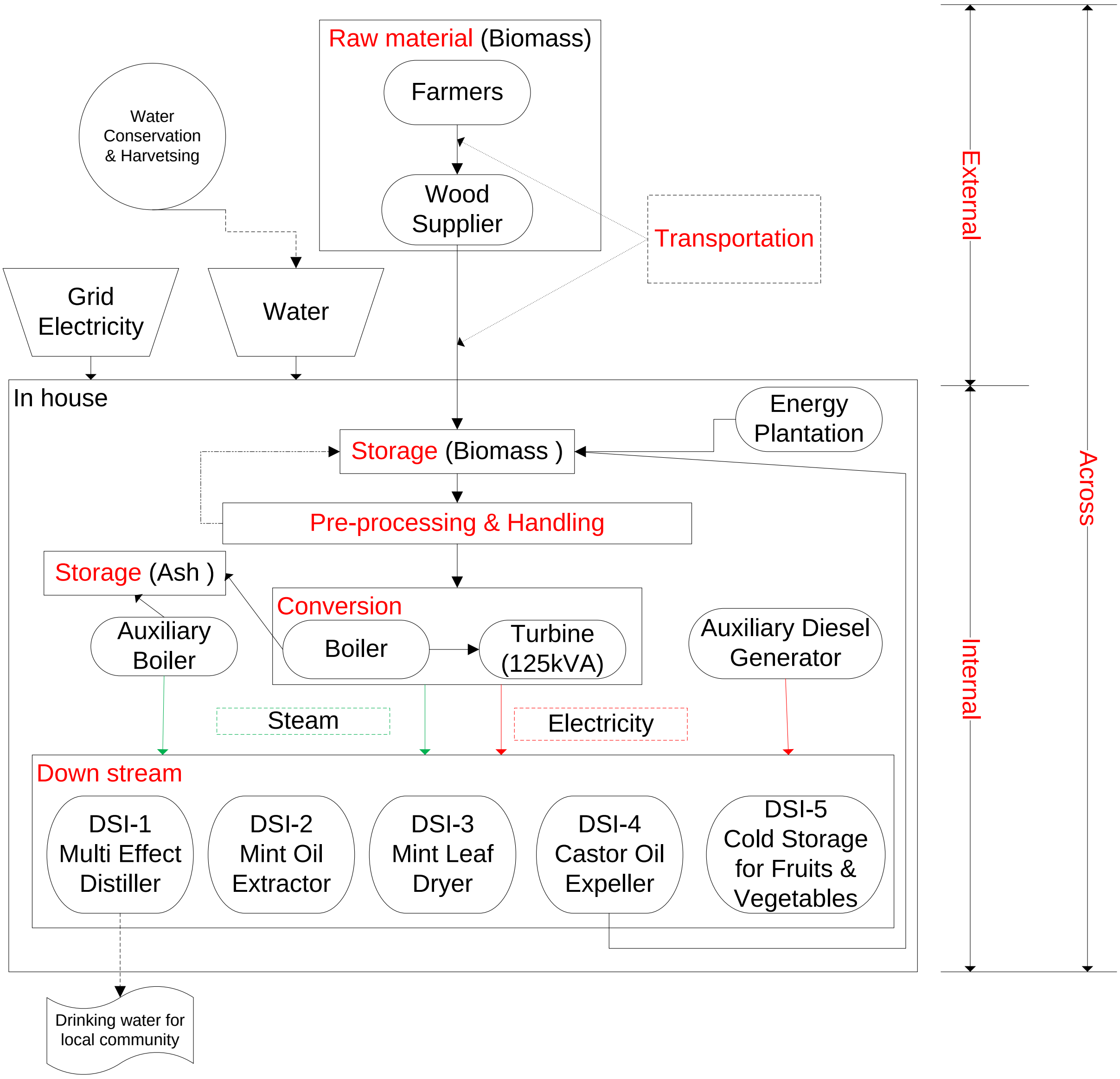

Figure 8.28: ARC Project - Final System Design

8.4 Evaluation of the Framework

The validation of the sustainable supply chain risk analysis framework and its future application potential are discussed in this section below.

8.4.1 Validation of the Framework

Validation of the framework is carried out by getting feedback from the expert user group (in focus group ARC-FG4) about the framework's usefulness and its ability to meet the functionality and usability requirements identified before in Chapter 5, which is discussed below.

All participants of the expert group acknowledged the merits of the framework. They agreed that the framework facilitated in systematically identifying the weaknesses across supply chain that can affect the system's ability to be sustainable. Through its outputs, it helps in taking better decisions to achieve sustainable supply chain. They affirmed that the identification of sustainability objectives and using that as a guide in locating the risks provided an organized approach in identifying global sustainability risks and it was a very useful procedure to consider all the supply chain processes from these different perspectives rather than only from business continuity perspective. The expert group also stated that the findings of RO2 and RO3 provided insights into the important lessons from the existing companies and have guided the discussion to look from different dimensions. All the project relevant stakeholders (Et1, Et2 & Et3) expressed that framework's application have provided them a very valuable opportunity to consider different issues which they have not thought before. They also stated that the focus group discussions with non-project related experts to identify the risks and risk mitigation measures have given important inputs for the project.

The steps to identify global sustainability objectives relevant for the project and to identify risks to achieve those objectives have addressed the functionality requirements recognized in chapter 5, such as the business case. The experts agreed that the business case is easy to see as the framework analysis is based on the objectives, which is not only affected by the business but also has an impact on the business itself. Yet, expert Et2 stated that to make the exact business case for individual global sustainability issues will always be difficult and it can only be anticipated for a particular situation, as in this framework. Therefore the users need to be cautious about these underlying assumptions.

This approach through its objective based risk identification approach also gives clear awareness about the supply chain activities impact on the sustainability objectives. Experts agreed that this risk analysis framework addresses other requirements such as complexity, proactive, involvement and contextual to a great extent. However, experts Et4 and Et5 stated one of the limitations of the framework is that while this framework reduces the complexity of looking at multiple dimensions of sustainability by looking at them individually, it does not provide a balancing or optimizing approach between those dimensions. While the approach provides project related analysis, for its findings to be relevant it requires expertise with good contextual understanding. This framework through its simple approach makes it easy for everyone to understand. Although for the involvement and actions from organisation members other enablers are required such as organisation culture, incentives, etc.

All the experts agreed that this framework can be used with very minimum resources and easily applicable in SME's, which can help in making positive changes. However the experts stated that it can also be possible to use the framework just as a procedure rather than as a proper analysis if the people who are using it do not really care about the sustainability aspects. For that reason, they stated that the framework's outputs are as good as the people who use it and their motivations. While discussing solutions for this challenge, they agreed that it won't be always possible for the SME's to involve external experts in the process due to their resource constraints. They suggested the following:

- When the SME's apply this framework they need to be objective as much as possible and conscious about the purpose of using the framework to get genuine results.
- SME's should involve external stakeholders in identifying global sustainability objectives and risks if possible.
- In SME's if they use the framework for analysis in a group discussion rather than by an individual can lead to better outputs due to multiple views.

The experts agreed about the limitations of SME's in India to access or measure global sustainability indicators where they see the advantage of the framework as it can work with the limited availability of information and do not need objectively measured indictors. However, as mentioned above the subjective inputs need to be closer to reality to get better result.

From usability point of view, the experts agreed that the framework was easy to use and the mathematical approach used for analysis is appropriate for the given problem, user group and its context. Nevertheless experts stated that the current mathematical approach (scientific model) for analysis may not be suitable for all the instances due to the amount of calculations and processing of data required to find the answers. Expert Et5 acknowledged that current model produces more accurate and trust worthy results but in the other hand it will be difficult for SME's with limited expertise to execute this framework. He said that, in his observation main purpose of the framework is to identify all the global and organisational sustainability risks, evaluate those risks and then prioritize them based on their ability to damage the corporate sustainability. Furthermore he argued that the above mentioned functions of the framework can be achieved by using simple and traditional mathematical approach (non-fuzzy approach) for risk analysis part of the framework, as the main purpose of the analysis part is to have a priority list of risks rather than having very accurate risk magnitude. Experts also suggested another option that is to develop software or excel program which can calculate the risk magnitude given the inputs.

8.4.2 Further Application of the Framework

Further application of the framework was evaluated in a focus group (QSR-FG9), which had potential user groups' representation. The participants of the focus group probed initially for their views on sustainable supply chain and their requirements for a DSS to achieve sustainable supply chain. Then short presentation about the framework and its application in ARC project given to the participants. Followed by that, their opinions on such a framework for further use to attain sustainable supply chain in their field collected. Summary of this discussion on adoptability of the framework for future use discussed below.

Participants agreed that there is ever increasing need for their companies and SME's in general to be more sustainable due to the demand from their customers and social pressure. They stated that another reason for the companies in UK (or developed countries) needs to engage more with sustainability issues, are the legislative and regulatory requirements in UK. They agreed that supply chain member's activity is also important for them as it can affect their overall sustainability performance and brand value. The reasons given above by the participants of the focus group once again reiterate the need to have sustainable supply chain, which is discussed in Chapter5.

The participants expressed some similar challenges to achieve sustainable supply chain for a SME as discussed in Chapter5, such as information availability, information processing challenge, difficulty in understanding about the multiple dimensions of sustainability, making a business case, challenge in maintaining the balance between different dimensions of sustainability awareness about the impact of global sustainability issues and expertise required. Participants discussing these issues in background acknowledged the need for a simplistic framework which can help them to overcome these challenges and realize sustainable supply chain. In addition to the above mentioned issues the participants also stated other challenges such as cost to achieve sustainability, low financial incentives such as subsidies from governments and low influence by SME's on their supply chain partners.

Following this discussion the conceptual framework and the ARC project application of the framework was presented to the participants. All of the participants agreed that the conceptual framework was simple and easy to understand and there is good scope for this framework to be applied in practice. They recognized some of the benefits of the objectives based risk identification across the supply chain, they are as follows.

- Framework can make clear business case for global sustainability issues through its objectives.
- It can help to probe impact on different sustainability objectives and their respective influence across the supply chain.
- Framework can help to look at the complete picture across the supply chain.

They raised some concerns such as can the framework give effective results if the external experts are not involved or the number of participants doing such an analysis for a project is low. This is also one of the drawbacks of the framework, as it's highly dependent on the quality input to get quality output. Whereas this garbage in - garbage out issue is a fundamental theme for any design and decision making processes output quality (Lidwell et al., 2010).

In summary, evaluation of framework has clearly displayed the framework's ability to address user requirements up to a greater extent. The framework provides an approach to look at both the global sustainability risks and organisational sustainability risks and assess them in a common scale that can be a basis for considering the business case for the sustainability. The framework has helped the stakeholders in ARC project to make decisions that can enable them to be more sustainable. Other practitioners have also agreed that there is a good potential for the further application of the framework. However, the framework still needs to be applied and tested in other industrial sectors. So that it can be generalized further.

8.5 Contributions of the Framework

The framework developed in this thesis (Chapter 5 - RO1) makes three important contributions. Firstly, it contributes to the bioenergy DSS literature with a framework that takes the risks into account and supports decision making to realize a sustainable supply chain. Since current studies, taking systematic approach to address the risks in bioenergy sector is scant (Awudu & Zhang, 2012; Shabani et al., 2013). Furthermore, the work addressing the complete supply chain (Gold & Seuring, 2011; Iakovou et al., 2010) and the DSS taking all the relevant sustainability parameters particularly social parameters (Awudu & Zhang, 2012; Shabani et al., 2013) into account are limited. In addition to that this framework provides solution to the small scale practitioners by taking their needs into account, which is inadequate in the current literature (Scott et al., 2012).

Secondly, in the process of developing this framework, the usability and functionality requirements of SME practitioners for this type of DSS are identified this contributes to the advancement of understanding about their needs, which is lacking in the literature (Scott et al., 2012).

Finally, this framework contributes in the sustainable supply chain management field with its risk analysis framework that includes both organisational and global sustainability perspective. Such an approach to manage risks in sustainable supply chain is lacking in the existing literature (Ashby et al., 2012). The research framework developed takes the initial steps to address this gap. Integration of the organisational and global perspectives of sustainability into the sustainable supply chain management field also provides a foundation to expand this field further (Carter & Easton, 2011).

This work addresses the specific future research proposal put forward by Ashby et al. (2012) following their systematic literature review on sustainable supply chain. That is to manage the risks in sustainable supply chain by taking also the environmental and social dimensions into account. In addition this work adds to the small number of work in sustainable supply chain management field that integrates all the three dimensions of sustainability (Ashby et al., 2012; Seuring, 2012). Furthermore, this work brings the organisational and global perspectives of sustainability from the strategy literature (Porter & Kramer, 2006) into sustainable supply chain management, which can provide a foundation to expand this field further.

In addition to the contributions through development of the framework, application of the framework has made two scholarly contributions.

Firstly, the application of fuzzy sets and fuzzy logic techniques and expert systems are scant in the bioenergy supply chain decision-making process (Shabani et al., 2013), where the framework implementation (scientific model) used in this research contributes to address both of this gap. Similarly, sustainable supply chain field is new and these methodological approaches in this field can develop the field further. In addition to that, there is a methodological advancement in the process to maintain consistency of fuzzy inputs by the group members. Furthermore, comparison of individual expert results with group inputs highlights the importance and sensitivity of the input values given.

Secondly, the application of decision supporting frameworks in an action research type of study is very low (less than 1 % when compared to other types of study) (Arnott & Pervan, 2005), while this application of a DSS in an action research project strengthens DSS literature by addressing this deficiency.

8.6 Chapter Summary

In this chapter, the conceptual framework developed in Chapter 5 was modelled into a scientific model and applied in ARC project with the help of inputs from RO2 (Chapter 6) and RO3 (Chapter 7). The findings of the applied model have made considerable impact on the project, which is discussed above. These steps forms a complete circle of systematic problem solving model suggested by Mitroff et al. (1974). In their model they also advocate feedback and validation of the model to increase its value, which is carried out using two focus groups and discussed in the section 8.4 of this chapter.

Chapter Nine: Conclusion

9.1 Research Summary and Major Findings

A small scale bioenergy sector has the potential to flourish and positively contribute towards tackling the energy poverty issue in India. In addition, it can offer environmental and socio-economic benefits. The motivation to support widespread adoption of small scale bioenergy technologies in India directed the study to be an applied research with relevance to practice and to look at the challenges for practitioners. Therefore, the research problem was defined by simultaneously collecting information from both the practitioners' and research gap in the literature.

The issues affecting organisational sustainability and global sustainability across the supply chain are recognised as the major barriers to the Indian small scale bioenergy sector achieving its potential. Furthermore, it is recognised that the management of those risks are a huge challenge for practitioners. Hence, this research aimed to identify and analyse sustainable supply chain risks within the small scale bioenergy sector. The research aim is achieved through four research objectives, as defined in Chapter 3 using the approach explained fully in Chapter 4. Synopses of those objectives are given below.

9.1.1 Research Objective 1

The first objective was to develop a sustainable supply chain risk analysis framework; this is fully discussed in Chapter 5. In order to conceptualise a practically useful (Corley & Gioia, 2011) and relevant (Mitroff et al., 1974) framework, the framework requirements were identified through suggestions from practitioners and experts. The sustainable supply chain risks and risk management where then defined by adopting and integrating organisational and global sustainability classifications of corporate sustainability (Garvare & Johansson, 2010; Ivory & MacKay, 2012) and supply chain risk management concepts. Finally, the sustainable supply chain risk analysis framework was developed through the disciplined imagination approach (Weick, 1989). The framework was developed primarily based on the framework requirements, sustainable supply chain risk management concepts, notion of sustainability action and control paths (Madlener et al., 2006) and the interdependence of society and business perspective (Porter & Kramer, 2006). Major findings from this objective (RO1) are as below.

- A sustainable supply chain risk analysis framework can help the small scale practitioners to identify, analyse and assess both organisational and global sustainability risks across the supply chain.
- The requirements of the SME practitioners for a decision support framework.

- The definition of ‘sustainable supply chain risk’ and ‘sustainable supply chain risk management’ can help to characterise the boundaries and process of this emerging field.

9.1.2 Research Objective 2

The identification of sustainability issues of existing small scale bioenergy projects in India is the second research objective (RO2). Following the recognition of the research gap, sustainability issues and objectives were collated from literature. They were then categorised, firstly into respective sustainability aspects and then into environmental and socio-economic categories. Empirical data collected from primary case studies and stakeholders was then utilised to address the research objective. The data was then analysed to identify sustainability issues with the help of a hybrid approach with inductive and deductive (synthesised from literature) themes (Fereday & Muir-Cochrane, 2008; Joffe & Yardley, 2004). The sustainability issues were then classified into respective sustainability aspects and dimensions. Finally, sustainability objectives were synthesised from the sustainability issues of small scale bioenergy projects in India. The important findings of this research objective are given below.

- Global sustainability issues (24 environmental and 15 socio-economic issues) and objectives (17 environmental and 10 socio-economic objectives) of small scale bioenergy projects in India based on the empirical evidence, presented in section 6.3.
- Categorisation of the issues and objectives into sustainability aspects (17 different sustainability aspects: 8 environmental and 9 socio-economic aspects).
- Synthesis of sustainability issues and objectives of bioenergy sector from the literature.

9.1.3 Research Objective 3

The third objective was the identification of supply chain (organisational sustainability) issues of small scale bioenergy projects in India. Initially, the bioenergy sector supply chain issues were synthesised from literature using both descriptive and analytical themes (Thomas & Harden, 2008), that were then classified based on the relevant supply chain processes. The empirical data collected from primary case studies, secondary case studies and stakeholders were then utilised to address this research objective. The final stage in achieving this objective was analysing the data thematically using the themes developed from the literature and classifying it according to the supply chain processes. The findings of this research objective are:

- Organisational sustainability supply chain issues of the small scale bioenergy projects in India identified from empirical data and classification of the issues based on the supply chain processes (In total 29 supply chain issues relating to raw material (3), transportation (2), storage (3), pre-processing and handling (2), upstream (1), conversion (9), downstream (7) and across (2) categories). These findings are presented in the section 7.3.
- Supply chain issues (in total 32 issues) of the bioenergy sector from literature review.

9.1.4 Research Objective 4

The final research objective was to apply and evaluate the sustainable supply chain risk analysis framework (RO4), discussed fully in chapter 8.The ‘scientific model’ to practically apply the framework was designed in the first part. In this part the complete mathematical model to carry out an effective risk analysis was planned and proposed on the basis of the conceptual framework (RO1). Selection and description of suitable mathematical approaches such as fuzzy sets, fuzzy logic systems and fuzzy AHP were discussed. In addition to that, information on experts involved and risk identification processes were provided.

The scientific model was applied in a small scale bioenergy project currently under development in Jodhpur, India. This case study application was also an action research project to support the project’s supply chain design decisions. The list of sustainability objectives and issues identified in objective RO2 and the library of supply chain issues identified in objective RO3 were also employed in the course of this framework application. Potential global and organisational sustainability risks across the action research project supply chain were identified, analysed and assessed against a single risk magnitude scale. The action research project results obtained were verified by testing the impact on final risk magnitude by varying some of the important parameters of the model.

The final outputs were presented to the expert group, to which they were prompted to make suggestions of how to mitigate the risks based on the risk magnitude score produced by the framework. The results of this applied framework and suggestions from the experts supported the project stakeholders to make considerable changes to their supply chain design, such as: a change of raw material; leasing of land for growing biomass, and; a backup boiler for the downstream industry.

Additionally, the expert group evaluated the framework for its usability and limitations. They recognised that the framework was very helpful in provoking thoughts about the bioenergy supply chain in a systematic manner and more suitable for collective decision making processes. Finally, the framework was evaluated by practitioners and experts from the UK for its future application potential. The important outcomes of this research objective are:

- Application and testing of the framework on a real world and active project. The practical impact on the system design due to the framework's application highlights its usefulness.
- A risk analysis model using mathematical approaches such as fuzzy sets, fuzzy logic and fuzzy AHP.
- Results verification by varying some of the important parameters.
- Evaluation of the framework's strengths, limitations and future application potential through experts input.

9.2 Research Contributions

The research, in the process of achieving its aim, has contributed to different areas of literature and addresses multiple research gaps. The major contributions of this research are summarised below.

- **Research Objective 1:** The framework developed in chapter 5 contributes in the sustainable supply chain management field with its risk analysis framework that includes both organisational and global sustainability perspective. This work addresses the specific future research proposal put forward by Ashby et al. (2012) following their systematic literature review on sustainable supply chain. That is to manage the risks in sustainable supply chain by taking also the environmental and social dimensions into account. In addition this work adds to the small number of work in sustainable supply chain management field that integrates all the three dimensions of sustainability (Ashby et al., 2012; Seuring, 2012). Furthermore, this work brings the organisational and global perspectives of sustainability from the strategy literature (Porter & Kramer, 2006) into sustainable supply chain management, which can provide a foundation to expand this field further (Carter & Easton, 2011).
- **Research Objective 2:** The recognized sustainability issues of the Indian small scale bioenergy sector contributes to the current literature from the perspective of a developing country, heat and power plants and small scale projects which are limited in the literature (OECD & IEA, 2012). The findings add new factors into the existing list of sustainability issues relevant to Indian bioenergy sector. In addition to that, the results make it clear that the perceptions about relevant sustainability issues are not identical in developed and developing countries. Also, this work is based on inputs

from all the relevant (both primary and secondary) stakeholders, which offers a multi-perspective finding.

- **Research Objective 3:** The identified supply chain issues of the small scale bioenergy sector in India contribute to the literature from an empirical perspective (Gold & Seuring, 2011). These findings present issues from multiple stakeholders' viewpoint, which provides further value from utilisation point of view. This adds to the literature with specific knowledge about the bioenergy supply chain from small scale and Indian perspective, existing literature on which is inadequate. In addition the empirical findings substantiate the issues recognised through literature synthesis and enlightens with new issues relevant to the Indian small scale bioenergy sector, which is related to the transportation and storage process of the supply chain.

In addition to the above mentioned major contributions there are other contributions in this work which are given below:

- Currently, decision support systems addressing the supply chain risks in the bioenergy sector are scant (Awudu & Zhang, 2012; Shabani et al., 2013). The sustainable supply chain risk analysis framework developed in chapter 5 contributes to the literature by addressing this research gap. (RO1 - Discussed in Section 8.5)
- Practitioners' requirements of the decision support systems are identified and used to develop the framework, which has been shown to be weak in existing DSS (Scott et al., 2012). (RO1 - Discussed in Section 8.5)
- Sustainable objectives for the Indian bioenergy sector developed based on multiple stakeholders' perspectives advance the current understanding of sustainability requirements of bioenergy projects in the Indian context (Harrison et al., 2009; Harrison et al., 2011). (RO2 - Discussed in Section6.4)
- Supply chain issues synthesised and compiled from literature contribute to the better understanding of the issues affecting the whole bioenergy supply chain (including the downstream), which is scant in the literature (Iakovou et al., 2010). (RO3 - Discussed in Section 7.4)
- Application of the framework in the ARC project, using fuzzy sets and fuzzy logic techniques and expert systems attend to the inadequacy of these approaches in the bioenergy supply chain decision-making process (Shabani et al., 2013). (RO4 - Discussed in Section 8.5)
- Application of a DSS in an action research project strengthens DSS literature with additional perspectives by addressing the deficiency of action research strategies adopted in this field (Arnott & Pervan, 2005). (RO4 - Discussed in Section 8.5)

9.3 Practical Implications

The practical implications are one of the main focuses of this research project as the intention behind this study was to support the widespread adoption of small scale bioenergy projects in India. Findings of this study have a number of important implications for future practice. Firstly, the findings suggest several courses of action for the upcoming ARC project supply chain design. These suggestions can improve performance of the project and help to achieve a sustainable supply chain with minimum risks.

Secondly, the developed framework can be used by the small and medium entrepreneurs to identify the risks and make targeted interventions to address those risks to achieve a sustainable supply chain. This framework can be used as a part of a new supply chain system design procedure or to evaluate the existing supply chain system and redesign it.

Thirdly, the supply chain and sustainability issues identified can inform and assist the proactive entrepreneurs to recognise relevant risks across their supply chain operations for both global and organisational sustainability. Taking the issues identified into account can help the practitioners to design a resilient supply chain through necessary risk mitigation measures which can lead to increased performance and competitiveness.

Fourthly, the findings can assist in notifying policymakers on important supply chain and sustainability issues in developing projects of this type. Moreover, this could lead to the development of required policy and regulatory frameworks to address those issues and promote the sector further through better support mechanisms.

Finally, the global sustainability related findings of this research provide a platform for the international policymakers to understand the current state of discussion about the sustainability issues, objectives and aspects of bioenergy sector in India. In particular, it can support the international organisations which have proposed to develop an internationally agreeable global sustainability standard for bioenergy (OECD & IEA, 2012), from the perspective of a developing nation.

9.4 Study Limitations

In order to avoid or mitigate the drawbacks of this research project, appropriate actions were taken wherever possible. However, as with any research project, avoiding all the limiting factors is not possible. The important limitations are discussed below, while these limitations need to be considered in future research and further application of the findings.

The framework is based on the inputs from a small number of experts mostly from the renewable energy sector and with a ‘small scale’ or decentralised project perspective. Therefore, this may limit the framework’s generalizability to other sectors or contexts. Due to resource constraints, the framework is applied and tested on only one renewable project, which limits the assessment perspective of the application. However, the action research application and the results produced confirm the benefits and wider potential for the framework.

In addition, there are some functionality limitations and boundary conditions which drive the framework effectiveness. Firstly, the framework reduces the complexity of handling multiple sustainable objectives by looking at them individually; but it does not provide a balance between those objectives concurrently. Secondly, as with any human forecast models, the results are dependent on the input quality. Therefore, the framework output can be improved through group decision making with inputs from people who have sufficient expertise, contextual understanding and are objective (to avoid any bias). Thirdly, to achieve useful outcomes from the framework, enablers such as the involvement of organisational members, organisational acceptance and incentive for sustainability are essential.

The mathematical model was selected based on the experts' opinion involved in the project and it may not be suitable in all the instances due to the amount of calculations and processing of data required to find the answers. This can be addressed by developing software or programs in the future that can improve the user interface for commercial application and ease of use.

The research objectives RO2 and RO3 are exploratory in nature within a specific context. Therefore, these findings are confined to be applicable within a similar context only and need to be statistically tested further before generalisation. Local public perception of global sustainability issues was not gathered directly due to resource constraints, this limitation of the study also needs to be taken into account before generalising across stakeholder groups. The supply chain issues (RO3) were investigated from an organisational sustainability of conversion plant point of view; due to this all the challenges of supply chain partners are not recognised.

9.5 Future Research Directions

This research has thrown up several key questions that require further investigation. It is recommended that further research be undertaken in the following areas:

- The sustainable supply chain risk management field is new and promising therefore efforts that can bring new perspectives are required to develop the field further.
- Further work needs to be done to develop a framework that can balance different sustainability objectives concurrently.
- It is suggested that the connection between organisational and global sustainability issues of a supply chain are investigated further in future studies.

- It would be interesting to assess the effects of the framework developed using a graphical user interface, as it can simplify the process for practitioners.
- More research is required to determine the framework application in other sectors and contexts.
- Large surveys of both supply chain and sustainability issues of the small scale bioenergy sector could provide more definitive and prioritised evidence.
- Further empirical investigations in other countries and contexts are needed to generalise the supply chain issues of the bioenergy sector further.
- Further studies should investigate the local public opinion (directly) on the bioenergy industry in developing countries such as India.
- More information on issues affecting other supply chain members of the bioenergy sector in developing countries would help us to establish a greater degree of accuracy on this matter.

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APPENDICES

Appendix One. Organisational Sustainability Risks

Risk Number	**Risk Event**	**Possible Causes**	**Possible Consequences**
Raw material			
SCR01	Unavailability or shortage of the raw material	Seasonal availability of the resources; Due to competition for resources with other industries; Use of land for other agricultural products; No agreement in place; Reduction in yield; Reduced production; Change in law (Restriction for selling/ cutting/ using Prosopis Juliflora);	Impact on number of operating hours; Impact on long term availability of the resource; Impact on investment for larger storage facility; Demand for larger storage;
SCR02	Poor quality of the raw material	Low calorific value; High ash content; No agreement in place; Improper handling; High moisture content;	Operational efficiency; Energy conversion rate; Technical constraints
SCR03	Increase in the price of raw material	Varying labour cost; Opportunity cost imposed by the suppliers; Due to competition for resources with other industries; Use of land for other agricultural products; No agreement in place; Reduction in yield; Reduced production; Change in law (Restriction for selling/ cutting/ using Prosopis Juliflora); Seasonal availability of the resources;	Impact on production cost; Impact on number of operating hours
Transportation			
SCR04	Delivery Failure	Due to strike; Break down of vehicle; Bad weather conditions;	Impact on number of operating hours; Demand for larger storage; Possible

Risk Number	Risk Event	Possible Causes	Possible Consequences
			Short term shutdowns and cost associated with it.
SCR05	Increase in the transportation cost of raw material	Due to distance travelled; Increase in the cost of Diesel; Low density of the raw material; Capacity of the truck; Number of journeys;	Impact on production cost; Increase the cost of raw material
Storage			
SCR06	Unavailability of the storage space	Limited storage space; Poor infrastructure; Increase in demand for storage space; Initial Cost for setting up storage;	Impact on number of operating hours; Impact on long term availability of the resource; Possible Short term shutdowns and cost associated with it.
SCR07	Storage imperfection	Poor storage facility; Open storage conditions;	Fire Hazard; Theft / Degradation / Storage loss of the raw materials. Possible impact on cost.
Pre-Processing & Handling			
SCR08	Pre-processing & Handling weakness	Non-automated system for pre-processing; Improper equipment for pre-processing; Improper handling; Improper chipping;	Sub-optimal combustion leading to poor conversion efficiency; Poor quality of raw material. Labour cost increase due to non-automated system for pre-processing;

Risk Number	Risk Event	Possible Causes	Possible Consequences
SCR09	Increase in the cost of pre-processing	Energy consumption for pre-processing; Increase in labour cost	Increase the cost of raw material
		Conversion	
SCR10	Community Objection	Proximity of the plant near to people's home;	Risk to permanent / temporary shutdown
SCR11	Breakdown risk	Poor maintenance; Unavailability of spare parts and technician on the required time; Slag; Improper ash removal.	Possible Short term shutdowns and cost associated with it.
SCR12	Low variation flexibility of heat & electricity mix ratio	Technological setup	Low energy conversion efficiency; Poor adoptability
SCR13	Low efficiency	Sub-optimal combustion due to poor quality of the feedstock or other technical reasons; Improper maintenance; Operator error;	Impact on production cost; Poor energy conversion rate
SCR14	Risk from competition	Due to low price of grid electricity; Increase in cost of the energy production;	Losing Customer, competitiveness at risk
SCR15	Increased Cost of operation	Due to bad conversion efficiency; Unbalanced economy of scale; Increase in the Labour Wages;	Increased production cost
		Consumer	
SCR16	Technical risk	Breakdown of the heat / electricity supply lines; Electrical short circuit	Impact on operation; Short term shutdown
SCR17	Requirement fluctuation	Day to day change of demand for heat and electricity;	Poor demand; Low energy usage; Energy loss

Risk Number	**Risk Event**	**Possible Causes**	**Possible Consequences**
SCR18	Demand risk	Failure of the downstream companies; Permanent Change in requirement of energy; High dependency (shutdown of downstream for maintenance);	Low / no demand; Impact on profitability and permanent running of the plant.
SCR19	Marketability risk	Unavailability of the proper backup system of heat & electricity for the consumers during shutdown of the conversion plant;	Customer Attraction is less; Will be a dependent system
Internal			
SCR20	Regulatory risk	Environmental board clearance; Boiler inspection failure; Labour regulations;	Legal challenges; Possible shut down for short or long term; Fines
SCR21	Labour shortages (skilled)	Skill set shortage; Unavailability of the skilled labour in the location;	Cost of production will increase; Labour unavailability risk
Across			
SCR22	Natural Disaster	Flood / Earthquake / Others	Plant breakdown / shutdown risk

Appendix Two. Global Sustainability Risks

Risk Number	Related Sustainable Objective	Risk Event	Possible Causes	Possible Consequences
		Raw material		
SUSR01	Biodiversity	**Allelopathic effect**	Quick spread of Prosopis Juliflora in nearby area; Using more of the available resources (such as nutrients, water or light) from the environment.	Impact on other plants in the region or land (Allelopathy is a biological phenomenon by which an organism produces one or more biochemical that influence the growth, survival, and reproduction of other organisms.) Suppression of grasses and crops. Damaging the natural ecosystems.
SUSR02	Land use change	**Land use conversion**	Due to farmers seeing more profit/ less risk in Prosopis Juliflora. Increasing demand leading to more price which increase the production by taking other lands. Importantly effect of colonization of agricultural land.	Can impact on the natural land-scape; Biodiversity; indirect GHG emissions; food security
SUSR03	Natural resource & Energy efficiency	**Low Yield**	As it's a weed the improper system for production can impact the yield.	Land required for the raw material can increase
SUSR04	Food security	**Indirect effect on food security**	Due to the land use change of agricultural lands.	Food availability reduces; Human survival under impact; can create social unrest

Risk Number	Related Sustainable Objective	Risk Event	Possible Causes	Possible Consequences
SUSR05	Local prosperity & Social wellbeing	**Fuel wood requirement for cooking**	Using huge quantity of raw material for this conversion plant, minimize the availability of it for other cooking purpose	Impact on the wellbeing of poor people and their dependence on cooking resource.
SUSR06	Local prosperity & Social wellbeing	**Change in occupational pattern change**	Reduction of agriculture and associated occupations because of moving to Prosopis Juliflora growth.	Loss of knowledge and skills.
SUSR07	Employment Generation	**Potential indirect job loss**	Agriculture land being converted into a land for Prosopis Juliflora can impact on the number of people dependent on the agriculture and related jobs.	Total number of jobs created might be reduced.
Transportation				
SUSR08	Biodiversity	**Spread of the seeds**	Due to poor transport mechanism, there is a possibility to spread this plants seed on its way, which can affect the biodiversity of those place.	Impact on other plants in the region or land.
Storage				
SUSR09	Labour working conditions	**Fire risk**	Due to improper storage facilities; Unavailability of the fire precaution arrangements.	Health hazard to the workers and nearby community.
Conversion				
SUSR10	Atmosphere	**Untreated / poorly designed exhaust**	Exhaust is not treated properly; Poor exhaust design leading it to enter in neighbourhood	Local atmosphere polluted. Neighbourhood opposition

Risk Number	Related Sustainable Objective	Risk Event	Possible Causes	Possible Consequences
SUSR11	Atmosphere	**Greenhouse gas emissions**	Increased GHG emissions for the energy produced due to poor maintenance and operation.	Increased GHG emissions; contributing negatively towards climate change
SUSR12	Water	**Water availability & quality**	Water deficit in the region, can impact on the use of water for conversion. Also water can have impurity after the conversion if not treated properly.	Water availability for drinking.
SUSR13	Natural resource & Energy efficiency	**Low conversion ratio**	Technological issues, poor maintenance, Optimum Operational error	Low net energy gain
SUSR14	Waste management	**Ash Disposal**	Dumping in the landfills / open dumping rather than utilizing effectively	Impact on surroundings with dust and space. Poor value maximization.
SUSR15	Waste management	**Dumping the heat in atmosphere**	When some downstream industries or not in use possibility of giving an open outlet for the steam in atmosphere	Improper waste management; Heat wastage; Concern from the local surroundings
Consumer				
SUSR16	Natural resource & Energy efficiency	**Transmission Losses**	Due to improper / poor energy transmission system; Leakage of steam	Low net energy gain; Low energy efficiency
Internal				
SUSR17	Human rights	**Equal opportunity for women**	Due to the cultural challenges. Also regional dress code and time constraints for the family.	Women development will be hampered.

Risk Number	Related Sustainable Objective	Risk Event	Possible Causes	Possible Consequences
External				
SUSR18	Atmosphere	**Indirect Greenhouse gas emissions**	Due to land use change; long distance of transport; high pesticide requirements;	Increased GHG emissions; contributing negatively towards climate change
Across				
SUSR19	Natural resource & Energy efficiency	**Increased energy consumption**	More energy spent on raw material collection and handling; Long distance of transport, poor mode of transport using more energy; Obsolete pre-processing technology, Quality of raw material requiring more energy for pre-process. Energy consumption increase due to auxiliary devices; Poor energy efficiency among consumers	Low net energy gain; Low energy efficiency
SUSR20	Labour working conditions	**Occupational Hazard**	In raw material collection, handling; Improper handling of chopping / pre-processing accessories; Inhalation issues of the dust. Hazard of working on machines and electric / thermal lines.	Staff health in danger; Motivation of the workforce will be affected. Risk is increased due to the location of the plant and unavailability of the nearby medical treatment centre.

Appendix Three. Rule Base for the Global Sustainability Objective Index

Impact of the Objective(OBJ IMP)	*Influence on the Objectives (INF OBJ)*	*Objective Index ($SUSR - OI$)*
VH	VH	H
VH	H	H
VH	M	H
VH	L	H
VH	VL	M
H	VH	H
H	H	H
H	M	H
H	L	H
H	VL	M
M	VH	H
M	H	H
M	M	H
M	L	H
M	VL	M
L	VH	H
L	H	H
L	M	H
L	L	M
L	VL	M
VL	VH	M
VL	H	M
VL	M	M
VL	L	M
VL	VL	L

Appendix Four. Rule Base for the Global Sustainability Risks

Objective Index ($SUSR-OI$)	***Risk Severity ($SUSR-RS$)***	***Risk Likelihood ($SUSR-RL$)***	***Risk Magnitude (RM^{susr})***
H	VH	VH	VH
H	VH	H	VH
H	VH	M	VH
H	VH	L	VH
H	VH	VL	H
H	H	VH	VH
H	H	H	VH
H	H	M	VH
H	H	L	H
H	H	VL	M
H	M	VH	VH
H	M	H	H
H	M	M	H
H	M	L	M
H	M	VL	M
H	L	VH	H
H	L	H	M
H	L	M	M
H	L	L	M
H	L	VL	L
H	VL	VH	L
H	VL	H	L
H	VL	M	VL
H	VL	L	VL
H	VL	VL	VL
M	VH	VH	VH
M	VH	H	H
M	VH	M	H
M	VH	L	M
M	VH	VL	M
M	H	VH	H
M	H	H	H
M	H	M	M
M	H	L	M

Objective Index ***(SUSR − OI)***	***Risk Severity*** ***(SUSR − RS)***	***Risk Likelihood*** ***(SUSR − RL)***	***Risk Magnitude*** ***(RM^{susr})***
M	H	VL	L
M	M	VH	M
M	M	H	M
M	M	M	M
M	M	L	L
M	M	VL	VL
M	L	VH	L
M	L	H	L
M	L	M	VL
M	L	L	VL
M	L	VL	VL
M	VL	VH	VL
M	VL	H	VL
M	VL	M	VL
M	VL	L	VL
M	VL	VL	VL
L	VH	VH	L
L	VH	H	L
L	VH	M	VL
L	VH	L	VL
L	VH	VL	VL
L	H	VH	VL
L	H	H	VL
L	H	M	VL
L	H	L	VL
L	H	VL	VL
L	M	VH	VL
L	M	H	VL
L	M	M	VL
L	M	L	VL
L	M	VL	VL
L	L	VH	VL
L	L	H	VL
L	L	M	VL
L	L	L	VL

Objective Index ($SUSR - OI$)	***Risk Severity ($SUSR - RS$)***	***Risk Likelihood ($SUSR - RL$)***	***Risk Magnitude (RM^{susr})***
L	L	VL	VL
L	VL	VH	VL
L	VL	H	VL
L	VL	M	VL
L	VL	L	VL
L	VL	VL	VL

Appendix Five. Rule Base for the Organisational Sustainability Risks

Risk Severity ($SCR - RS$)	*Risk Likelihood* ($SCR - RL$)	*Risk Magnitude* (RM^{scr})
VH	VH	VH
VH	H	VH
VH	M	VH
VH	L	H
VH	VL	M
H	VH	VH
H	H	H
H	M	H
H	L	M
H	VL	M
M	VH	H
M	H	H
M	M	M
M	L	M
M	VL	L
L	VH	H
L	H	M
L	M	L
L	L	L
L	VL	L
VL	VH	M
VL	H	L
VL	M	L
VL	L	VL
VL	VL	VL

Appendix Six. Expert Contribution Factor AHP

	E1	E2	E3	E4	E5
E1	1	1	2	3	2
E2	1	1	2	3	2
E3	0.5	0.5	1	2	2
E4	0.33333333	0.33333333	0.5	1	0.5
E5	0.5	0.5	0.5	2	1
	Eigen value		Lambda		5.074492
	Consistency Ratio		CR		1.70%

Appendix Seven. Sample Coding of a Field Notes Transcript

Field Notes Transcript Coding Sample of an Interview (PCS2-IN6)

Global Sustainability Issues (Chapter 6)

Sustainability Aspects	**Code**	**Related Notes**
Resource Efficiency	Sustainability Issues - Resource Efficiency	Lot of heat is wasted in exhaust. We are planning to use the exhaust flu gas to dry biomass in rainy season and for cooking in our hostels.
Waste Management	Sustainability Issues - Waste Management	By product is charcoal, it is used for electricity connection purposes. This saves us money.
Energy Security and Access	Sustainability Issues - Energy Security and Access	The cost of operation for electricity produced is cheaper than diesel generator but costly than grid supply.
Fossil Fuel Conservation	Sustainability Issues - Fossil Fuel Conservation	Bioenergy saves lot of diesel, which we will instead use in our diesel generators.

Supply Chain / Organisational Sustainability Issues (Chapter 7)

Supply Chain Issues	**Code**	**Related Notes**
	Raw Material	
Price	Supply Chain Issues - Raw Material - Price	Main concern is the cost of raw material. Change in fuel price is due to competition with other industries for raw material. Cost increase of raw material due to non - automated process.
Quality and characteristics	Supply Chain Issues - Raw Material - Quality and characteristics	Quality of the fuel is important especially moisture in biomass is a problem.
	Storage	

Supply Chain Issues	**Code**	**Related Notes**
Unavailability of storage space	Supply Chain Issues - Storage - Unavailability of storage space	Storage space is required for biomass to manage the price fluctuation of raw material.
Pre-processing & Handling		
Improper handling	Supply Chain Issues - Pre-processing & Handling - Improper handling	Manual labour issues during loading and handling.
Manual pre-processing	Supply Chain Issues - Pre-processing & Handling - Manual pre-processing	Cost increase of raw material due to non - automated process. Also slow production due to non - automated process. Automation is required.
Conversion		
Breakdown risk	Supply Chain Issues - Conversion - Breakdown risk	Issues with the quality of the infrastructure for boiler and grid supply lines.
Maintenance difficulties	Supply Chain Issues - Conversion - Maintenance difficulties	Requires a good maintenance otherwise there are too many issues. Maintenance cost is an issue but to a lower extent when compared to the raw material cost. Availability of spare parts for the conversion plant is difficult in rural areas (this leads to time delay). Associated parts and products (grease, oils, and spares) are only available in huge quantity, and not in small quantity. This leads to lot of waste and losses.
Service support	Supply Chain Issues - Conversion - Service support	Maintenance commitment issues from supplier. Availability of spare parts for the conversion plant is difficult in rural areas (this leads to time delay).

Supply Chain Issues	**Code**	**Related Notes**
	Downstream / Market	
Technical risk	Supply Chain Issues - Downstream / Market - Technical risk	Issues with the quality of the infrastructure for boiler and grid supply lines.
Infrastructure risk	Supply Chain Issues - Downstream / Market - Infrastructure risk	Unavailability of suitable grid line nearby to operate full time and supply in gird.
Cost of energy	Supply Chain Issues - Downstream / Market - Cost of energy	The cost of operation for electricity produced is cheaper than diesel generator but costly than grid supply.
Competition with other energy industries	Supply Chain Issues - Downstream / Market - Competition with other energy industries	The cost of operation for electricity produced is cheaper than diesel generator but costly than grid supply.
	Across	
Labour shortages	Supply Chain Issues - Across - Labour shortages	Skilled man power is required. Technical know - how will make the job easy.