SUSTAINABILITY ASSESSMENT OF SECOND- GENERATION BIOFUEL SUPPLY CHAIN WITHIN CIRCULAR ECONOMY FRAMEWORK

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by

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Abstract

The global demand for renewable energy sources has intensified and, the second-generation ethanol has emerged as a promising alternative to traditional fossil fuels. This study presents a comprehensive sustainability assessment of second-generation ethanol production, focusing on environmental, economic, and social dimensions. The evaluation incorporates a life cycle perspective to analyse the entire production process, from feedstock cultivation to fuel distribution. The environmental assessment considers key factors such as greenhouse gas emissions, land use change, water consumption, and other relevant indicators. By employing advanced modelling techniques and up-to-date data, the study aims to provide a nuanced understanding of the environmental impact of second-generation ethanol compared to conventional ethanol and other biofuels. In addition to environmental considerations, the economic analysis explores the financial viability and competitiveness of second-generation ethanol production. Factors such as production costs, market dynamics, and policy incentives are examined to determine the economic feasibility and potential for widespread adoption. Social aspects are crucial in assessing the overall sustainability of second-generation ethanol. The study examines the impacts on local communities, employment opportunities, and potential conflicts with food production. The analysis also addresses the broader societal implications, including issues of equity, accessibility, and social acceptance. The findings of this sustainability assessment aim to inform policymakers, industry stakeholders, and the public about the strengths and challenges associated with second-generation ethanol. By identifying areas for improvement and potential trade-offs, the study contributes to the development of a more sustainable and socially responsible bioenergy sector.

As the global energy landscape evolves, understanding the holistic sustainability of second-generation ethanol becomes imperative for making informed decisions and achieving a more sustainable energy future. The chapter starts with the global statistics of greenhouse gas emission from the fossil fuel and biofuel. The advantages of biofuel over the fossil fuel are the major reason to switch for the biofuel technology and the advantages have been described in a comprehensive manner. As India is rich in agricultural resources, an agricultural waste to ethanol pathway is possible for future transport. Ethanol blending has been implemented in India; but currently it is limited to 10 percent in petrol; but the ethanol is a first generation based which directly comes from plant-based feedstock. The first-generation ethanol might arise the issue of food versus fuel as India has the global hunger index of 111 out of 125. The idea is inspired from the circular economy (CE) framework here. Like the CE we have tried to close the loop through our study. Hence farm area to farm area analogy has been presented which can be termed as cradle-to-cradle technology. CE promotes the diversification of supply chains by reducing dependence on a linear flow of resources. This can enhance resilience against supply chain disruptions and price fluctuations.

A descriptive case study is performed for the analysis of the agricultural waste suitable for the generation of ethanol, viability of the upstream of the supply chain, feasibility of the thermochemical and biochemical conversion and finally closing the loop. A detailed study shows the efficacy of the proposed ethanol supply chain with the help of sustainability indicators.

The economic indicator encapsulates revenue generated, IRR (Internal rate of return) and NPV (net present value), whereas the environmental indicator includes emissions, and the social indicator includes number of jobs created.

The mathematical modelling has helped in assessment of the sustainability indicators. The amalgamation of heuristic based algorithm and circular economy framework is one of the innovative works done to prove the sustainability. The heuristic algorithm is based on the cognitive behaviour of birds who search for optimal location of food. It is a new methodology where the machine learning is used to predict the total revenue, emissions and number of jobs generated for the next 5 years. A constrained based non-linear optimisation is the main part of the algorithm which is known as particle swarm optimisation algorithm. Few constraints are connected to the mass and energy balance of the supply chain. The mass and energy balance are performed to analyse the total influx and outflux from the farm area and the collection centre. The circular economy framework has enabled to visualise the role of many components starting from farmers to policymakers in the loop. The defined 9R framework is radical in the way it has been implemented to prove the cradle-to-cradle thinking. It connects each component of the defined ethanol supply chain with the sustainability indicators intact. The aim of the work is to establish a path leading research to enable waste to energy concept. In this model the research work is based in the state of Karnataka, India. The work can be extrapolated to any geographical area on the globe.

Chapter 1

Introduction

This chapter encompasses the summary of the purpose of the research, methodology and the global conditions in the sector of biofuel supply chain. The preamble is the abstract of the introduction section and there is an outline section to describe the contents of each chapter.

1.1 Preamble

The progressing globalization of production and the related supply chains are the reason for the growing demand for transport. The transportation energy consumption is expected to increase up to 155 quadrillion B.T.U (British thermal units) in 2040 (World Energy Council). In developed countries, the transport sector energy consumption is continuously increasing and estimated more increase up to 30% due to improvement in living standards in the world[1]. The fossil fuel-based transport leads to air pollution while excavation and by burning it. These fuels, primarily derived from petroleum, coal, and natural gas, are burned in internal combustion engines to generate the energy needed for vehicle movement. While they have enabled tremendous mobility and economic growth, the combustion of fossil fuels in the transportation sector has significant environmental consequences, primarily due to the emission of various pollutants and greenhouse gases . The transport CO_2 emissions (TCO_2) has increased by approximately 80% from 1990 to 2019 [1]. To address the environmental challenges posed by the combustion of fossil fuels in the transportation sector, governments and international organizations have established emissions standards and regulations. These standards set limits on the number of specific pollutants that vehicles and engines can emit. Instead of fossil fuels, biofuels such as ethanol, methanol, and dimethyl ether can be potential alternative fuels. Globally, the biofuel share in transport fuel consumption climbs from 4.3% to 5.4% during 2022-2027[2]. On a life-cycle basis, biofuel (ethanol) has a low carbon footprint. Ethanol emits 8.58 kg of CO_2 per gallon combusted, [2] whereas methanol emits 10.40 kg per gallon combusted, and gasoline emits 8.88 kg per gallon combusted. A graph is plotted is to show the share of emissions in various fuel types. The graph clearly states that unlike fossil fuel, biofuels reduce around 83 % of greenhouse gas emissions throughout the life cycle and improves air quality as per the data presented in Figure 1.1 [4].

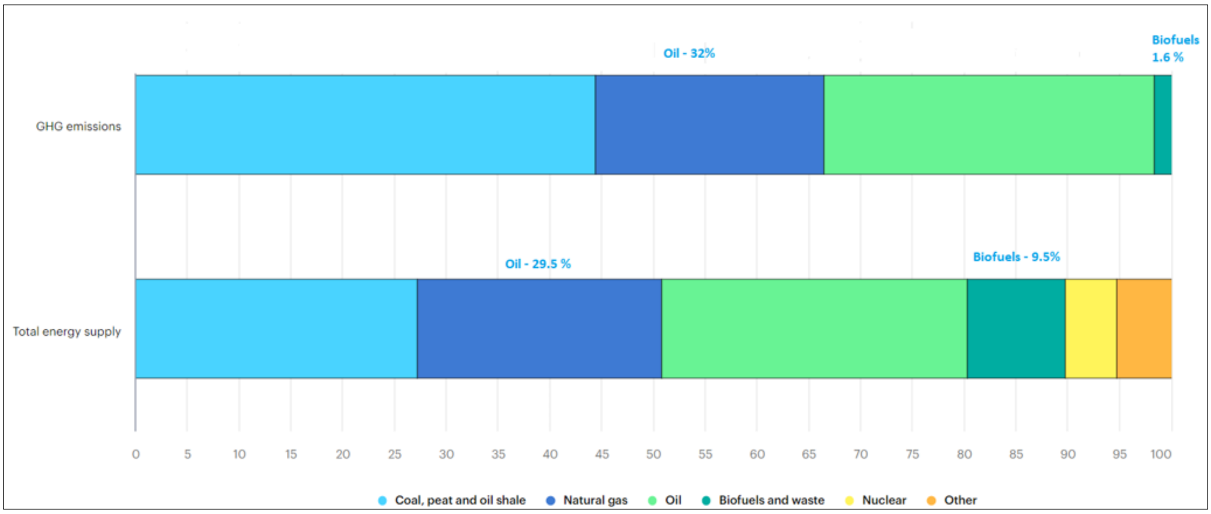


Figure 1.1 GHG Emissions in various fuel

1.1.1 Drawbacks of fossil fuel - based supply chain

Fossil fuel-based transport, which primarily relies on gasoline and diesel, comes with several significant disadvantages, including:

Air Pollution and Greenhouse Gas Emissions: Burning fossil fuels in vehicles releases harmful pollutants into the air, including particulate matter, nitrogen oxides, sulphur dioxide, and volatile organic compounds. These pollutants contribute to smog formation, respiratory illnesses, and other health problems [2]. Fossil fuel-based transport is a major contributor to greenhouse gas emissions, primarily carbon dioxide (CO_2). These emissions are a significant driver of global climate change and contribute to rising temperatures, sea level rise, and more frequent extreme weather events. Annual production-based emissions of carbon dioxide (CO_2) from oil, measured in tons per person is:

Climate Change: The emissions from fossil fuel-based transport are a significant driver of climate change, leading to long-term disruptions in ecosystems, food production, and overall environmental stability.

Energy Security: Fossil fuels are finite resources and subject to geopolitical tensions, price volatility, and supply disruptions. Dependence on fossil fuels for transport can make countries vulnerable to these uncertainties.

Resource Depletion: The extraction and consumption of fossil fuels contribute to resource depletion. As these resources become scarcer, extraction becomes more challenging and can result in environmental damage, such as oil spills during offshore drilling.

Public Health Costs: The health impacts of air pollution from fossil fuel transport can lead to increased healthcare costs and reduced quality of life for affected individuals [3]. This burden is often borne by society.

Economic Costs: Fossil fuel-based transport involves costs related to fuel extraction, refining, distribution, and maintenance. Additionally, countries often spend significant resources to mitigate the environmental and health impacts of fossil fuel use.

Innovation and Technological Lock-In: Relying on fossil fuels can hinder the development and adoption of cleaner, more sustainable transportation technologies, such as electric vehicles or hydrogen-powered vehicles.

Loss of Biodiversity: The extraction, transportation, and use of fossil fuels can lead to habitat destruction and ecosystem disruption, affecting biodiversity and causing harm to ecosystems.

For oil the emission is 10919.7 MT of CO_2 equivalent and for biofuels the emission is 545.3 MT of CO_2 equivalent globally in the year 2021[3].

The advantage of the second-generation ethanol is its resource i.e., biomass has abundance availability. Unlike other renewable resources we get plenty of biomass (different types) throughout the year. The total agricultural residues annually amount to more than 1000 MT in India, 75 % to 80 % of which gets used as fodder for livestock and other societal needs [24]. Considering the surplus portions of residues available from the selected crops, the annual national potential is only 234 MT [3]. The 'first-generation' biofuels appear unsustainable because it possesses food versus crop issue [3]. These are dependent on simple materials (i.e., cellulose, ethanol, and biofuels).

1.1.2 History of Ethanol

Ethanol was developed as an alternative fuel by Edwin Drake in 1859 [4]. Previously, the energy crisis emerged, and lamp oil was used as a replacement for the diminishing supply of whale oil. Instead of vegetable-based oil, whale oil was preferred. By the late 1830s, ethanol blended with turpentine (refined from pine trees) was being used to replace the more expensive whale oil. Biofuels became prominent in the early twentieth century and were a crucial source in the discovery of the automobile.

Henry Ford envisioned automobiles that relied on ethanol as their fuel source. As ethanol gained interest worldwide as a fuel for automobiles, a piece of article in 1906 New York Times said: “Auto Club Aroused Over Alcohol Bill”. This article described concerns over the influence of ethanol on the gasoline industry in the quote, “Gasoline is growing scarcer, and therefore dearer, all the time.” This might be the first indication of competition between the petroleum and ethanol industries.

Furthermore, Alexander Graham Bell was quoted in a 1917 National Geographic interview stating that biofuel can be produced from Corn stalks, and in fact, from almost any vegetable or agro residue matter which is capable of fermentation. Our growing crops and even switchgrass can be used. The waste products of our farms and municipal solid waste in the cities are available for this purpose. We need not fear the exhaustion of our present fossil fuel supplies so long as we can produce an annual crop of biofuel to any extent desired [4]. Also, the existing policies by ministry of petroleum and oil are favorable for implementing an ethanol supply chain.

Ethanol is derived from biomass material, commonly used as an alternative, cleaner fuel source to burning fossil fuels. Biomass can be of two types. 1.Plant-Based 2. Animal Based. At the beginning of the year 2001 India started blending the first-generation ethanol in petrol; but the 1st generation ethanol plant is not enduring due to the reasons explained in Table 1.1. So, the concept of second-generation and third-generation ethanol has been initiated. The third-generation ethanol technology is in the nascent stage and will take longer than the second-generation technology to be commercially viable. The table 1.1 gives the comparison between three types of biofuels depending upon the synthesis methodology and resources.

First Generation	Second Generation	Third Generation
i. Agricultural-based crops. ii. E.g., sweet sorghum, sugarcane, -, broken wheat, corn. iii. Usually, the cellulose and hemicellulose are the main component of the feedstock is utilized here. Example: deconstruction and fractionation, synthesis and upgrading [25]. iv. The conversion paths are biochemical pathways in most the cases. v. The prices are too high. vi. It gives rise to the food vs. fuel problem.	i. Here agricultural waste is considered. ii. E.g., Corn Stover, Switchgrass, Forest residue iii. The lignocellulosic component is utilized in this methodology. iv. Here the conversion pathways are biochemical, thermochemical or hybrid. Example: Gasification followed by biochemical route, fermentation, pyrolysis [25]. v. Feedstock value remains high due to processing. (Shredding, densifying, pulverization, handling).	i. Like 2nd generation biofuels, they are made from non-food feedstocks. ii. E.g., Algae is a potential biofuel or 3G biofuel. iii. Like second - generation, the pathways of conversion are both biochemical and thermochemical here. iv. Example: gasification, extraction and transesterification, fermentation, and anaerobic digestion processes [25]. v. Several Techno-Economic challenges exist while bringing 3G biofuel.

Table 1.1 (Categories of biofuel)

1.2 Introduction to Biofuel Synthesis Methods

The synthesis of biofuel production might be done either in biochemical or in thermochemical pathways. The figure 1.2 shows the two types of pathways for extracting ethanol.

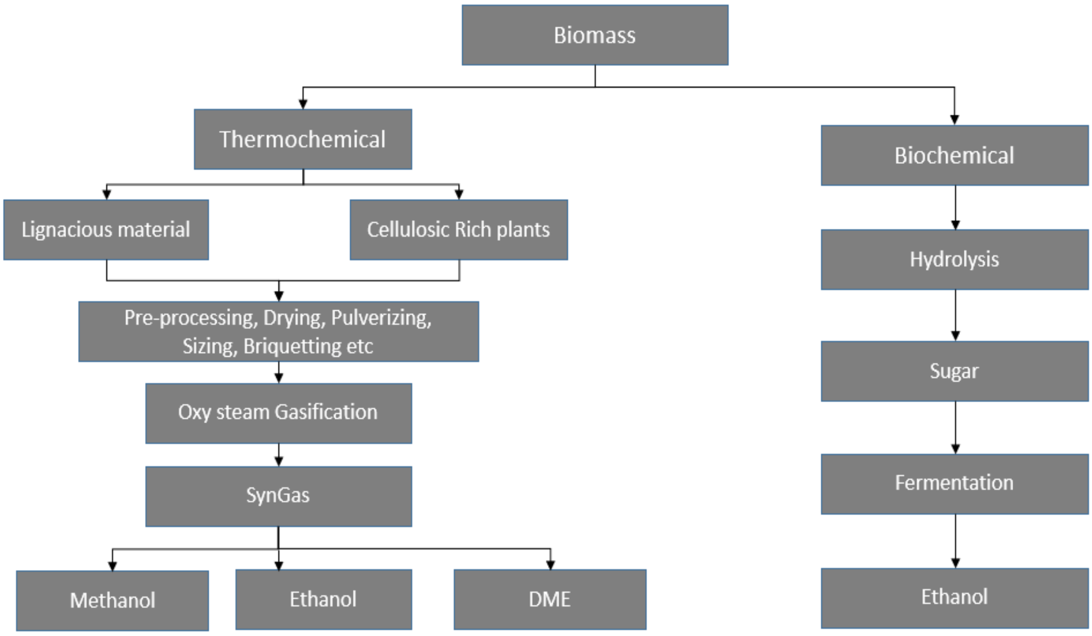


Figure 1.2 (Different types of biomasses to biofuel conversion methods)

1.2.1 Thermochemical pathway of conversion

It is a step-by-step process which starts from preprocessing. Such as 1- Pulverization 2- Briquetting 3- Drying. In the biomass supply chain, it is included in the storage and handling stage. Primarily for surplus biomass, step 2 or step 3 is preferred.

The next step can be pyrolysis or gasification. As we are proposing the conversion process of our CGPL lab, so oxy-steam gasification is considered. Syngas is synthesized after the conversion is completed. The syngas is further converted into ethanol, methanol, and DME, butanol etc. A detailed study is presented in chapter 4. It has four basic steps. 1- Hydrolysis 2- sugar formation 3- Fermentation 4- Ethanol formation. The detailed process of 1G and 2G ethanol is described later in this chapter. In the context of the Biochemical pathway, we are considering the Ethanol Synthesis Process. Its manufacture in the distilleries involves mainly three steps.1-Feed Preparation 2- Fermentation 3-Distillation.

Feed Preparation

As molasses are considered biomass, they will be diluted with water first to obtain a feed containing sugar. The PH is adjusted if required by the addition of Sulfuric Acid. The diluted molasses solution is transferred to a fermentation tank.

Fermentation and the subsequent process

Fermentation is the anaerobic or aerobic pathway where organic compounds' enzymatic conversion occurs. Especially Carbohydrates break into Simpler compounds, mainly Ethyl alcohol or ethanol.

When reactions begin with yeast, the initial concentration of glucose ($C_6H_{12}O_6$) will be very high, so through diffusion, glucose enters the yeast. As the reaction proceeds, the glucose molecule is broken down into a 10-step process is known as glycolysis. The product of glycolysis is two three-carbon sugars, named pyruvates and some ATP (adenosine triphosphate, brought up earlier in the photosynthesis process). The ATP supplies energy to the yeast allowing it to multiply. The two pyruvates are converted by the yeast into carbon dioxide (CO_2) and ethanol (CH_3CH_2OH, which is the biofuel) [2].

The overall reaction is:

$$\mathbf{C_6H_{12}O_6 + Yeast \rightarrow 2CH_3CH_2OH + 2CO_2} \qquad (1)$$

The flowchart gives the generic way of extraction of ethanol in biochemical and thermochemical pathways. Figure 1.3 shows the 1st generation and 2nd generation ethanol extraction processes.

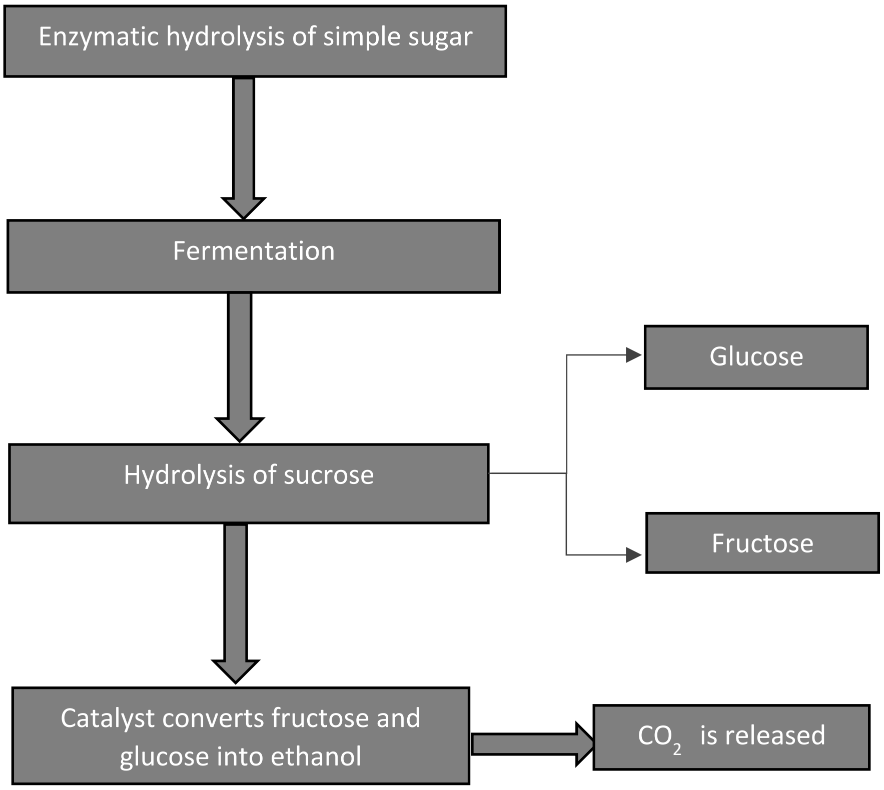


Figure 1.3(Biochemical pathway of 1st generation ethanol synthesis)

1.2.2 Second -generation ethanol synthesis

Second-generation biofuel synthesis is complex as lignin is hard to break. So, 2nd Generation biofuel synthesis through biochemical pathway is difficult. Still, many pieces of literature have cited various ways of extracting ethanol from Crop Residues. One such example is given in the following figure. The conversion of lignocellulose biomass to alcohol requires a three-step process, i.e., pretreatment of biomass, acid or enzymatic hydrolysis, and fermentation/distillation. The steam explosion process is an efficient pre-processing method for converting lignocellulosic biomass. In the biofuel conversion process, biomass sample is placed in a pressure vessel (i.e., digester) and vaporized using saturated steam for a short time (20 s to 20 min) at a temperature 473–543 K and high pressure 14–16 bar. The pressure in the digester is then dropped quickly by opening the steam, and the material is exposed to normal atmospheric pressure to cause an explosion that disintegrates lignocellulose biomass. Several types of devices are used for steam explosions. It causes the lignin and hemicellulose from the wood to be decomposed, and it gets converted into low molecular weight fractions, which can be easily extracted. Most of the water-soluble fraction of hemicellulose is removed by water extraction. At the same time, a part of the low molecular weight fraction of lignin is also extracted. The lignin is further processed to produce other fuels, and the xylose can be fermented to ethanol. The crystalline cellulose remains solid after the pretreatment, and later its alcohol, and the hemicellulose fraction gets converted to xylose. The conversion of xylose to ethanol is a difficult process. Therefore, pretreatment is necessary to reduce the crystallinity of cellulose to reduce the average polymerization of the cellulose, hemicellulose, and lignin sheath that surround the cellulose and to increase the available surface area for the enzyme to attack [2]. The fig 1.4 represents one of the methods of synthesizing ethanol from lignocellulosic mass.

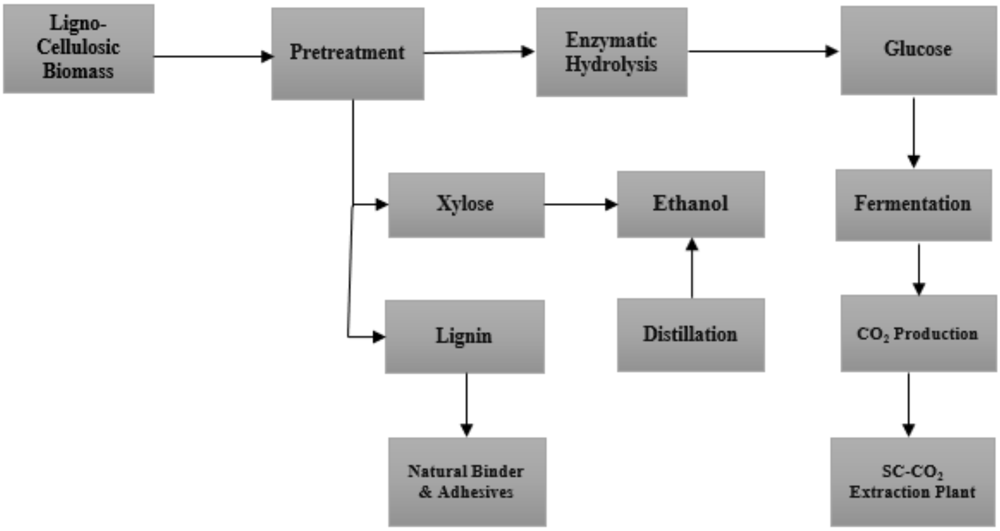


Figure 1.4(Block Diagram Demonstrating the 2^{nd} *Generation Biofuel Extraction Process)*

1.2.3 Thermochemical Pathway of Conversion for 2^{nd} Generation Ethanol

Thermochemical conversion encompasses thermal breakdown of organic components of biomass to produce biofuels obtained via various procedures—for example, direct combustion, pyrolysis, gasification, and thermochemical liquefaction [10]. Biomass gets converted to energy by mainly two processes. They are either thermochemical or biological. The thermochemical conversion process includes direct combustion, gasification, liquefaction, and pyrolysis. When heated under oxygen-deficient conditions, biomass generates synthesis gas or syngas, primarily hydrogen and carbon monoxide. The syngas can be directly burned or processed for other gaseous or liquid products. In this sense, biomass's thermal or chemical conversion is very similar to coal.

1.2.3.1 Gasification process

In the gasification-synthesis route, biomass is converted into raw syngas, which are further reformed, cleaned, compressed, heated, and converted into mixed alcohols, from which ethanol and higher alcohols are obtained through a series of separation and purification treatments. This route has the following advantages: short reaction time, inexpensive and abundant raw materials, nearly complete biomass conversion, and so on [1]. We already work on various pathways of synthesising biofuel in CGPL (Combustion Gasification Propulsion Lab), IISc, Bangalore. The overall view of synthesizing biofuel is provided in figure 1.5. The detailed study is provided in chapter 4.

Example of Work done in CGPL

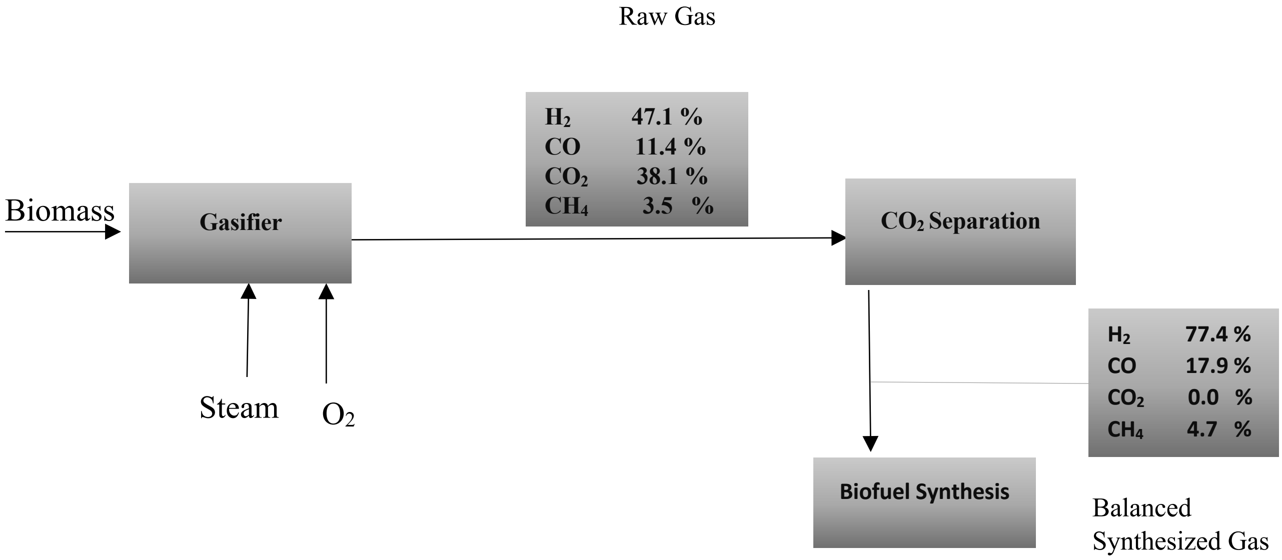


Figure 1.5(Biofuel synthesis in thermochemical pathway performed at CGPL, IISc)

The technical route gives the idea about the conversion of biomass to ethanol. But it has given no idea on the viability of the biomass, scale of production, feasibility of the supply chain or replacement factor of the ethanol with the traditional fossil fuel. To establish a decisive theory on whether second generation ethanol is feasible, the research work is made with the help of the data by NITI Aayog, TIFAC and some non-profit organizations. Based on the theory justification of the overall net zero goal through the supply chain analysis was needed. Hence, circular economy framework played an important role while establishing the proposed work.

1.3 Introduction to Biofuel supply chain

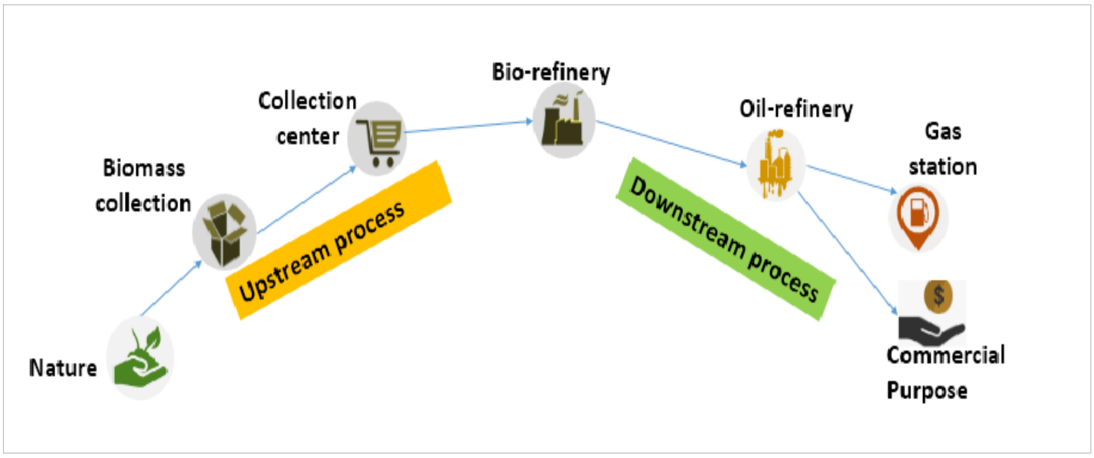


Figure 1.6(A conventional linear economy-based biofuel supply chain)

The figure 1.6 gives an idea about a traditional biofuel supply chain system depicting a linear economy. It has 2 parts 1. Upstream 2. Downstream. The drawback of linear economy-based supply chain lies with the fact of an increased openness to renewable energy resources, national and international and energy security, and the need for expansion into new markets for crops in the world trade sector are all parameters making a shift in expanding biofuel use. However, developing countries with tropical climates might have a comparative advantage in growing energy rich biomass; and second-generation technologies could expand of the range of feedstock used from the traditional paddy, sugarcane, Corn, and cotton to grasses and trees that can thrive in less fertile and more drought prone regions. When we discuss Indian scenario, the increasing demand for energy has become paramount to identify indigenous renewable sources to supplement traditional sources. On the other hand, the drawbacks in case of environmental factor can be demonstrated by the help of Fig 1.1. The plot (Fig 1.1) gives the information on CO_2 emissions due to the transport sector. The drawbacks of the present fossil fuel-based transport system demand an entire shift in lieu of climate change and greenhouse gas emissions. Hence the proposed research work is based on a sustainable biofuel supply chain within the circular economy framework.

A significant drawback in the well-to-wheel analysis is that it only discusses the life cycle assessment of a resource until it becomes a product. This analogy is a bit incomplete as it does not include the GHG, and CO_2 emissions after the product has been utilized. It neither talks about the socio-economic condition of the people attached to the system nor about the environmental impact after the product has reached the consumer.

1.3.1 Global methodology to deal with the second generation - based ethanol supply chain.

Below are some common policy approaches that were being implemented or considered globally:

i. Renewable Fuel Standards (RFS) and Biofuel Mandates: Many countries and regions have established Renewable Fuel Standards or biofuel blending mandates. These policies require a certain percentage of transportation fuels to come from renewable sources, including second-generation biofuels. Compliance with these mandates often leads to increased demand for advanced biofuels, driving investment and growth in the supply chain.

ii. Subsidies and Incentives: Governments may provide financial incentives or subsidies to support the production and distribution of second-generation biofuels. These incentives can help reduce the cost of production, making biofuels more competitive with traditional fossil fuels. They can also encourage investment in research and development to improve technologies and processes [12].

iii. Tax Incentives: Tax credits or exemptions can be provided to biofuel producers, distributors, or consumers to stimulate the adoption of second-generation biofuels. These measures can help create a more favorable economic environment for the biofuel industry.

iv. Research and Development Funding: Governments may allocate funding for research and development initiatives aimed at advancing second-generation biofuel technologies. This support can accelerate innovation, improve efficiency, and reduce the production costs of biofuels [12].

v. Sustainability Certification: Some countries and regions have implemented sustainability certification schemes for biofuels to ensure that they meet specific environmental and social criteria. These certifications can help differentiate sustainable biofuels in the market and provide assurance to consumers and stakeholders about the environmental benefits.

vi. Carbon Pricing and Emissions Reduction Policies: Carbon pricing mechanisms, such as carbon taxes or cap-and-trade systems, can create economic incentives to reduce greenhouse gas emissions. Second-generation biofuels, which are often considered to have lower lifecycle emissions compared to fossil fuels, can benefit from such policies [12].

vii. Government Procurement: Government agencies may incorporate biofuels into their own fleets or operations as part of their commitment to sustainability. Government procurement can serve as a significant market driver for second-generation biofuels.

viii. International Agreements and Cooperation: International agreements and collaborations between countries can foster the development and trade of sustainable biofuels. Harmonizing standards and regulations can facilitate the global supply chain for second-generation biofuels.

ix. Land Use and Environmental Regulations: Land use regulations can impact the availability of feedstocks for biofuel production. Governments may implement policies to ensure that biofuel feedstocks are sourced sustainably without contributing to deforestation or biodiversity loss [12].

x. It is important to note that the policy landscape for second-generation biofuels is constantly evolving, and new policies may have been introduced or existing policies may have been updated since my last update. For the most current information on policies related to second-generation biofuels, I recommend consulting official government sources, international organizations, and reports from reputable research institutions.

1.3.2 Need of Second generation - based ethanol supply chain in India

i. Energy sector accounts for more than 70% of greenhouse gas emissions in India. India aims to reach net zero carbon emissions by 2070. India's public think tank NITI Aayog, provides a detailed picture on how CO_2 emissions from road transport are likely to grow under existing policies and compares these projections with a pathway that could bring the sector on track with the 2070 goal. It discusses various policy options that the country could consider to accelerate the shift to sustainable road transport, focussing on the benefits that energy efficiency improvements and a switch to cleaner energy sources can bring.

ii. Compared to methanol, ethanol is nontoxic, less corrosive, has higher energy densities, and is already available in large volumes, reducing the vulnerability of racers to oil price increases and supply disruptions. Low-level blends of E10 or less require no special fuelling equipment, and they can be used in any conventional petrol or diesel-based vehicle [23].

iii. The previously developed methodologies have elaborated on how a product can be derived from the source and utilized commercially, i.e., well-to-wheel analogy. The afterlife of a product or entity in a system was questioned as we know landfilling is not a solution. The established well-to-wheel analysis does not address the issue of the 'after life' of the product. The current linear economy fails as it does not address the problem of the afterlife or the impact on the environment and social indicators. The reason for selecting the biofuel supply chain in the transport sector is that the transport sector contributes to emissions.

iv. Another drawback is the carbon footprint of the electric vehicles which is a major source of scope 3 emissions. As we all know of the 'Kyoto Protocol,' in the second commitment period, parties committed to decreasing greenhouse gas emissions by at least 18 percent below 1990 levels in the eight years from 2013 to 2020. So, the Indian Authority has tried implementing Electric Vehicles (EVs) and Hybrid Vehicles. Still, an electric vehicle's drawback is the Carbon Emission during EV manufacturing, and the Charging station is more than that of an IC engine Vehicle since the power comes from a coal plant [3]. Additionally, the disposal of batteries used in EVs is a difficult task.

v. Besides, various social, economic, and environmental reasons show the necessity of alternative fuels. Negative social indicators are unemployment, poor working conditions, social vulnerability, the poverty trap, intergenerational equity, and widening inequalities [9]. Similarly, the drawbacks which press upon the need for economic indicators are supply risk, complicated ownership structures, deregulated markets, and flawed incentive structures that lead to increasingly frequent financial and economic instabilities for individual companies and entire economies. In the environment, it is the toxic emissions from various transport modes and maintaining profitability in all segments of the transportation-based supply chain. The supply chain based on fossil fuels is not sustainable as it solves a few issues related to social and environmental indicators [10].

vi. The paradigm shifts from linear to circular economy is a necessity today. Waste handling is one of the biggest concerns of today's world. The linear economy is already well established, and the drawbacks are evident from the crisis of Bolivia and Indonesia [19][20].

vii. In September 2021, India was indeed actively promoting second-generation ethanol production as part of its efforts to increase biofuel usage and reduce its dependence on fossil fuels. Second-generation ethanol is produced from non-food feedstocks, such as agricultural residues, lignocellulosic biomass, and municipal waste, making it a more sustainable and environmentally friendly option compared to first-generation ethanol.

viii. National Policy on Biofuels: The Indian government has been formulating and updating its National Policy on Biofuels to create an enabling environment for the production and utilization of biofuels, including second-generation ethanol.

ix. Ethanol Blending Program: India has been implementing the Ethanol Blending Program (EBP), which aims to blend a certain percentage of ethanol with gasoline to reduce greenhouse gas emissions and promote the use of renewable fuels. The focus is to increase the blending percentage gradually, with an emphasis on second-generation ethanol.

x. Incentives and Subsidies: The government has been providing various incentives, subsidies, and financial support to encourage investment in second-generation ethanol production facilities. These may include tax benefits, grants, low-interest loans, and viability gap funding.

xi. Research and Development: India has been investing in research and development to improve the technology and efficiency of second-generation ethanol production processes. Several public and private research institutions have been involved in this area.

xii. Public-Private Partnerships: The government has been encouraging public-private partnerships to foster collaboration between the government, industry, and research institutions to accelerate the development and commercialization of second-generation ethanol technologies.

xiii. Setting Up Ethanol Plants: Indian Oil Marketing Companies (OMCs) and other private players have been setting up ethanol plants to produce second-generation ethanol from various feedstocks like agricultural residues, wheat straw, paddy straw, sugarcane bagasse, and others.

xiv. Alternative Feedstocks: Besides agricultural residues, India has also been exploring other non-food feedstocks like bamboo, algae, and industrial waste for second-generation ethanol production.

xv. Infrastructure Development: The government has been working on enhancing the necessary infrastructure, such as storage, transportation, and distribution facilities, to support the increased production and usage of ethanol as a transport fuel. The Cabinet has approved a scheme to give Rs 1969 crore as viability gap funding to second-generation (2G) ethanol projects over the years [9]. The government of India aims to achieve a 20% blending percentage of ethanol in petrol by 2023. The government explores an alternate channel of 2G ethanol from agro residue and other kinds of wastes to bridge the supply gap for the ethanol blending program. The scheme aims to incentivize the 2G Ethanol sector and support this nascent industry. The proposed idea can be made possible by creating a suitable ecosystem to set up industries and to increase research & development in this area [9]. In line with National Policy on Biofuels, Government has approved "Pradhan Mantri JI-VAN (Jaiv Indhan-Vatavaran Anukool Fasal Awashesh Nivaran) Yojana" for providing financial support to the integrated ethanol projects which use lignocellulosic biomass & other renewable feedstock, with a total financial outlay of Rs 1969.50 crore for the period 2018-19 to 2023-24[15]. Through Oil Marketing Companies (OMCs), the government is implementing the Ethanol Blended Petrol (EBP) program under which OMCs sell ethanol blended with petrol with a percentage of ethanol up to 10%, subject to its availability. OMCs procure ethanol for blending in petrol. In the Ethanol Supply Year 2018-19, 180.80 crore liter of ethanol has been procured by OMCs up to 11.11.2019 [15].

A detail state of art referred to evolution of biofuel is presented in Chapter 2 as a part of literature review. Although second generation ethanol supply chain is an effective technique, to establish the supply chain the cradle -to- cradle (circular economy) technology has played an important role.

1.4 Circular Economy

A circular economy keeps materials, products, and services in circulation for as long as possible. It is a change to the model in which resources are mined, made into products, and then become waste. It reduces material use, redesigns materials, products, and services to be less resource intensive, and recaptures "waste" as a resource to manufacture new materials and products [7]. Earlier, the cradle-to-grave analogy (well to wheel) gave abridged information about system/product sustainability, but a research gap exists while implementing the analogy. Therefore, the novel idea of cradle-to-cradle analysis has come into the picture. The novelty of this proposed idea is that it encloses the path from its origin. The well-to-wheel or the techno-economic analogy mainly talked about two indicators.

1- Technical 2- Economic. But in a circular economy, the environmental and social indicators have been added, which gives perfect information on the valorization of by-products. The foundation of Circular Economy is based on the 4 R principle. 1- Reduce, 2- Reuse, 3- Recycle 4- Recover. It is explicit that a circular economy is restorative and eliminates waste by using better materials, systems design and products enabled by innovative business models. The circular economy's principles are based on systems thinking, designing waste, embedding diversity, using waste as food, and running closed-loop systems on renewable energy. Many postulates, such as 1. Blue's economy, systems thinking, performance economy etc. have helped to derive the concept of circular economy and the details have been provided in chapter 5. The failure of the take-make-use theory has given birth to a circular economy theory. The circular economy is regenerative or restorative by design and intention. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of harmful chemicals, which impair reuse, and aims for the elimination of waste by introducing the concepts of waste valorization through the superior design of materials, products, systems, and, within this, business models [11]. In other words, it encourages reusing, refurbishing, and recycling when needed. Therefore, it is proposed to use the cradle-to-cradle (circular economy) impact assessment framework, including energy, economic, environment, ecology, and socio-economic impacts. Karnataka is a state in the southwestern region of India. Corn, Paddy, and Cotton are some significant crops grown in the state.

1.5 Research Gaps

The research aims to develop a framework that will address the drawbacks of the existing linear economy framework and establish a circular economy framework through energy modelling, life cycle assessment technique, mass balance circular business model, and suggestions of policy implementation. The following research gaps are articulated for the above research problem and are addressed appropriately at various phases of the research.

Standardization and Metrics: There was a lack of standardized metrics and methodologies for assessing the cradle-to-cradle performance. This made it challenging to compare circular economy initiatives across regions and industries. Researchers were working to develop comprehensive metrics to measure the circularity of products, processes, and systems.

Circular Business Models: While there were successful case studies of circular business models, there was a need for more in-depth research to understand their scalability and replicability across various sectors and contexts. Understanding the economic implications and incentives for businesses to transition to circular models was also a research gap.

Supply Chain Integration: Integrating circular practices into complex global supply chains presented challenges. Research was required to understand how different sectors could collaborate, how circular principles could be incorporated throughout the supply chain, and how this integration could be incentivized.

Technological Innovations: While technological advancements were driving circular economy solutions, there were still gaps in understanding how emerging technologies such as blockchain, artificial intelligence, and the Internet of Things could be optimally integrated into circular systems.

Regulatory and Policy Frameworks: Policymakers needed more evidence-based research on the impact of various policy interventions to promote circularity. Understanding the trade-offs and potential unintended consequences of policy measures was essential for effective decision-making.

Social and Equity Dimensions: Research on the social implications of the circular economy was relatively limited. It was essential to assess the distributional effects of circular economy practices and ensure that they do not exacerbate existing inequalities.

Circularity in Developing Countries: Most of the existing research focused on circular economy initiatives in developed countries. More research was needed to understand the challenges and opportunities for implementing circular practices in developing economies.

Lifecycle Assessment and Environmental Impact: Comprehensive life cycle assessments were essential to understand the overall environmental impact of circular products and services compared to traditional linear ones. Researchers were working to improve the methodologies and data availability for these assessments.

The proposed work has tried to answer all the research gaps through all the chapters. Also, some of the research questions have been summarized to give a comprehensive view of the objectives.

1.5.1 Research Questions

1) What are the different stages of a second-generation biofuel (Agro-residues to biofuel; Ethanol, Methanol, DME) supply chain?
2) How suitable are these methods for implementation in the transportation sector?
3) How to design a biofuel supply chain within a circular economy framework (Cradle to Cradle)?
4) How sustainable is such a biofuel supply chain?
5) What are the significant sustainability impacts (positive and negative) at every stage of the supply chain (resources, technology, economics, environment, social)?
6) What are the possible analytical approaches to assess the sustainability of the biofuel supply chain?
7) How to validate such an approach in a real-life situation

1.6 Research objectives

As the transport sector contributes to 30% GHG emissions in the world [16], it is a priority to assess the sustainability of an alternate fuel which can reduce the negative impacts caused by fossil fuels. The earlier approaches have given an idea of the techno-economic assessment of the system, but it remains silent on its carbon footprint and social impacts. The proposed work is validated by selected biomass type in the case of Karnataka. The novelty lies in developing and validating an optimisation model to assess the cradle-cradle sustainability of the biofuel supply chain. At last, it will be beneficiary in providing inputs for industries and policymakers based on the results and findings.

The research objectives can be summarized as follows:

1) To develop a generalized second-generation biofuel supply chain adopting a circular economy framework.
2) To conceptualize and develop a sustainability assessment framework for biofuel systems.
3) To use the cradle-to-cradle (circular economy) impact assessment framework, including energy, economic, environmental, ecology, and socio-economic impacts.
4) To validate the above framework for selected biomass types in the case of Karnataka.
5) To develop and validate an optimisation model to assess cradle-cradle sustainability of the biofuel supply chain.
6) To provide inputs for industries and policymakers based on the results and findings.

To assess the sustainability of the second generation - based biofuel supply chain cradle-to-cradle analysis is done to analyse the importance of introducing the biofuel in the IC engine of the vehicles. The traditional cradle to grave analogy has a few considerations on the social and environmental parameter especially while the raw materials are extracted and the end-of-life condition of the product begins. The circular economy framework will help to examine the proposed supply chain's economic, social, and environmental indicators and how it would benefit the transportation sector. In this context a second generation (2G) biomass to ethanol conversion-based supply chain is addressed, so agricultural waste such as corn cobs, corn stalks, and paddy straw are being considered for the proposed work.

The sustainability assessment uses a heuristic-based method, precisely the particle swarm optimisation technique. Finally, a 9R framework is introduced in the form of circular economy concepts and suggestions for new policy implementation for overall indicator establishment.

1.7 Research Approach

The proposed research is focused on assessing the economic, environmental, and social sustainability of a biofuel supply chain, preferably an ethanol supply chain. The biomass availability is intermittent for a fixed number of years. Its chemical composition such as moisture content, ash content and dry matter loss adds uncertainty to the mentioned model. Therefore, a need for a certain mathematical model was arising which will address the uncertainty and randomness. Heuristic based approach was more suitable than linear programming method for handling the issues with biomass. Hence, the assessment is done with the help of the particle swarm optimisation (PSO) technique which is a heuristic-based approach. The details of the method are given in chapter 3. The economic indicator category analyses the system profit or the revenue of the harvesting area, storage center, and thermochemical plant.

Similarly environmental and social indicators are also analyzed. The ecological indicator category includes kg CO_2 equivalent per unit, and the social indicator comprises the total number of jobs generated in each block. The CO_2 emissions in each block ensure the postulates of circular economy as it evokes the idea of waste to clean energy. The social indicator is an additional benefit in the loop as it gets satisfied in each block of the circular economy loop. The circular economy concepts are implemented in both upstream and downstream processes, which gives an idea that in each block of the biofuel supply chain, we have sub loops that verify the sustainability of each block w.r.t the indicators. At the end of the dissertation, a proper justification of the circular economy framework is encapsulated. An appropriate explanation of how the circular economy framework helps to achieve sustainability is also described. The flowchart of the entire work is provided in Figure 1.7 as a research schema.

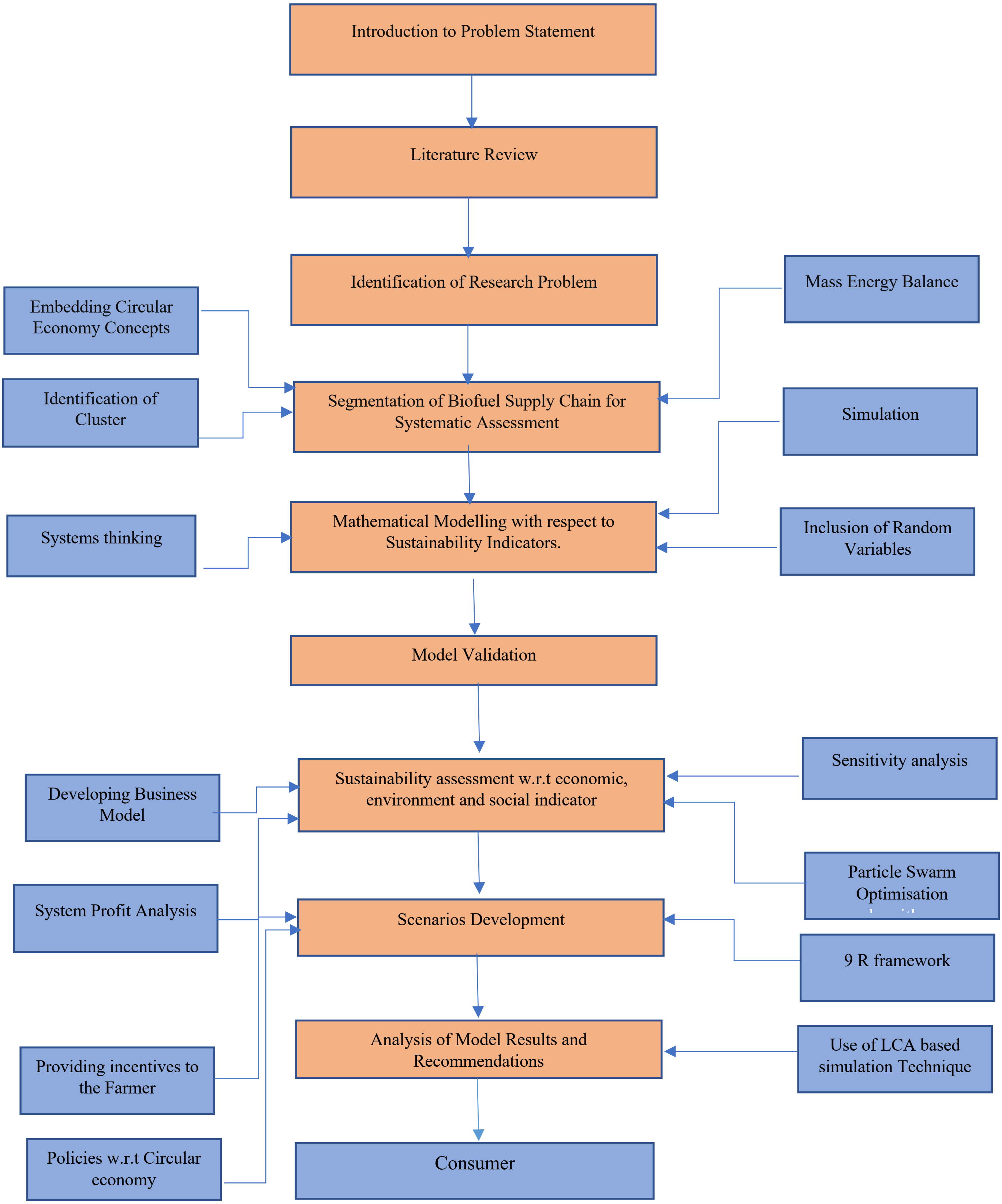


Figure 1.7(A hierarchical methodology for research approach)

1.7.1 Investigating the biomass cluster for identifying surplus biomass

The first objective is to decide on the surplus biomass that will be the proposed supply chain source. The primary data is accumulated by an extensive survey done by Punjab Renewable Energy private limited and TIFAC. In the first phase, the total biomass generated, biomass required for fodder and other activity, and surplus biomass are measured using Microsoft Excel and NREL calculator [27]. Three types of biomasses are considered for the case study, i.e., corn cob, corn stalk and paddy straw, based on their availability throughout the year. The biomass cost at the collection centre is adapted from the data provided by PRESPL [66]. The data enabled us to decide the revenue generated in the assessment stage. The same procedure is repeated for the conversion plant.

1.7.2 Developing a mathematical modelling approach to assess the sustainability

The proposed biofuel supply chain is mathematically modelled for the assessment of sustainability. Initially, the linear optimisation and constrained non-linear optimisation techniques were carried out, but none gave satisfactory results. So, a heuristic-based optimisation has been implemented, which addresses both randomness and uncertainty of the supply chain. The evaluation is done concerning economic, environmental, and social indicators. Biomass is intermittent as we can't get biomass throughout the year, and the processes involved in the supply chain are random. Hence a heuristic-based approach is implemented in terms of the optimisation method. Business models have been developed, followed by sensitivity analysis to showcase the feasibility. Detailed analysis is provided in chapter 3.

1.7.3 Developing mass and energy balance for the entire supply chain

To present the incoming and outgoing energy and mass, the mass balance is carried out. Mass balance is an integral part of the proposed research. The research mentioned above is implemented in every segment of the biofuel supply chain. Mass balance is needed as it is a mathematical model constraint. The mass energy balance for upstream is calculated for corn and paddy. The mass balance of the corn cobs to syngas is demonstrated in the downstream process. Since the technology for conversion of agricultural waste to ethanol is in the initial stage, only corn cob to ethanol, mass balance is presented.

1.7.4 Closing the loop for the circular economy approach

The most challenging part is to design a circular economy framework in every block of the biofuel chain, whether upstream or downstream. The postulates of circular economy are described in chapter 2. According to it, the smaller the loop more efficient it is in the end[27]. The tools for defining a circular economy are life cycle assessment, sustainability assessment using mathematical analysis, circular business models and circular strategies. In the proposed work, the circular strategies, mathematical modelling for sustainability assessment, and a business model are implemented to verify the circular economy framework. The objective is to provide suggestions to the government/industries that seek inputs for policy formulation. A detailed description is provided in the subsequent chapters.

1.8 Thesis Outline

Chapter 1: It gives the introduction on biomass, biofuel, supply chain, supply chain assessment and circular economy and the policies an India and in the world towards second generation ethanol supply chain. The research gaps, questions and research objectives are addressed in the chapter 1.

Chapter 2: In the second chapter the uncertainties of biofuel supply chain is addressed along with the introduction to availability of biomass in India. The chapter comprises a thorough literature review of the biomass availability, biofuel supply chain, methodology of assessment, and circular economy framework. In the methodology section all the possible methodologies have been discussed. It comprises state of art study of the modelling techniques and circular economy framework.

Chapter 3: The chapter 3 deals with the methodology part. The optimisation techniques are formulated, and the model is validated concerning the optimal value of indicators. The plots and graphs have been discussed extensively in the chapter. It is the crux of the biomass to biofuel supply chain model.

Chapter 4: This chapter is based on the mass balance in the agricultural land as well as in the conversion plant. In this chapter, the mass input and output at the farm area is calculated and the energy balance in the thermos-chemical conversion plant is explained.

Chapter 5: The chapter 5 gives idea about the circular economy framework, objectives, and methodology of implementation. It gives a descriptive idea on how the 4r framework has been implemented in the proposed supply chain model.

Chapter 6: The chapter 6 is the last and concluding chapter. It narrates the summary of the proposed work and an introduction to the scale up strategies implemented by the Government of India.

Chapter 2

Literature Review

In the previous chapter we have given a brief overview about the biofuel supply chain, the need of circular economy, drawbacks of well to wheel analysis and the novel technique implemented to assess the economic, social, and environmental sustainability. A biofuel supply chain encompasses all activities from feedstock production, biomass logistics of storage and biofuel production, transportation, and distribution to end consumers. The chapter gives the idea of the state of art in the theory of second-generation ethanol supply chain, biomass availability, optimisation algorithm and circular economy.

2.1 Existence Of uncertainties in biofuel supply chain

The previously published manuscripts use deterministic methods to inform supply chain decisions under the assumption that all problem parameters are well-known in advance. This work has led to important insights regarding supply chain costs and operations. Various papers have discussed uncertainties in supply transportation, biofuel demand, biomass price, or biofuel price. Dal-Mas et al. proposed a mixed integer linear programming (MILP) model for the biofuel supply chain that considers corn and ethanol selling price uncertainty in Northern Italy. Their model has two objectives to maximize expected profit and to minimize expected economic loss under different scenarios of corn production cost and ethanol selling price. Marvin et al. proposed a MILP model for multiple biomass types. Their model aims to determine optimal bioenergy plant locations and capacities in the midwestern U.S. The authors used sensitivity analysis to demonstrate the supply chain robustness to ethanol selling price uncertainty. Cundiff et al. formulated a linear stochastic optimisation model with recourse under biomass production uncertainty due to weather conditions. For the biofuel industry, strategic level decisions prevail a long-term impact and are oriented toward achieving overall supply chain objectives. Strategic decisions include but are not limited to production technology selection, location and capacity of bioenergy plant and satellite storage locations, and transportation mode. Facility location is one of the most-studied strategic decisions. Facility location is a crucial decision due to its long-term influence on the entire supply chain and the difficulty of changing the decision once it has been made. Transporting of biomass between harvesting area and collection center represents a high percentage of the final cost of delivered biomass to the conversion plant [11]. As a result, collection center location decisions should be robust; the solution should remain near optimal even if input parameters, such as customer demands, transportation costs, raw material prices, or environmental conditions, change [46]. Researchers have used various methods, the most common of which are geographical information system (GIS) analysis and mixed integer linear programming (MILP), to select locations for biofuel supply chain facilities.

2.2 Biofuel availability in India

India is the second-largest populated country globally with 1.36 billion people, and the number is increasing eventually. The large growing population and economic development will result in high energy demand in the country. So, it is predicted that by the year 2040, the need for energy in India will be doubled [2]. It is that one of the possible means to meet the energy demand sustainably in the world is through renewable energy. In the context of India, many researchers have taken insights into various forms of renewable energy that can be harvested for the sustainable growth of the nation [13, 14]. However, the utilization of renewable energy has its limitations. For instance, setting up a solar plant is not always suitable as it requires a vast quantity of land having a good intensity of sunlight [15]. Besides this, setting up a hydroelectric plant requires massive investment and involves the modification of indigenous land usage patterns, resettlement, and navigation restriction [15]. The primary problem involved with wind power generation is that there are fewer stronger wind locations than low wind speed locations. It also requires a high investment in terms of installation cost [15]. As far as the geothermal power plant is concerned, the major problem is that it depends upon the geographical condition and requires a massive initial investment. Besides, lengthy construction and payback time and difficulty in modularization and assessing resource are also associated with geothermal power plant [8]. Currently, India can meet only 23% of its energy demand domestically, and it depends upon the imported crude oil to meet the rest of its demand. Data reveals that crude oil import is increasing every year, and it has increased by 43% from 2009–10 to 2018–19 [14]. The largest share (37%) of crude oil is consumed by the transportation sector [15]. Though at present, it is not possible to replace crude oil entirely. But biofuels may be a renewable energy source to stabilize this energy demand [15, 16]. Biofuels can be solid (wood pellets) and liquid, as well as gaseous (biogas or syngas). Bioethanol and biodiesel are two of the most used types of liquid biofuels [16]. Besides, coal-based methanol and electric vehicles are expected to decrease the crude oil dependency in future. But in India, the total sale of electric vehicles is negligible (less than 1%) compared with the total sales of vehicles. It is predicted that the sales can improve only a little due to various challenges. Though in India, methanol from coal is recognized as an efficient and environmentally friendly alternative compared with gasoline or diesel, there is no commercial coal to methanol plant in India. This is because importing methanol from Iran and Saudi Arabia is economical for India [15], as the cost of methanol import is 0.27 USD/ Liter [13], and the cost of domestic production of methanol from natural gas is 0.36 USD/Liter [13] (considering 1 USD = 73 INR). Besides, setting up coal to a methanol plant with a production capacity of 2 million Liters of methanol per day will require a capital investment of approximately 164 million USD [15]. In contrast, ethanol is being domestically produced in a large quantity in India. Though ethanol is slightly less energy efficient than methanol, it can be effectively used as an alternative to gasoline. In addition, setting up an ethanol plant requires much less capital investment. For instance, a molasses ethanol plant with a capacity of 0.05–0.12 million Liters per day will require a capital investment of 3.3–22 million USD (considering 1 USD = 73 INR) [18, 19], this cost becomes even lower for setting up a plant in attachment with sugar factories [19]. Thus, ethanol becomes a clear choice for the Government of India (GOI). Most countries have the potential to produce ethanol, as it can be extracted from sugar, starch, and lignocellulose-based materials. It is one of the earliest ventures to produce ethanol from starchy and sugar-based feedstocks. In 1917, Alexander Graham Bell successfully converted sugars into clean-burning ethanol fuel [20]. Ethanol (C_2H_6O) is a chemical compound known as alcohol, drinking alcohol, grain alcohol, or ethyl alcohol. Alcohol is produced in various forms such as Rectified Spirit (95 to 96 % v/v ethanol), and extra neutral alcohol (96 % v/v ethanol), and fuel ethanol or absolute alcohol (99.8 % v/v). Among these, the rectified spirit is used for industrial purposes, extra natural alcohol is used to produce potable liquor, and absolute alcohol is used mainly for blending with gasoline [21]. Unlike fossil fuel, which promotes global warming by contributing to the formation of carbon dioxide (CO_2) [22], the overall emission of CO_2 is nil during combustion of ethanol because of the amount of CO2 released at the time of combustion is equal to the amount of CO2 absorbed during photosynthesis [23]. Further, ethanol blending with gasoline increases the octane number, oxygen content, and latent heat of evaporation of the blended fuel [24,26]. In addition, the increased octane number contributes to the reduction in the engine knocking tendency and the higher latent heat of evaporation reduces the cooling loss, as well as improves the engine's thermal efficiency [24, 25]. Besides, the complete combustion of ethanol-blended fuel due to the presence of increased oxygen content and increased volumetric efficiency of the engine helps in the reduction of the content of carbon monoxide (CO), oxides of nitrogen (NO_X), and saturated hydrocarbon emissions [25, 26]. So, it has been reported that ethanol blending with gasoline improves engine efficiency while reducing environmental hazards significantly [27, 28]. This makes ethanol a promising biofuel as future energy rendering renewable fuel. Thus, considering ethanol's advantages, ethanol's blending with gasoline has been made mandatory by different ethanol producing countries across the world. Brazil has successfully implemented the global highest blending rate of 27% (E27) throughout the country [29, 30]. The blending of ethanol with gasoline is also made mandatory in India to reduce dependency on imported crude oil [37]. The Government of India (GOI) is encouraging sugar factories by giving loans and other financial benefits for producing ethanol [3], as it is considered that the ethanol sector of India possesses the potential to meet the blending target [38]. As a result, India has already experienced steady growth in its production.

In addition to loss of entire amount of C, 80% of N, 25% of P, 50% of S and 20% of K present in straw are lost due to burning. If the crop residues are incorporated or retained, the soil will be enriched, particularly with organic carbon and N. Heat from burning residues elevates soil temperature resulting in elimination of bacterial and fungal populations which may regenerates after few days. However, repeated burning in the field may permanently diminish the microbial population. Burning may also immediately increase the exchangeable NH_4^+ and mineral N, bicarbonate, and extractable P content; but there is no build-up of nutrients in the profile. Long-term burning reduces total N, potentially mineralizable N and C in the 0-15 cm soil layer. The straw which is burned causing environmental pollution and other adverse consequences can be gainfully utilized for livestock feed, composting, power generation, production of biofuel and mushroom cultivation. Crop residues are low density fibrous feeds having low nitrogen, soluble carbohydrates, minerals, and vitamins. These have varying amounts of lignin which acts as physical barrier and may impede microbial breakdown. Crop residues, being unpalatable and low in digestibility, cannot form a sole ration for livestock. To meet the nutrient requirements and the ruminant production system efficient, the crop residues must be processed and enriched using urea and molasses, ensiling with animal wastes (urine and faeces) and supplementing green fodders (leguminous/non-leguminous) and legume straws (sun hemp, horse gram, cowpea, gram straw, pulse straws). Biofuels have been used globally for years to increase energy self-sufficiency, reduce vehicular emissions, and increase transport sustainability. Transport sector accounts for one-third of global energy utilization, half of oil consumption, and approximately one fourth of CO_2 emissions from combustion of fossil fuels. The global biofuel supply has increased by 8% since 2000 which is equivalent to 4% of the world’s transport fuels in 2015 [30]. The global biofuel supply was approximately 35 billion gallons in 2015, with approximately three fourth of ethanol and one fourth of biodiesel supply. Till 2015, 70 % of the global biofuel supply was met by Brazil and United States [30]. The main raw materials used by these countries were sugarcane (Brazil) and corn (USA) for bio ethanol production. This type of biofuel which is produced from food-based crops is also known as 1st generation biofuel. Globally more than 50% of bioethanol is produced from corn. In Asia Pacific region the biofuel production picked up from 2004 onwards. The ethanol can be either blended with gasoline as a fuel extender and octane-enhancing agent or used as a neat fuel in internal combustion engines. In India the National Policy on Biofuels was announced in 2009 with an aim of promoting of Bio-ethanol and Biodiesel blending with fossil fuels and a target of 20 per cent blending by 2017 (MNRE report). The biofuel policy made mandatory for oil companies to sell petrol blended with 5-10% of ethanol. However, due to insufficient supply a national average of less than 3 per cent ethanol blending could be achieved [20]. The Union Cabinet has now approved a newer National Policy on Biofuels – 2018 to promote biofuels in the country. The main aim of this policy is to expand the scope of raw materials used for ethanol production such as surplus food grains that are unfit for human consumption, solid waste, crop biomass, etc. to reduce the dependency on import, cleaner environment, management of municipal solid waste, and additional income to farmers. Conversion of lignocellulosic biomass into alcohol is of immense importance as the competition for cropland between biofuels and food can be minimized. The biofuels produced from non-food crops and residues (lignocellulosic/cellulosic biomass) or waste materials are known as second-generation biofuel. The technology of ethanol production from crop residues is, however, evolving in India.

2.2.1 2nd Generation Ethanol based Policy by Ministry of Petroleum and Gas

To set up the second-generation ethanol plants, Government has launched a scheme namely i.e., "Pradhan Mantri JI-VAN (JaivIndhan- Vatavaran Anukool Fasal Awashesh Nivaran) Yojana" for providing financial aid to integrated bioethanol or blended ethanol projects, using renewable feedstock and lignocellulosic biomass. In the scheme, financial support to twelve integrated bio-ethanol projects using cellulosic, lignocellulosic biomass & other renewable feedstock with total financial outlay of Rs 1969.50 crore for the period 2018-19 to 2023-24 will be provided along with support to ten demo projects for 2G technology [44].

Government of India launched Ethanol Blended Petrol (EBP) program in 2003 for undertaking blending of ethanol in Petrol to address environmental concerns due to fossil fuel burning, provide remuneration to farmers, subsidize crude imports, and achieve forex savings. Ministry of Petroleum & Natural Gas has targeted to achieve 10% blending percentage of ethanol in petrol by 2022. Presently, EBP is being run in 21 states and 4 UTs of the country. Under EBP program, OMCs are to blend up to 10% of ethanol in petrol. To meet 10% ethanol blending target with a projected demand for petrol in 2021-22, about 450 crore liters of ethanol would be required [2]. The estimated production of bioethanol in the country is around 300 crore liters, a large part of which is required for potable alcohol and chemical industries and the balance is used for ethanol blending petrol (EBP) program. The present policy allows procurement of ethanol produced from molasses and non-food feed stock like celluloses and lignocelluloses material including petrochemical route. Despite efforts of the government such as higher ethanol prices and simplification of ethanol purchase system, the highest ever ethanol procurement stands around 150 crore liters during Ethanol supply year 2017-18 which is sufficient for around 4.22% blending on pan India basis [2]. Therefore, an alternate route viz. second generation (2G) ethanol from biomass and other wastes is being explored to bridge the supply gap for EBP program. In this direction, "Pradhan Mantri JI-VAN Yojana" is being launched as a tool to create 2G Ethanol capacity in the country and attract investments in this new sector.

2.3 Biomass supply chain: synthesis of literature

Report by PRESPL (2017) has analysed location wise agricultural crop pattern, the crop area, yield, productivity of seasonal crops (like Kharif and Rabi) to understand the consistency in crop performance for last 10 years. The main objective was to calculate the quantities of crop wise realizable biomass surplus availability exclusively for 2G ethanol generation in assessment area.

The study was mostly based on analysis of secondary data pertaining to crop cultivation patterns, crop residue ratios and consumption patterns to assess the taluka wise biomass surplus availability across all the districts and talukas. The study considered production trends over the last ten years to assess the overall biomass surplus availability in the state and identify clusters with the highest biomass surplus density [28]. The biomass surplus density defined as the net biomass availability per unit area (MT per sq. km.) has been used to define clusters with the best availability of biomass surplus and hence the highest potential for establishing a 2G ethanol processing plant.

TIFAC Report (2018). [20] has estimated the amount of biomass generated from rice, wheat, corn, sugarcane, cotton, pulses (Gram & Tur) and oilseed (groundnut, mustard, and castor) crops in different states of India. The objective is to assess the amount of surplus crop residues from the identified crops and to assess the feasibility of the identified crop residues for biofuel production. To assess the feasibility of the identified crop residues for biofuel production. The study quantified the generation of surplus crop biomass at district level in three crop growing seasons (kharif, rabi and summer) for all the 662 districts of the country[27]. A total of eleven crops, namely rice, wheat, Corn, sugarcane, cotton, pulses (Gram & Tur) and oilseed (groundnut, mustard, soybean, and castor) were selected for the study. The crops were selected based on their acreage and total production across the country. The total gross cultivated area of the country is about 195 million hectares. The area under cultivation for the selected eleven selected crops is 137 M ha i.e., about 70% of gross cultivated area.

Jain et al. (2014) [21] has mentioned the amounts of crop residues in the country and degree of on farm burning, and identified the uses of crop residues and research needs. The paper discusses the amounts of crop residues available in the country and extent of on-farm burning, and identifies the competing uses of crop residues, and the research needs. The residues can be gainfully utilized for livestock feed, composting, power generation, production of biofuel, mushroom cultivation and extraction of bioactive compounds using secondary agriculture technologies. Conservation agriculture (CA), can be effectively practiced if need-based region-specific, crop residue management plans are developed taking into consideration generation, demand, quality, feasibility and economics of residue management.

Jain et al. (2015) [22] has used extant coefficients to estimate the cost of paddy residue burning which is INR 8953 per ha, and the social cost of burning is INR 3199 crores per annum in the region.

2.3.1 Biomass Supply Chain

The First 3 blocks talk about Biomass Harvesting and Collection. So, it is imperative to know about the Biomass Supply Chain first. Depending on the kind of biomass to be handled i.e. primary or secondary and types of equipment to be used, biomass supply chain is classified as below [12].

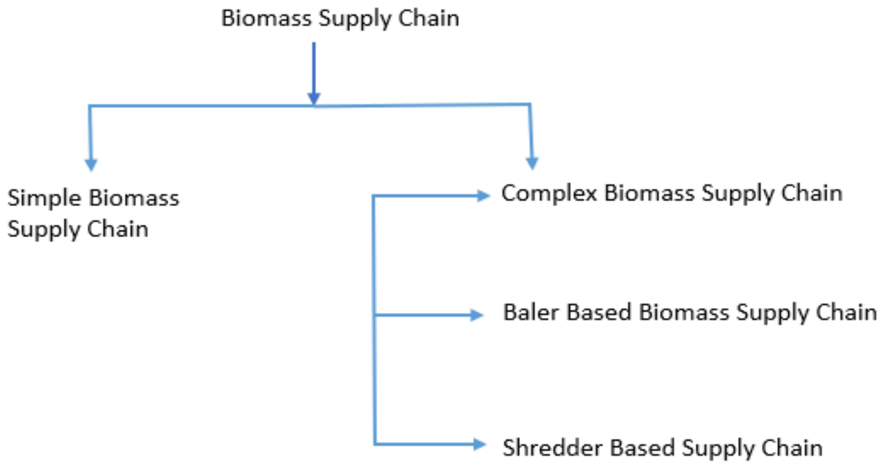


Figure 2.1(Classification of biomass supply chain)

Biomass Supply Chains (BSC) can broadly be classified into simple and complex supply chains. Simple BSC refers to simple operations of shifting the biomass from the field to point of consumption without involving any pre-processing at the field level. In this case, biomass is the output of the thresher which is in processed form. Village Level Entrepreneur (VLE) is one who plays the pivotal role in arranging the resources such laborer, load carrier to shift biomass from field to point of consumption. Corn hull, Paddy Straw, and Corn stalk supply chain which we have come across in the cluster falls under this category. While Complex BSC refers to involvement of equipment to collect, pre-process biomass before it is shifted to consumption point. Sometimes, biomass needs intermediate storage before it is forwarded to consumption point. This type of system is further divided into two based on key equipment required to collect the biomass, i.e., baler based, and shredder based.

a. Baler based BSC: In this supply chain balers driven by tractors are used to collect the biomass spread on the fields by moving the balers all over the field and simultaneously compresses it into bales. Such type of supply chain is absent in the cluster.

b. Shredder based BSC: In this supply chain, shredder driven by tractor is either used to cut standing biomass in the fields (Stalks of various crops) by moving all over the field or cut manually uprooted stalks in stationery mode in the fields as per the situation or prevailing conditions. This type of biomass supply chain was active on Juliflora and Cotton stalk in the cluster during the year 2013-14 when HBPL was functional but is not seen in present times.

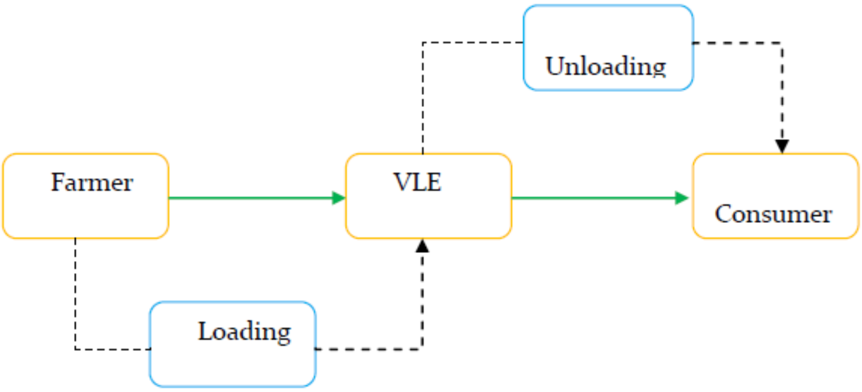


Fig 2.2

Figure 2.2 (Biomass supply chain in village level)

The Fig 2.2 is a simple biomass supply chain in any village of the country. It starts from the farmer and ends at the customer through village level entrepreneur (VLE).

2.3 Salient Features of Existing biomass supply chain:

i. It is simplistic in nature and run by proprietary concerns. It is unregistered and unorganized.

ii. It is very flexible in nature and entry barriers in this supply chain system is very less.

iii. Rural logistics owner who has carrier, contacts with farmer and skill to maintain and handle laborer can easily start.

iv. Identifying the farmers with surplus biomass (Corn hull, Corn stalk, and paddy straw) is the key.

v. In some cases, it is very inefficient. Corn hull is transported in light commercial vehicles, loose paddy straw is carried, and laborers are employed to collect and cut paddy straw and corn stalk respectively. It lacks the element of mechanization and customized transport system to carry biomass.

vi. It lacks professional attitude and has opportunistic behavior. There is no loyalty towards buyer. Price is the only criterion.

To ensure regular and adequate supply of required biomasses, the model with cluster-based collection centers is most appropriate. For this reason, PRESPL has proposed a simple and optimal cluster-based Biomass Supply Chain approach. The initial calculation such as system profit follows the same model and the biomass data provided by PRESPL.

2.4 Ethanol Synthesis Pathways: Literature Review

S.N Naik et al. (2014) has given a descriptive idea regarding origin of first-generation biofuel and second-generation biofuel. The literature has emphasized on various processes of extraction biofuel in both the generations. The 'first-generation' biofuels appear unsustainable because it possesses potential stress that their production places on food commodities [22]. For organic chemicals and materials these needs to follow a biorefinery model under environmentally sustainable conditions. Where these operate at present, their product range is largely limited to simple materials (i.e., cellulose, ethanol, and biofuels). Second generation biorefineries need to build on the need for sustainable chemical products through modern and proven green chemical technologies such as bioprocessing including pyrolysis, fisher tropsch, and other catalytic processes to make more complex molecules and materials on which a future sustainable society will be based [26]. This review focus on cost effective technologies and the processes to convert biomass into useful liquid biofuels and bioproducts, with particular focus on some biorefinery concepts based on different feedstocks aiming at the integral utilization of these feedstocks to produce value-added chemicals.

National Biofuel Policies,India (2018) has provided information on policies related to first generation ethanol.It gives a thorough detail on subsidies and percentage of blending by 2030. The policy categorizes biofuels as "basic biofuels" viz. first generation (1G) bioethanol & biodiesel and "advanced biofuels" – second generation (2G) ethanol, municipal solid waste (MSW) to drop-in fuels, third generation (3G) biofuels, bio-CNG etc. which will enable extension of appropriate financial and fiscal incentives under each category. The agenda of the biofuel policy is to 1. utilize raw materials, to give protection to farmers, viability gap funding and boosting the biodiesel production. Farmers are at a risk of not getting appropriate price for their produce during the surplus production phase [20]. Taking this into account, the policy allows use of surplus food grains for production of ethanol for blending with petrol with the approval of National Biofuel Coordination Committee. With a thrust on advanced biofuels, the policy indicates a viability gap funding scheme for 2G ethanol bio refineries of Rs.5000 crore in 6 years in addition to additional tax incentives, higher purchase price as compared to 1G biofuels. The policy encourages setting up of supply chain mechanisms for biodiesel production from non-edible oilseeds, used cooking oil, short gestation crops. To summarize, annual ethanol procurement quantity (i.e., off take assurance) is worked out by the oil marketing companies (OMCs) along with ethanol procurement price derived from damaged and surplus food grains (if applicable), whereas ethanol procurement price derived from sugarcane based raw materials is fixed by the Government considering sugar sector scenario. Government directs OMCs to accord prioritization of raw material for ethanol procurement, guidance on transportation rate (which is fixed by OMCs), payment of GST and other administrative requirements to take forward the EBP Program.

Tomes, D., Lakshmanan, P., & Songstad, D. (Eds.) (2018) has presented a literature on the economic and technical analysis of biofuels.it has presented various perspectives on extracting biofuel from crop residues and technologies for corn tissue culture and corn transformation. Minteer, S. (Ed.). (2016) has described the latest methods for production of fuels containing varying percentages of alcohol alongside the various applications they benefit, including combustion engines, fuel cells, and miniature power generators.

FAO 2005b has discussed that the agricultural development alongside the socio-economic growth can go hand in hand if we give enough room for the alternate fuels in the future. The first section of the report analyses long-term trends in decreasing the undernourishment and explores the impact of governance, economic growth, and natural disasters.

A. Markandya, m. Pemberton (2016) A framework is designed to analyze the energy security in a utility framework, where there is a risk of disruption of imported energy [23]. The analysis shows the importance of energy tax as a tool in maximizing the utility, and how the level of that tax varies according to the key parameters of the system: risk aversion, demand elasticity, probability of disruption and cost of disruption.

J.S. Cundiff, N. Dias, H.D. Sherali (1997) This modeling effort is directed towards the design of a biomass delivery system that considers storage, scheduling, and transportation issues. It gives an idea of linear programming approach for designing an herbaceous biomass delivery system, bioresource.

With respect to the synthesis route , the biomass takes majorly two routes and to showcase the methodology an example of each process is shown in the next paragraph. The first one is biochemical and the second one is thermochemical. The figure 2.3 gives a block diagram representation of the biochemical pathway. In biochemical case, the recalcitrant lignin and cellulose fractions must be broken down into simpler intermediates that can subsequently be converted to ethanol. In the conversion the cellulose and hemicellulose fractions of the raw biomass are hydrolysed and broken down to simple sugars i.e., glucose and xylose, which are then fermented and distilled to ethanol. Lignin,

which cannot be broken down in hydrolysis reactions, is usually combusted to generate heat and electricity to drive the conversion process .

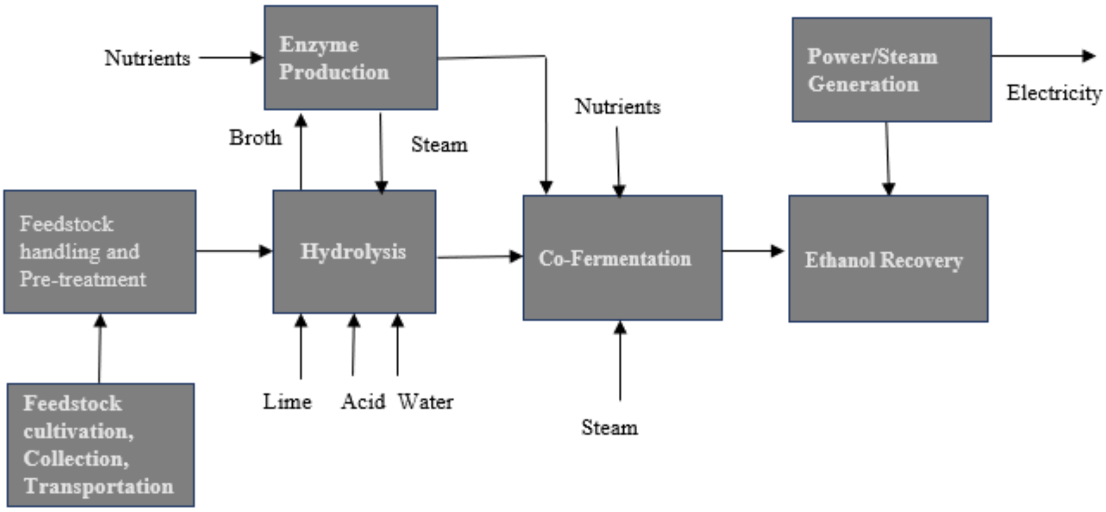


Figure 2.3 (A descriptive diagram of biochemical process) [26]

In biochemical case, the recalcitrant lignin and cellulose fractions must be broken down into simpler intermediates that can subsequently be converted to ethanol. In the conversion the cellulose and hemicellulose fractions of the raw biomass are hydrolysed and broken down to simple sugars i.e., glucose and xylose, which are then fermented and distilled to ethanol. Lignin, which cannot be broken down in hydrolysis reactions, is usually combusted to generate heat and electricity to drive the conversion process [26].

In the thermochemical case, the recalcitrant lignin and cellulose fractions must be broken down into simpler intermediates that can subsequently be converted to ethanol. In thermochemical conversion (Fig. 2.4), heat is used to break raw biomass into syngas (a mixture of carbon monoxide and hydrogen), which is further reassembled into ethanol (and higher molecular weight alcohols) in the presence of catalysts .

Many pathways have been discussed targeting the specific crops. In our analogy we have taken corn stalk, corn cobs and paddy straw into account. So, a brief insight is discussed in this chapter regarding those conversion processes. There are many ways to demonstrate biochemical route of conversion of corn. The agricultural residues from Corn production are potential sources of sugar for ethanol production, in addition to starch and by-products. When Corn is harvested in the field, the corn grain is separated from the cobs, stalks, and leaves. While the grain is transported for storing and processing, the stover is currently not widely collected. However, this biomass could be used for lignocellulosic ethanol production. Corn stover includes stalks, leaves, and corn cobs. Unlike the corn grains, of which the major component is starch, the main components of corn stover are cellulose, hemicellulose, and lignin. Lignocellulosic material is characterized by its strength and complexity due to a network formed between hemicellulose and cellulose in close association with lignin. A number of processing steps is required to overcome this complex structure to make it suitable for fermentation. The figure is described below.

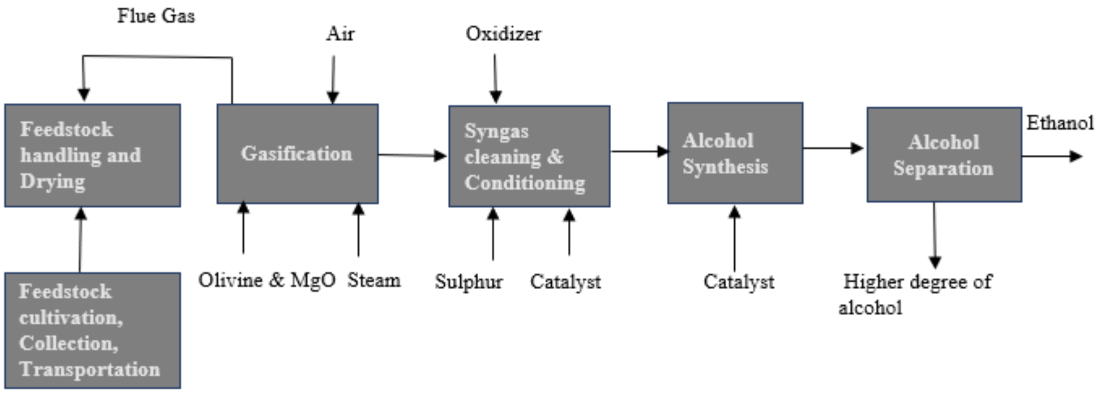


Figure 2.4(Thermochemical process of conversion)

The process starts with feedstock, gasification. The route mostly oxysteam based gasification The syngas is then gone through the normal catalytic route like biochemical pathways. Hence the Figure 2.4 is a prototype picture of the proposed conversion block/thermochemical plant of the supply chain as stated in the Figure 2.5.

2.5 Proposed Ethanol Supply Chain

The chapter 2 has discussed on biomass supply chain and the various methods of biomass to biofuel conversion. The novelty in the proposed work is the identification of the supply chain and sustainability assessment of the same with respect to sustainability indicators. The figure 2.5 demonstrates the proposed supply chain with respect to circular economy framework.

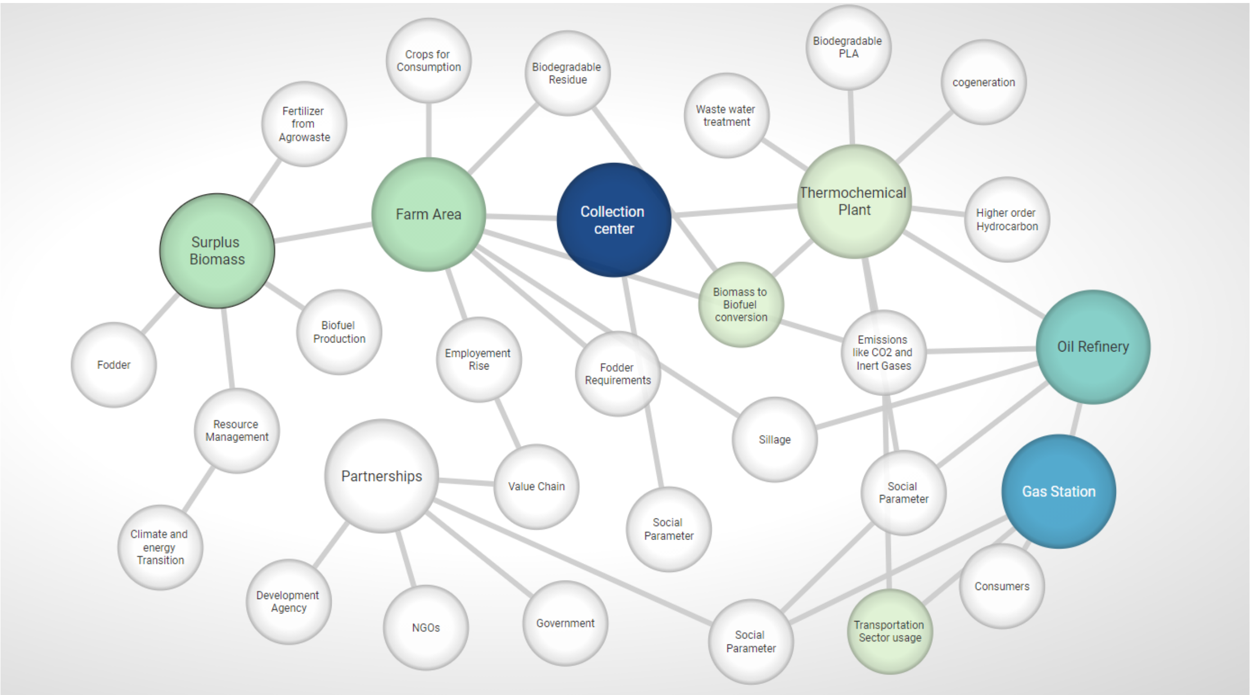


Figure 2.5(A circular economy perspective of potential biomass to biofuel supply chain)

The colored bubbles are the major contributors to the supply chain. The circular economy framework has been built around all these factors.

2.6 Sustainability Indicators

The concept of sustainability originated in forestry, where it means never harvesting more than what the forest yields in new growth .The word Nachhaltigkeit (the German term for sustainability) was first used with this meaning in 1713 [30]. The concern with preserving natural resources for the future is perennial, of course: undoubtedly our Paleolithic ancestors worried about their prey becoming extinct, and early farmers must have been apprehensive about maintaining soil fertility. Traditional beliefs enjoined thinking in terms of stewardship and concern for future generations, as expressed in the oft-quoted words of a Nigerian tribal chief who saw the community as consisting of “many dead, few living and countless others unborn" [30]. Perhaps there have always been two opposing views of the relation between humankind and nature: one which stresses adaptation and harmony, and another which sees nature as something to be conquered. While this latter view may have been rather dominant in Western civilization at least in recent centuries, its counterpoint has never been absent. Sustainability is a natural topic of study for economists: after all, the scarcity of resources is of central concern to the dismal science. A famous example is the work of Thomas Malthus, who published his theory about looming mass starvation in 1798. A theory on the optimal rate of exploitation of non-renewable resource which is still relevant today was formulated by Harold Hotelling, an American economist, in 1931 [31]. We shall have more to say about his views later. A milestone in capturing the attention of global public policy was the report of the club of Rome [32], which predicted that many natural resources crucial to our survival would be exhausted within one or two generations. Such pessimism is unbecoming in public policy which is, after all, supposed to be about improving things. Therefore, the report of the UN world commission on environment and development, better known as the Brundtland report after its chairperson, was welcomed for showing a way out of impending doom. It was this report which adopted the concept of sustainability and gave it the widespread recognition it enjoys today. When performing a sustainability evaluation of biofuels, its environmental, economic, and societal impacts throughout the supply chain must be identified. These impacts include issues of concern that one could think of when analyzing the potential impacts of biofuels at each stage of the supply chain. Based on a literature review [34],[35] some of the main relevant aspects associated with biofuels supply chain were identified, which can lead to an impact. These aspects are summarized in table below.

Environmental
Biodiversity loss and habitat degradation of many species
Biomass power offset
Biospheres preservation with high natural value
Carbon stock changes
Co-products and residues utilization (e.g., for energy)
Deforestation
Energy use
Fertilizer (N, P, K) and pesticide use
GHG balance and net carbon neutral biofuels
Land use and land use change
Occupation of arable land for energy crop cultivation
Potential environmental risk
Potential for cropland expansion
Soil degradation by erosion and slat increase
Use of genetically modified crops
Wastewater to be treated
Water use for irrigation

Table 2.1(Environment Parameters of biomass collection site)

Biodiversity Loss and Habitat Degradation: The decline in biodiversity and degradation of habitats for various species are critical indicators of environmental health. Loss of biodiversity can disrupt ecosystems, leading to imbalances in ecosystems' functioning and resilience [34].

Biomass Power Offset: Biomass power generation involves using organic materials such as wood, agricultural residues, or waste to produce electricity. This indicator assesses the extent to which biomass energy production offsets carbon emissions compared to fossil fuel-based energy sources.

Biospheres Preservation with High Natural Value: This indicator focuses on the conservation of biospheres with high ecological value, emphasizing the importance of protecting natural habitats and ecosystems that are rich in biodiversity and ecosystem services [34].

Carbon Stock Changes: Monitoring changes in carbon stocks in forests, soils, and other ecosystems is crucial for understanding carbon sequestration and release dynamics, which directly influence climate change mitigation efforts.

Co-products and Residues Utilization for Energy: Utilizing co-products and residues from agricultural and industrial processes for energy production can contribute to reducing waste and dependence on fossil fuels, while also mitigating environmental impacts associated with waste disposal.

Deforestation: The clearing of forests for agriculture, urbanization, or other purposes leads to habitat loss, biodiversity decline, and increased carbon emissions. Monitoring deforestation rates helps track the extent of forest loss and assess its environmental impacts.

Energy Use: Tracking energy consumption patterns provides insights into resource utilization efficiency and the environmental footprint associated with energy production and consumption activities.

Fertilizer and Pesticide Use: Monitoring the use of fertilizers and pesticides helps evaluate their impacts on soil health, water quality, biodiversity, and human health. Excessive use can lead to pollution, eutrophication, and ecosystem degradation [34].

Greenhouse Gas (GHG) Balance and Net Carbon Neutral Biofuels: Assessing GHG emissions and the carbon neutrality of biofuels is crucial for evaluating their overall environmental impact and contribution to climate change mitigation goals.

Land Use and Land Use Change: Understanding patterns of land use and changes in land cover is essential for assessing ecosystem health, habitat fragmentation, and the impacts of human activities on natural landscapes [35].

Occupation of Arable Land for Energy Crop Cultivation: The conversion of arable land for growing energy crops can compete with food production and have implications for food security, biodiversity, and land degradation.

Potential Environmental Risk: Identifying and assessing potential environmental risks associated with various activities, technologies, or developments helps in proactively managing and mitigating negative impacts on ecosystems and human health.

Potential for Cropland Expansion: Evaluating the potential for expanding agricultural land can inform land-use planning decisions and help minimize the conversion of natural habitats to croplands, thereby reducing biodiversity loss and habitat degradation [35].

Soil Degradation by Erosion and Salinity Increase: Soil erosion and salinization are major threats to soil fertility, agricultural productivity, and ecosystem stability. Monitoring these indicators helps identify areas vulnerable to degradation and implement soil conservation measures.

Use of Genetically Modified Crops: Assessing the adoption and cultivation of genetically modified crops helps understand their environmental impacts, including potential effects on biodiversity, soil health, and pesticide use [35].

Wastewater to be Treated: Proper treatment of wastewater is essential for protecting water quality, preventing pollution of aquatic ecosystems, and ensuring public health.

Water Use for Irrigation: Monitoring water use for irrigation helps assess water resource management practices, identify water scarcity hotspots, and minimize water-related environmental impacts such as depletion of aquifers and degradation of freshwater ecosystems.

Social
Agriculture, crop diversity and rural development
Competition for land use besides for energy production (e.g., food)
Competition for water
Cultural acceptability and respect for minorities
Employment or job creation
Maintenance of native and essential food crop habitats
Food security
Impact on communities (e.g., value-chain and regional growth)
Potential chemical risk
Chemicals use for biodiesel production (e.g., CH_3OH, NaOH)
Chemicals use for lipids extraction from seeds (e.g., *n*-hexane)
Working conditions and workers' rights

Table 2.2 (Social parameters linked to cradle-to-cradle analogy)

Agriculture, Crop Diversity, and Rural Development: Agriculture plays a crucial role in rural development by providing livelihoods, food security, and economic opportunities. Promoting crop diversity not only enhances resilience to pests and diseases but also supports sustainable farming practices and biodiversity conservation.

Competition for Land Use Besides for Energy Production: Competition for land use extends beyond energy production to include food production, urbanization, infrastructure development, and conservation efforts. Balancing competing land uses is essential for ensuring sustainable resource management and equitable access to land [35].

Competition for Water: Increasing competition for water resources among various sectors, including agriculture, industry, and domestic use, highlights the importance of efficient water management practices to mitigate conflicts and ensure water security for all stakeholders.

Cultural Acceptability and Respect for Minorities: Acknowledging cultural diversity and respecting the rights and traditions of minority groups are essential for fostering social cohesion, preserving cultural heritage, and promoting inclusive development processes in rural communities.

Employment or Job Creation: Agriculture remains a significant source of employment, particularly in rural areas. Promoting job creation in agriculture through training, infrastructure development, and value-chain integration contributes to poverty reduction and economic growth in rural communities [35].

Maintenance of Native and Essential Food Crop Habitats: Conserving native habitats of essential food crops is critical for maintaining genetic diversity, ensuring food security, and adapting to environmental changes and emerging pests and diseases.

Food Security: Ensuring access to sufficient, safe, and nutritious food for all individuals is fundamental to achieving food security. Addressing factors such as poverty, inequality, and climate change resilience is essential for enhancing food security in rural communities [35].

Impact on Communities (Value-Chain and Regional Growth): Assessing the socio-economic impacts of agricultural activities along the value chain helps identify opportunities for value addition, job creation, and regional development, while also considering potential risks and externalities.

Potential Chemical Risk: Managing and minimizing chemical risks associated with agricultural inputs such as pesticides, fertilizers, and processing chemicals is crucial for protecting human health, environmental quality, and biodiversity [35].

Chemicals Use for Biodiesel Production (e.g., CH3OH, NaOH): Understanding and regulating the use of chemicals in biodiesel production processes is essential for ensuring safety, environmental sustainability, and compliance with regulatory standards.

Chemicals Use for Lipids Extraction from Seeds (e.g., n-hexane): Utilizing chemicals for lipid extraction from seeds, such as n-hexane, requires proper handling and disposal to minimize environmental contamination and health risks associated with chemical exposure.

Working Conditions and Workers' Rights: Ensuring safe working conditions, fair wages, and respect for labour rights in agricultural and rural settings are essential for promoting social justice, enhancing productivity, and fostering sustainable development [35].

By monitoring and addressing these indicators, policymakers, stakeholders, and communities can promote sustainable agricultural practices, enhance rural livelihoods, and achieve inclusive and resilient rural development.

Economic aspect
Agricultural prices
Balance between biofuels production cost and market prices
Decent workers remuneration in the biofuels supply chain
Food, fuel, and land prices
Net cash flow generated

Table 2.3(Economic parameters of the supply chain)

Agricultural Prices: Agricultural prices reflect the market dynamics of agricultural commodities, including crops, livestock, and other products. Fluctuations in agricultural prices impact farmers' incomes, food prices for consumers, and overall economic stability in rural areas.

Balance Between Biofuels Production Cost and Market Prices: Achieving a balance between biofuels production costs and market prices is essential for the viability and sustainability of the biofuels industry. Factors such as feedstock costs, technology efficiency, government subsidies, and market demand influence this balance [35].

Decent Workers Remuneration in the Biofuels Supply Chain: Ensuring decent remuneration and fair labour practices throughout the biofuels supply chain is crucial for promoting social equity, improving livelihoods, and upholding workers' rights. Fair wages and safe working conditions contribute to the overall sustainability of the biofuels industry.

Food, Fuel, and Land Prices: Interactions between food, fuel, and land prices have significant implications for food security, energy affordability, and land use decisions. Understanding these price dynamics helps policymakers assess trade-offs and potential impacts on various stakeholders, including farmers, consumers, and the environment [35].

Net Cash Flow Generated: The net cash flow generated from agricultural and biofuels activities provides insights into the financial performance and profitability of these sectors. Monitoring cash flow helps businesses make informed decisions, allocate resources efficiently, and assess their long-term sustainability [35].

By monitoring these pricing indicators, policymakers, businesses, and stakeholders can better understand market dynamics, address challenges, and promote policies that support equitable and sustainable agricultural and biofuels systems. The growth in the use of sustainability indicators is nothing short of phenomenal. We have them at all levels of policy making from the international to neighborhood communities.

2.7 Evolution Of Circular Economy Theories

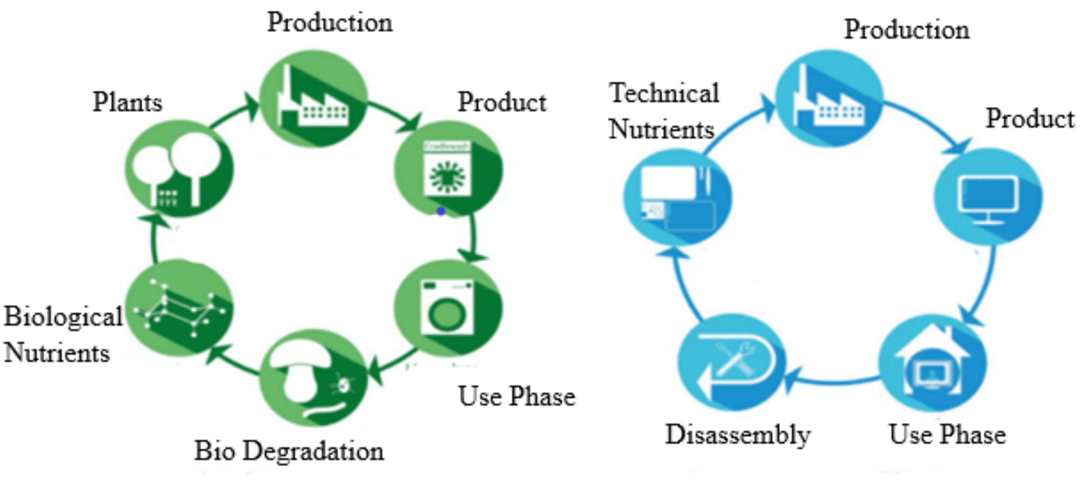


Figure 2.6(Concepts of Circular Economy: Its Origin and Evolution [6])

In a circular economy, value is created using loops using biological as well as technical cycles. In the technical cycle, product repair and maintenance are the most important block followed by reuse (it comes in between disassembly and technical nutrients), while in the biological block, biodegradation and biological nutrients are the important blocks. As it is a circular economy, any anomalies/dysfunctionalities in a block will affect the previous and next one in the cycle. Some postulates of circular economy are -: the smaller the loop more profitable and resource-efficient it is. Do not repair what is not broken, do not remanufacture what can be repaired, do not recycle what can be remanufactured. The major theories which support the theory of circular economy have been listed below.

2.7.1 Blue's Economy

Blue's economy suggests that it is possible to generate more revenue while generating more jobs and still compete in the market. It shifts away from the core business/core competence that forces companies to focus on one industry by considering local economic development as a priority, ensuring that local purchasing power increases and more money circulates regionally. This enables growth without inflation through an increase in the local production of goods and services. The blue economy also comes with a core set of over 100 pre-screened innovations.

that have multiple benefits and multiple applications [36]. In addition to its business models, the Blue Economy supports global progress indicators (GPI). The concept of GPI is a more precise measure of economic activity. GDP makes no attempt to include the depletion of natural resources or degradation of the environment [36].

2.7.2 Industrial Ecology

Industrial ecology has come from the idea that human economic activity is causing unacceptable environmental changes, and it emerged in the 1970s in opposition to the consideration of the industrial system as separate from the environment [36]. It needs functioning markets where supply and demand can meet. It holds on to the principle that valorization of by-products and waste leads to better-closed loop performance. Other main points are 1) Loss caused by dispersion must be minimized 2) The economy must be dematerialized 3) Energy must rely less on fossil hydrocarbon.

2.7.3 Biomimicry

The circular economy is sometimes considered as an implementation of biomimicry at an ecosystem level. Biomimicry aims at providing innovation inspired by nature [36]. The three pillars of biomimicry are:

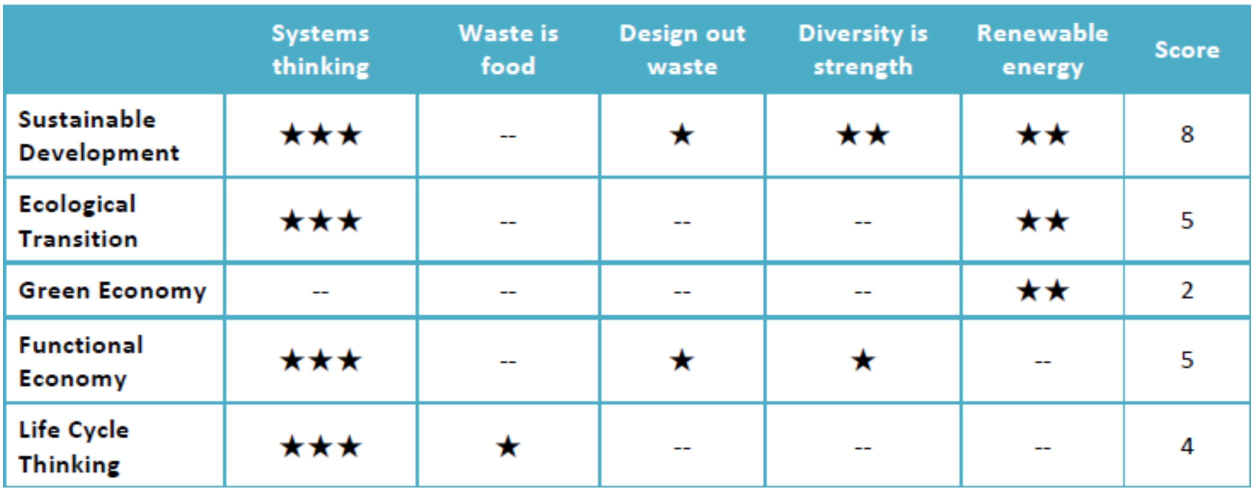
Nature as a mentor – There is no concept of waste in nature. If a leaf dries, it becomes manure for the plants. "It's viewing nature not for what we can extract, harvest or domesticate, but for what we can learn." as cited by Janine Benyus. In her book, Benyus calls for a shift in paradigm from learning about nature to learning from nature so that it will be a way to solve human problems.

Nature as a measure – It enables us to use ecological standards to evaluate the sustainability of innovations and designs. As an example, by leveraging the knowledge of the splash-less entry of kingfishers into the water and the silent flight pattern of owls, engineers managed to decrease the noise generated by Shinkansen Bullet trains (high-speed trains in Japan) .

Nature as a Model **-** Biomimicry looks at the form of nature, its processes, and ecosystems as a source of inspiration to create new design solutions for our products and industrial systems [36]. The idea is to mimic nature at all scales when solving design problems. For example, a leaf can help to design a better solar cell, or at a larger scale, termite colonies can be taken as an inspiration for the construction of buildings with natural ventilation and solar heating.

2.7.4 Performance Economy

The theory of performance economy is like blue's economy. Sustainable taxation is one of the theories proposed in this section. It encourages not to tax renewable resources like labor rather tax the non - renewable sources. It suggests the manufacturer make durable and reliable products and companies to be incentivized to minimize resource consumption and prevent losses. The Ellen Mc Arthur's butterfly diagram shows that the circular economy also gives us a choice to go for decision making on recycle, reuse, remanufacture or repair [37].The Butterfly diagram was designed in order to acknowledge the need of addressing the entire life cycle of a product. Products are recycled and redesigned in a way that lasts longer through circular processes such as maintenance, repair, remanufacture, recycle or biochemical feedstock, cascading, anaerobic digestion, composting. The diagram's crux part is based on the linear economic model, while the rest of it shows a continuous flow of technical and biological matter through 'value circles'. The smaller the cycle is, the greater the product's value that maintains. An interactive map showing the need for a circular economy has been described in Table [7] below.



	Systems thinking	Waste is food	Design out waste	Diversity is strength	Renewable energy	Score
Sustainable Development	★★★	--	★	★★	★★	8
Ecological Transition	★★★	--	--	--	★★	5
Green Economy	--	--	--	--	★★	2
Functional Economy	★★★	--	★	★	--	5
Life Cycle Thinking	★★★	★	--	--	--	4

Table 2.4(Mc Ellen Arthur's explanation of precedence of systems thinking)

	Systems thinking	Waste is food	Design out waste	Diversity is strength	Renewable energy	Score
Cradle-to-cradle thinking	★★★	★★★	★★★	★★★	★★★	15
Shared Value	★★	--	--	★★	--	4
Industrial Ecology	★★★	★★★	★	★★★	--	10
Extended Producer Responsibility	★★★	--	★★★	--	--	6
Ecodesign	★★★	--	★	--	--	4

Table 2.5(Systems Thinking)

We draw a conclusion is that among the ten theories/propositions, cradle to cradle thinking scores the highest. Systems thinking includes LCI and LCM model, which gives a relative idea about sustainability, whereas circular economy gives the absolute idea of sustainability. The details of systems thinking are demonstrated in chapter 3. In the table 2.5 systems thinking is a holistic approach to analysis that focuses on the way that a system's constituent parts interrelate and how systems work overtime and within the context of larger systems. The systems thinking approach contrasts with traditional analysis, which studies systems by breaking them down into their separate elements. Systems thinking can be used in any area of research and has been applied to the study of medical, environmental, political, economic, human resources, and educational systems, among many others. According to systems thinking, system behavior results from the effects of reinforcing and balancing processes. A reinforcing process leads to the increase of some system component. If reinforcement is unchecked by a balancing process, it eventually leads to collapse. A balancing process is one that tends to maintain equilibrium in a particular system. Attention to feedback is an essential component of system thinking. For example, in project management, prevailing wisdom may prescribe the addition of workers to a project that is lagging. However, in practice, that tactic might have slowed development in the past. Attention to that relevant feedback can allow management to look for other solutions rather than wasting resources on an approach that has been demonstrated to be counterproductive [59]. Systems thinking uses computer simulation and a variety of diagrams and graphs to model, illustrate, and predict system behavior. Among the systems thinking tools are the behavior over time (BOT) graph, which indicates the actions of one or more variables over a period; the causal loop diagram (CLD) , which illustrates the relationships between system elements; the management flight simulator, which uses an interactive program to simulate the effects of management decisions; and the simulation model, which simulates the interaction of system elements over time [59]. It helps to handle inequality. One of the most profound challenges of this world is to address inequalities that will ensure inclusive prosperity, jobs, and infrastructures in rural and "depressed" areas. The biological resources are owned and distributed, and even the difficulties related to their mobilization, transport, and processing might offer potential opportunities in the future [60]. For example, Forests in Europe occupy more than forty percent of the land and are owned by about 16 million forest owners. The forest-based sector already now includes around 400,000 companies, mostly small enterprises, and provides more than 3 million jobs [61]. This is a very valuable socio-ecological infrastructure that needs to be nurtured and acknowledged. It is true that mobilizing and transporting oil is much easier than producing, managing (for 100 years), transporting, and processing wood. But this difficulty is a better opportunity to look at. It helps in redistributing wealth, jobs, and infrastructures which will establish enough human capital to take care of our natural capital [14].

2.8 Circular Economy: Synthesis of literature

Wautelet, Thibaut. (2018) [6] has demonstrated the various literatures and definitions on cradle to cradle technology or circular economy. The idea of a circular economy has its roots in industrial ecology (IE) (Preston (2012, p. 3), Andersen (2007, p. 133), Murray et al. (2017, pp. 372–373)). Industrial ecology arose from the perception that human economic activity is causing unacceptable environmental changes and emerged in 1970's in opposition to the consideration of industrial system as separate from the environment (e.g., factories and cities on one side and nature on the other) . The core idea of industrial economy is the redesign our industrial society as a specific ecosystem within the Kottaridou, Anna & Bofylatos, Spyros. (2019) [21] has demonstrated the concepts of technical nutrients, biological nutrients, recycle, reuse, remanufacture in an effective manner in the biosphere. In accordance to the established literature, the concept of IE relies on a systemic, comprehensive, and integrated analysis of the industrial system and all its components within its environment, considering them as a joint ecosystem. This approach aims at understanding how the industrial system works, how flows of material and energy (called industrial metabolism) are regulated and how it interacts with the biosphere. The analysis of the industrial metabolism is then used as a basis to optimize the total industrial materials cycle (from virgin material to finished product to ultimate disposal of wastes) through transposition of the nature principles or at least through inspiration from them The circular economy builds on IE's concept for the optimisation and analysis of industrial systems at a micro-level, scaling it up to an economy-wide system in which products and processes are redesigned to maximize the value of resources through the economy. Accordingly, industrial ecology promotes the transition from open to closed cycles of materials and energy thus leading to less wasteful industrial processes.

McDonough, William, and Michael Braungart. (2009) [22] have stated the errors in industrial economy and given ways of rebuilding it with the help of circular economy. While the term Cradle to Cradle (C2C) was coined by Walter Stahel in opposition to the current linear economic system [28], the concept of C2C was firstly developed by the architect William McDonough and the chemist Dr Michael Braungart in their book Cradle to Cradle: Remaking the way we make things [22]. In their book, McDonough and Braungart called for a new way of designing the material goods and for going beyond the concept of eco-efficiency which only focuses on reducing the ill effects of human activity on the environment. The reference [26] recognized the potential of eco-efficient strategies2 in the short term to reduce the ecological impact of business' activities (creating at the same time costs savings), but they argued that they are insufficient to achieve the goals in the future. According to McDonough and Braungart (2002, p. 51), “eco-efficiency is about getting more from less”. For example, a car can be more eco-efficient (while it reduces petrol consumption and CO_2 emissions) but it is still not environment friendly. Furthermore, Braungart and McDonough considers that most recycling constitutes “downcycling” because products are not designed to be recycled and the recycling process reduces the quality of materials making them eligible for use only in lower value applications. Therefore, eco-efficiency strategies address problems instead of the source and thus they do not call for a deep redesign of our contemporary industry. In the concept of eco-effectiveness, the notion of waste is erased and the focus is shifting from reduction of quantity for negative impact to increase of quality for positive impact.

Geissdoerfer, Martin & Savaget, Paulo & Bocken, Nancy & Hultink, Erik. (2017) [23] has focused on the advantages of circular economy over the traditional linear economy system. While the terms sustainability and circular economy are gradually gaining traction with industry academia, and the policymakers, the similarities and variations between both concepts remain ambiguous. The relationship is not made explicit in literature, which in result is blurring their conceptual contours. Also, it restricts the efficacy of using the approaches in research and practice. This research addresses the gap and aims to provide conceptual clarity by distinguishing the terms and synthesizing the different types of relationships between them. The paper conducted a literature review, employing bibliometric analysis and snowballing techniques to investigate the state of the art in the field and synthesize the similarities, differences, and relationships between both terms.

2.9 Assessment Technique: A Heuristic Based Approach

The assessment methodology is based on one of the heuristic-based approach known as particle swarm optimisation technique (PSO). The main objective is to optimize the mathematical models with respect to the indicators. The goal is to have the same accuracy as of the traditional life cycle assessment software such as GaBi and SimaPro. PSO enables efficient, multi-objective, and data-driven forecasting for agricultural systems, helping stakeholders make informed decisions about future profitability, environmental impact, and employment sustainability. PSO can account for fluctuating input costs, crop prices, and market trends, optimizing revenue predictions. By integrating environmental data such as carbon emissions from machinery and fertilizers, PSO helps model future emission levels and suggests mitigation strategies. PSO considers labour demand patterns tied to seasonal agriculture, automation levels, and policy impacts, providing insights into workforce trends [23][24]. Since the analysis involves numerous uncertainties and randomness associated to the supply chain, a heuristic model can be a best solution for the assessment. In the heuristic approach which refers to modern optimisation theory numerous literature and definitions have been given. These methods are known as non-traditional methods in the field of optimisation technique. These methods are based on characteristics and behaviour of biological, molecular, swarm of insects, and neurobiological systems. The following are the examples of such optimisation techniques:1-Genetic algorithms 2-Simulated annealing 3-Particle swarm optimisation 4 - Ant colony optimisation etc. These algorithms have been developed in recent years and are emerging as one of the best methods for the solution of complex engineering or mathematical problems. They require only the function values and not the derivatives.

2.9.1 Genetic Algorithm

The genetic algorithm is a random-based classical evolutionary algorithm. The word random suggests that to find a solution using the GA, random changes applied to the current solutions to generate new ones. GA may be called Simple GA (SGA) due to its simplicity compared to other evolution based algorithms.GA is based on scientist Darwin's theory of evolution.

It is a slow gradual process that works by making slight and slow changes. Also, GA makes slight changes to its solutions slowly until getting the best solution . The genetic algorithm (GA) is based on the ideas of natural genetics and selection. Simulated annealing is established on the simulation of thermal annealing of critically heated solids [23]. In genetic algorithm population size is fixed since it deals with DNA; hence it is not suitable for supply chain-based problem [22].

2.9.2 Simulated Annealing

Simulated Annealing (SA) mimics the physical annealing process but is used for optimizing the parameters in a model. Physical Annealing is the process of heating up a material until it reaches an annealing temperature and then it would be cooled down slowly in order to change the material to a desired structure. When the material is hot, the molecular structure is weaker and it is more susceptible to change [23]. When the material cools down, the molecular structure is harder and is less susceptible to change. This process is very useful for situations where there are a lot of local minima such that algorithms like gradient descent would be stuck at. The advantages of the method are it is easy to implement and use and it provides optimal solutions to a span of problems, but it can take a long time to run if the annealing schedule is long. Also, there are lots of tuneable parameters in the algorithm. So, a better search algorithm was evolved which is best fit for supply chain problems as it can handle randomness and uncertainties. Particle swarm optimisation is one of the best fit algorithms for the proposed work [23].

2.9.3 Particle swarm optimisation

The word particle refers to flock of birds, colony of ants or group of insects. The particle swarm optimisation algorithm mimics the behavior of social organisms. Each particle in a swarm behaves in a distributed way using its own intelligence. If one particle discovers an optimum path to food and the rest of the swarm will also be able to follow the optimum path instantly. The particle is assumed to be of specified or fixed size [23]. Each particle is located initially at random locations in the multi - dimensional space. Each particle has two characteristics: a position and a velocity. It wanders around in the design space and memorizes the best position (in terms of objective function value) it has discovered. When one bird locates a target or location of food (or maximum of the objective function), it will instantaneously transmit the information to all other birds. The other birds gravitate to the target or location of food (or maximum of the objective function), but not directly. There is a component of each bird's own independent thinking as well as its past memory. An algorithm can be defined to demonstrate the PSO model. The detailed analysis is given in chapter 3.

2.10 Particle swarm Optimisation: Synthesis of literature

Kennedy Eberhart (1995) [23] have discussed the nonlinear approach in particle swarm optimisation. Also, it has drawn a relationship network between genetic algorithm and artificial life. The literature introduces a method for optimisation of continuous nonlinear functions. The method was discovered through simulation of a simplified social model; thus, the social metaphor is being discussed, though the algorithm stands without metaphorical support. It describes the particle swarm optimisation concept in terms of its precursors, briefly reviewing the stages of its development from social simulation to optimizer. Also, a few paradigms are discussed which implement the concept.

Al-Noweam, F. A., El-Khouly, I. A., & El-Kilany, K. S. (2018) has described about the economic, social, and environmental assessment via mathematical model and mixed integer linear programming model is implemented for solution of the supply chain problem. Waste and food losses occur along the entire food supply chain from harvesting to consumption. It will be a sustainable solution if we tackle the problem of food waste. Another problem our society is facing is the drastic increase in energy consumption due to the rise in standard of living and the continuous growth in the world population. The increased stress on the amount of fossil fuels being used to meet current demand, and eventually fossil fuel alone will not be able to meet the amount of energy needed by the world. This literature addresses the design of a food waste to bioethanol supply chain to tackle both problems of food wastes and energy. Three key decisions are addressed for the optimal design of the supply chain: 1) the sites and amount of food wastes collected; 2) the number, sizes, and location of the bio-refineries; 3) the transportation plans of ethanol to demand points. A multi-objective (economic, environmental, social) model is proposed. A case study in Egypt is introduced and is proposed for future implementation.

Rao Singresu S (2009) has given a descriptive vision of modern optimisation technique. In past few years, some optimisation methods that are conceptually different from the traditional mathematical programming techniques have been developed. These methods are labelled as modern or non -traditional methods of optimisation. Most of these methods are based on certain behaviour and characteristics of biological, swarm of insects, molecular, and neurobiological systems[24]. The methods are described in this chapter are genetic algorithms, simulated annealing, particle swarm optimisation, ant colony optimisation, fuzzy optimisation, neural-network-based methods. Most of these methods have been originated only in the recent years and are considered as popular methods for the solution of complex engineering problems[26]. Most require only the function values (and not the derivatives). Simulated annealing is based on the simulation of thermal annealing of critically heated solids. The genetic algorithm is based on the principles of natural selection and natural genetics Both simulated annealing and genetic algorithms are stochastic methods that can find the global minima and maxima with a high probability and are naturally applicable for the solution of discrete optimisation problems. The particle swarm optimisation is based on the social behaviour of a colony of living things such as a swarm of insects, a school of fish or a flock of birds. Ant colony is based on the cooperative behaviour of real ant colony, which are able to find the shortest path from their habitat to a food source. In many practical systems, the objective function, constraints, and the design data are known only in vague and linguistic terms. Fuzzy optimisation methods have been developed for solving such problems[26]. In neural-network-based methods, the problem is modelled as a network consisting of a number of neurons, and the network is trained suitably to solve the optimisation problem efficiently.

An, H., Wilhelm, W. E., & Searcy, S. W. (2011) has developed a time - based optimisation system to find out the net profit of the system. This study formulates a model to maximize the profit of a lignocellulosic biofuel supply chain ranging from feedstock suppliers to biofuel customers. The model deals with a time-staged, multi-commodity, production/distribution system, prescribing facility locations and capacities, technologies, and material flows. A case study based on a region in Central Texas demonstrates application of the proposed model to design the most profitable biofuel supply chain under each of several scenarios. A sensitivity analysis identifies that ethanol (ETOH) price is the most significant factor in the economic viability of a lignocellulosic biofuel supply chain.

2.11 Summary Of Literature Review

In this section, we have attempted to summarize important insights and inferences drawn from the above detailed literature review. This, we envisage, would help to identify the prevailing research gaps and enable us to formulate the proposed research problem. Several studies have been done to showcase the various pathways of ethanol synthesis. Ethanol blended petrol (EBP) Program is aimed at achieving multiple outcomes such as addressing environmental concerns, reducing import dependency, and providing boost to agriculture sector. The National Policy on Biofuel (NPB) – 2018 provides an indicative target of 20% ethanol blending in petrol by 2030.As a step in this direction, oil marketing companies (OMCs) are to procure ethanol derived from C heavy molasses, B heavy molasses, sugarcane juice, sugar, sugar syrup, damaged food grains unfit for human consumption, surplus food grains as decided by National Biofuel Coordination Committee (NBCC) under the ambit of NPB-2018, including fruit and vegetable wastes. Under the EBP Program, OMCs procure and blend up to 10% ethanol in petrol. The circular economy postulates [6] is derived from the postulates of performance economy, blue’s economy, biomimicry, and systems thinking etc. It is based on waste valorization or waste to wealth concept except of assessing the sustainability indicators.[25] [27] gives the information on assessing the sustainability of biofuel supply chain in mixed integer programming method and time-based optimisation method respectively.

2.12 Summary

We can find established literature on power and heat generation by the virtue of biofuel, cooking stoves using biofuel; but there are a few literatures on sustainability assessment of biofuel in the transport sector. The previous studies give an elaborated idea on biochemical pathways of extracting ethanol and biodiesel in first generation(1G); but in 1G biofuel supply chain system, the resources are based on crops, which can create food versus fuel problem. Whereas the second-generation biofuel is based on agricultural residues, switch grass, waste from food crops, wood chips etc. The cradle to grave assessment has only two blocks. 1- Harvesting site and 2- Bio-refinery.

It does not include the environmental and social factors. It only deals with resource extraction and utilization; but it does not cover the factors associated with it. As a result, the efficiency of entire system could not be assessed properly.

For this reason, circular economy, or cradle to cradle approach is followed in the proposed work. The previously established well to wheel analysis and the linear economy do not consider the byproducts of the industries to become a potential input, whereas the circular economy framework is based on the waste valorization concept. For example, in the proposed theory, the source is a waste from a farm area, which is known as agro-waste. Further in the biorefinery there are various kinds of waste available such as after conversion to ethanol, the residual higher order alcohols can be converted into aromatic compounds. The supply chain consists of many sub blocks which can be postulated through circular economy framework. The Figure 2.3 gives the idea about it. The mentioned work in the literature review section of the optimisation algorithm has demonstrated time-based optimisation technique in a biofuel supply chain; but it is silent on the randomness and uncertainty in the supply chain system.

Chapter 3

Sustainability Assessment of 2G Biofuel Supply Chain using Particle Swarm Optimisation

The chapter describes the algorithm element of the assessment. Energy modelling and life cycle assessment through data science algorithm is the core element of the sustainability assessment for the research work. The entire procedure of the sustainability assessment is described in the chapter 3. Particle swarm optimisation is the core algorithm for the energy modelling and sustainability indicator analysis. The drawbacks of the existing life cycle analysis with respect to the Karnataka reason is well presented in the chapter 3.

3.1 Introduction

This chapter encompasses optimisation engineering, mass balance and waste valorization to represent the sustainability analysis of second - generation ethanol supply chain. In efforts to stimulate sustainable development, the circular economy represents the most recent attempt to reduce the pressure on the environment by attaining harmony between the economy, environment, and society. In theory, this is accomplished by establishing ‘closed loop’ flows of resources in a way that enables businesses and society to reap benefits from maintaining products, components and materials at their highest utility and value, while reducing the generation of waste. The circular economy offers considerable potential to address the environmental challenges in the design of products and the built environment, yet there are also several technical and non-technical challenges to overcome in its implementation. In circular economy, the notion of waste is eliminated by maintaining products, components and materials at their highest utility and value always [59] which can be achieved, for example, through long-lasting design, maintenance, repair, reuse, remanufacturing, and recycling [60]. The ultimate objective of this model is to achieve the decoupling of economic growth from natural resource depletion and environmental degradation [61]. Although the idea of closing resource loops is not necessarily novel, it has been popularized in recent years by NGOs (non-governmental organizations) such as the Ellen MacArthur Foundation and has gained a place on political agendas across Europe, as it is seen as a way of implementing sustainable development without limiting economic growth. The figure 3-1 shows the proposed ethanol supply chain within the framework of circular economy.

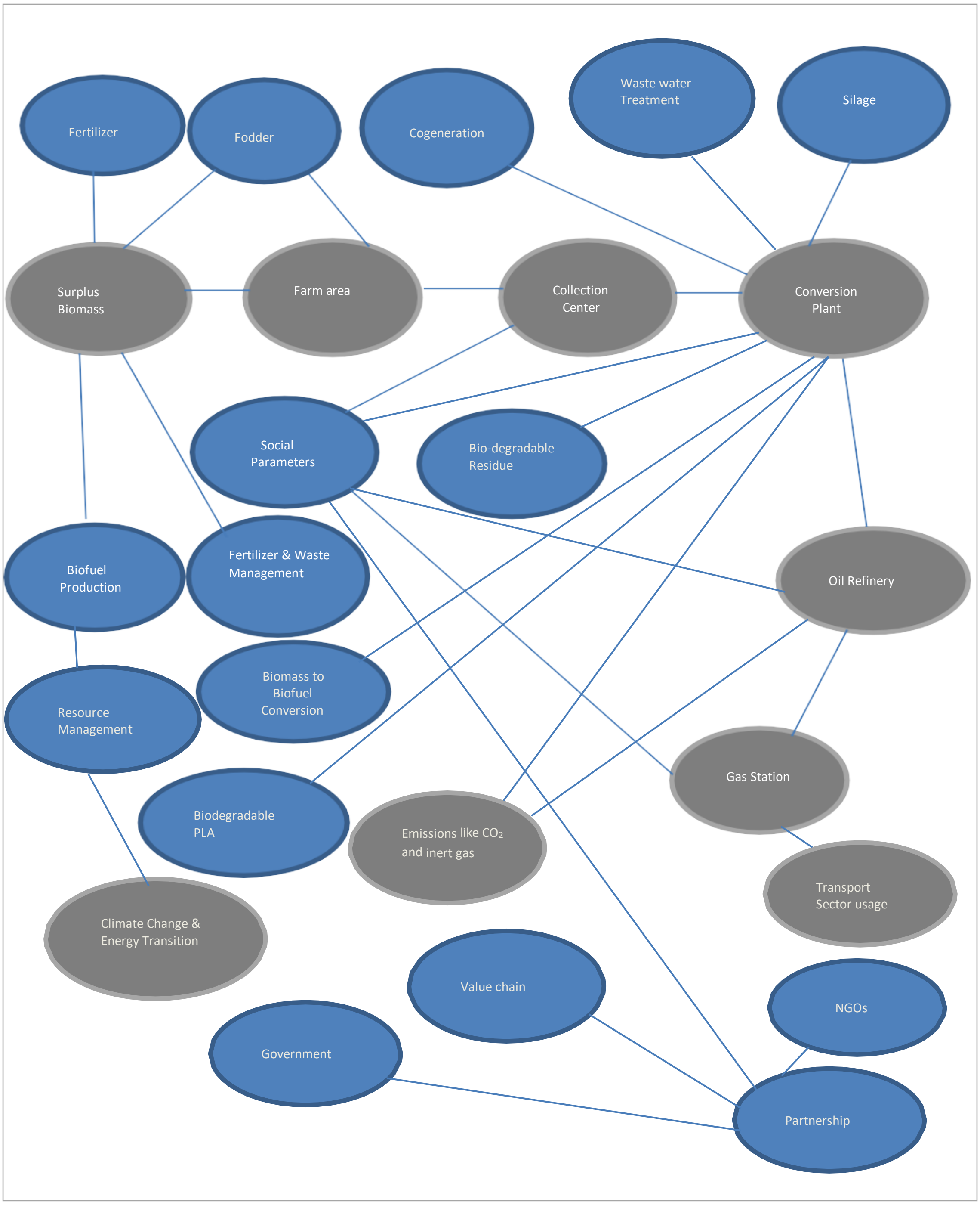


Figure 3.1 (Functional map of the proposed framework)

3.2 Methodology

The research work has many stages. The first stage is the pilot study of Karnataka's agricultural conditions. A dataset of various crops is accumulated. The data set is derived from Raitamitra Karnataka's official portal. All the 31 districts rice, Corn, sugarcane, cotton, lentils, coconut etc. crop data is assimilated to see the majority production in the state. The details are presented in the appendix section. Since rice and Corn have come out as one the major crops in Karnataka the proposed work is based on rice and Corn crop. The average amount of Corn and rice is tabulated below.

Rice production in Karnataka (in MT) (1999-2022) [62]

Northern Karnataka	334053.437
Southern Karnataka	114650.902
Coastal Karnataka	47251.607

Table 3.1 Rice production

Corn production in Karnataka(in MT) (1999-2022) [62]

Northern Karnataka	334105.146
Southern Karnataka	114658.513
Coastal Karnataka	2116.585

Table 3.2 Corn Production

The 3 pillars of sustainability indicators mentioned in the work are 1- Economic 2- Environmental 3- Social. The concept of circular economy is applied while assessing the sustainability of the entire supply chain system. The "Reuse" concept is primarily used in terms of waste valorization in the proposed work. The proposed circular economy framework or cradle to cradle analogy is based on 3 major sustainability indicators. i.e., Economic, Social and Environmental. The goal is to suggest the feasibility of the proposed biofuel supply chain for transportation industry. The major blocks of the proposed supply chain are (i) Harvesting Site (ii) Transport (iii) Conversion Plant (iv) Oil Refinery (v) Ethanol blended with petrol in IC engine and (vi) Consumers.

The primary objective is to develop a generalized second-generation ethanol supply chain adopting a circular economy framework. To validate the above framework corn cob, corn stalk and paddy straw are taken as the biomass which are generated in a certain cluster (Ranebennur, Davangere, Harpanahalli, Anagodu etc.) in the state Karnataka.

3.2.1 Optimisation in social indicator factor

The social indicators are measured in the various categories.

i. Employment rate
ii. Rate of unemployment
iii. Access to health care
iv. Access to clean water
v. Infant mortality rate

It is not possible to perform the assessment study with respect to each kind of social indicators. So, we are only looking at the employment rate. The mathematical model for calculating employment rate is,

Employment rate = (workers + threshers/labourers) *100 (in percentage) (1)

3.2.2 Optimisation in economic indicator factor

The economic indicator is measured with respect to revenue generated in the entire supply chain system.

So, system profit = Revenue generated – (Capital cost + Operational cost) (2)

3.2.3 Optimisation in environmental indicator factor

The environmental indicator is measured in terms of CO_2 emissions. There are various parameters to evaluate environmental indicators such as CO_2 emissions, NOx emissions, SO_2 emissions, particulate matter emissions. We have proposed to measure the NOx and CO_2 emissions to evaluate the environmental indicator.

So, Total emissions = Emissions in the farm area + Emissions in the transportation + Emissions in the conversion plant + Emissions in the oil refinery (3)

3.3 Identification of biomass cluster

A cluster-based approach is implemented in biomass supply chain. The proposed collection centers are selected so that the biomass which is available in the vicinity can be collected. The report by PRESPL [66] has enabled to locate the collection center as well as the biomass cluster a priori. A diagram of proposed biomass supply chain is described in figure 3-2.

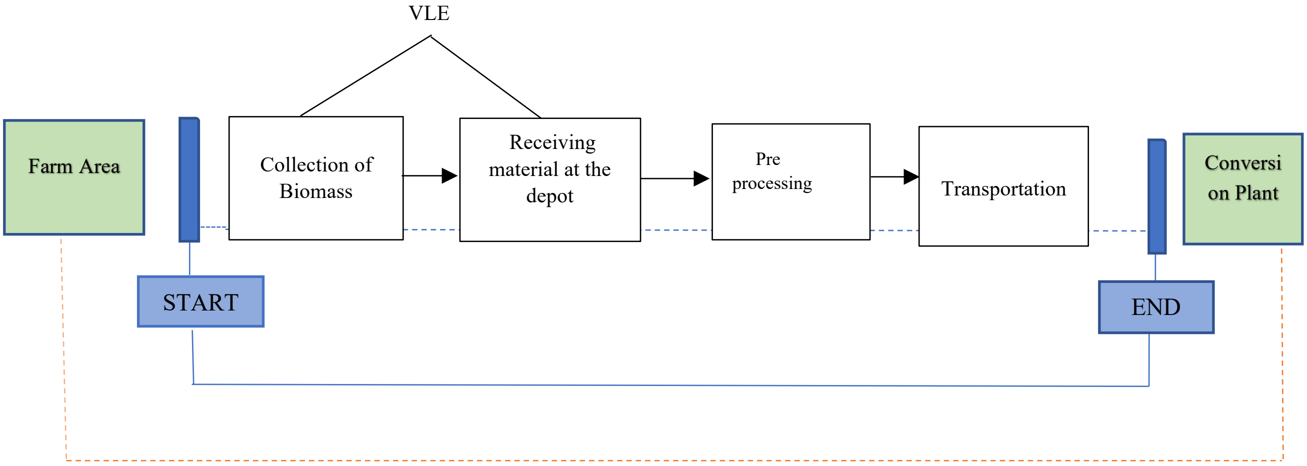


Figure 3.2(A typical biomass supply chain from site area to collection unit)

The sub blocks of the supply chain are defined as collection, receiving, pre-processing and transportation. A brief explanation of each sub block is given below. The geo spatial location, the data about the biomass is considered from the PRESPL [66] report.

Collection of Biomass

The mentioned block refers to farm area where the surplus biomass is collected. Also, baling and shredding kind of activities are performed here.

Receiving Depo

The receiving depo refers to the collection center where the biomass from many villages is stored. The receiving depo is mainly the center of the cluster selected in accordance with the availability of biomass.

Pre-Processing

Pre-processing includes shredding, conversion of biomass into briquettes and pellets. Sometimes drying and pulverization is needed before it goes into the thermo- chemical plant/bio-refinery. In the proposed model pre-processing takes places just before the thermo-chemical conversion. Hence pre-processing and the thermo- chemical process is assumed to be a single block.

Point of Consumption

In the proposed model, point of consumption refers to the plant where biomass to biofuel conversion takes place. These are villages / towns, which are accessible, spread out in the area as per biomass availability. The proposed collection centers in this cluster can be seen from following figure and table and are discussed in detail in the following sections.

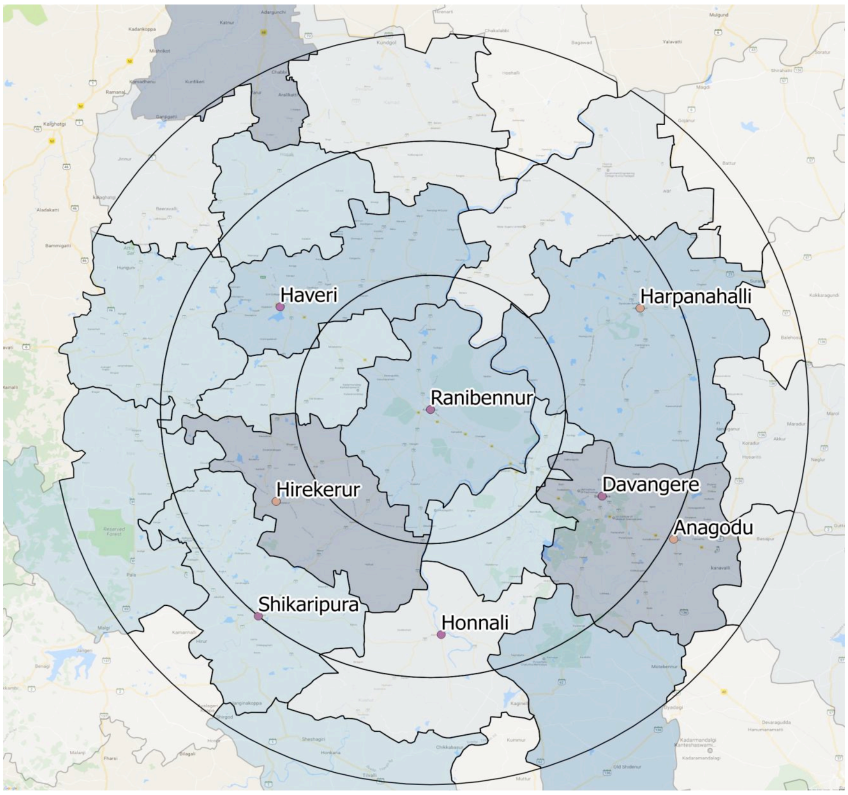


Figure 3.3(Proposed Collection centers within maximum radium of 100km)

We have discussed the type of crop, the profit, social, environmental sustainability assessment from farm to collection center/storage. Three kinds of crops have been discussed here.1- Corn stalks 2- corn cobs 3- paddy straw. Since the area has abundance of these two crops, these 2 crops have been taken as crop for the model. The GIS mapping and the abundance of the resources have indicated that Ranebennur, Haveri, Hirekerur, Honalli and Anagodu are the strategic points for the sustainability analysis [67]. A detailed analysis of the calculation of the socio-economic and environment indicators are given below.

Supply Chain of Corn Cobs

It is VLE driven supply chain and is free from any biomass processing activity. It is quite simple. Activity starts with i) identifying farmers with surplus/willing to sale Corn cobs, purchase rates are to be negotiated (most of the time it is ruling price), ii) if deal clicks labor team with bags need to be sent there iii) bags need to be loaded and iv) transported.

Procurement and stock Plan

As discussed earlier, Corn cobs are expected to be available from November to April, i.e., collection window, and hence required quantity needs to be purchased and stored during this period for ensuring regular supply. The total quantity of Corn cobs to be collected during this period will be 169522 MT, which is available within 70 km from the plant [67]. The procurement is expected to be at peak during November to January. The month-wise estimated surplus quantity of Corn cobs, and the quantity to be purchased, during the period can be seen from following figure.

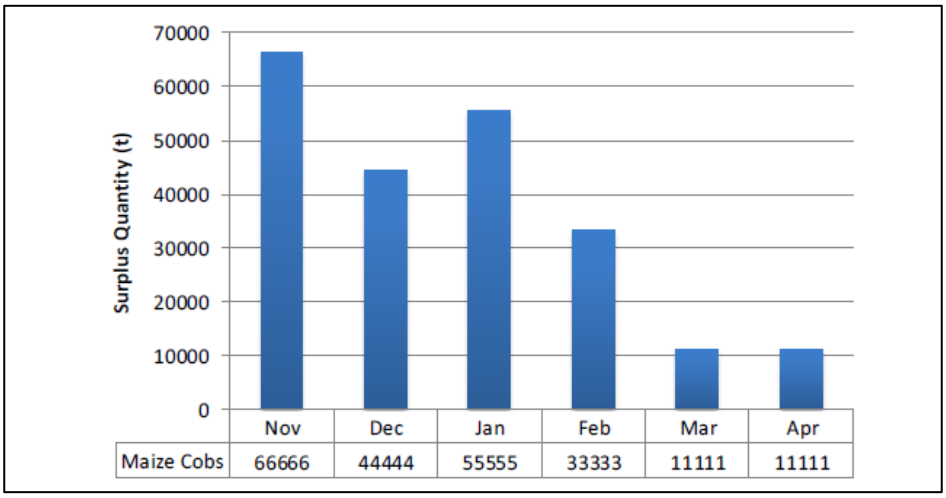


Figure 3.4 (Month wise Surplus Quantity - Corn Cobs) [67]

Collection System

No separate equipment is required for collection of cobs, and Corn cobs suppliers are already present in the cluster. These suppliers are basically Village Level Entrepreneurs (VLEs) who own/operate transportation vehicles. These suppliers act as intermediaries who arrange vehicle and labor, buy Cobs from the farmers at farm gate, pay them in cash, and then transport and sell it to the buyer where it is required. These VLEs will supply Corn cobs directly to plant within 25 km radius and to collection centers above 25 km radius through their own load carriers. It is expected that a VLE will be able to supply about 500-800 MT of Corn Cobs during the collection window depending on the resources he owns. Therefore, a large network of VLEs of around 250-300 need to be established. However, Corn cobs collected at CCs would be transported during the lean period to plant through hauling contractors who will be guided to make the customized trolley system to accommodate large quantity (5-6 MT) of Corn cobs.

Collection Centers and Storage

To expedite the collection of Corn cobs during the collection window, CCs at strategic locations having catchment radius of 20-25 km is formed. Thus, based on the procurement and stock plan detailed above, the maximum stock that reaches during collection period is around 85000 MT. The collection and storage system advocated for Corn cobs is in bags. Bags of customized material need to be given to VLEs registered with project developer. Material of these bags would be durable and can be used multiple times. These bags would be stored at CC. This act would optimize the handling, bring the traceability to the system and would also put checks on VLEs from material being diverted to other prospective buyers. During rainy season, stacks of bags would be covered with good quality plastic sheets to avoid damage from elements of nature. Maximum 4500 MT of Corn cobs is stored in 1 Ha land and thus the capacity of CC is 18000 MT. Therefore, 5 CCs would be required to be established in the catchment radius of 70 km. The figure 3-5 gives the detail list of CCs for collection of Corn cobs.

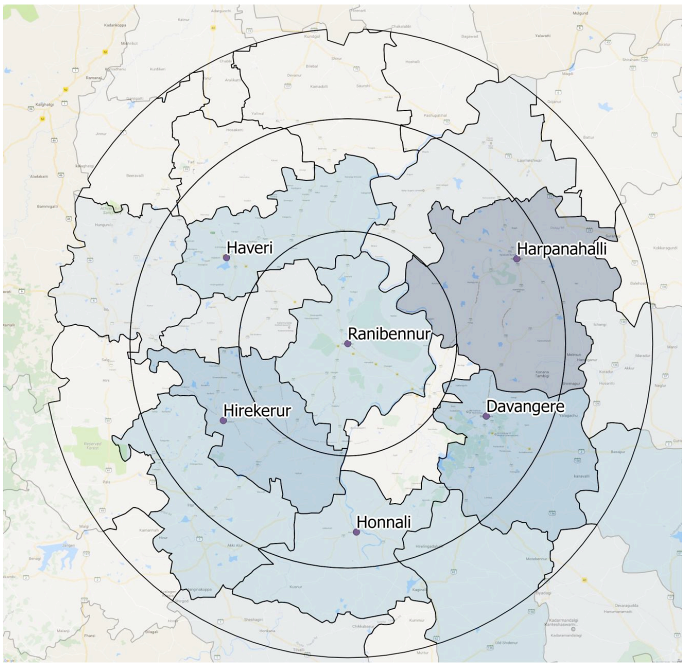


Figure 3.5 (Proposed Collection Centers for Corn Cobs)

Supply Chain of Corn Stalks

Corn Stalks are expected to be available from November to January, i.e., collection window, and hence required quantity needs to be purchased and stored during this period for ensuring regular supply. The total quantity of Corn stalks to be collected during this period will be 108283 MT. The procurement is expected to be at uniform throughout these 3 months.

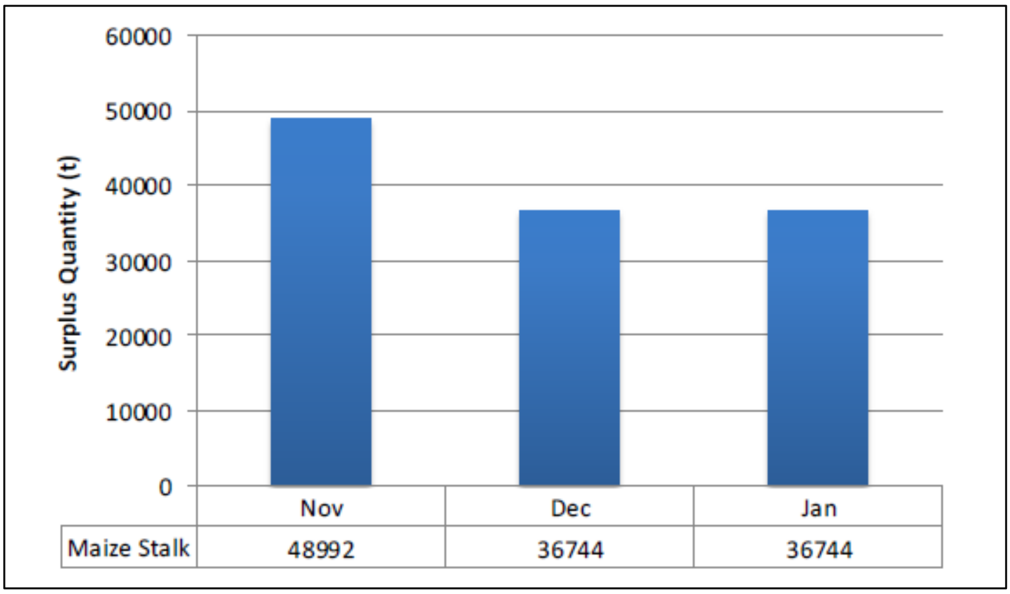


Figure 3.6(Surplus Corn Quantity) [67]

Collection of corn Stalks will start as soon as corn is detached from the plant. Corn stalk is harvested only if required for fodder else it remains standing in the field. During the primary survey interactions were held with government officials, farmers, rototillers etc. regarding its availability for intended use. The responses were quite mixed as it is used as fodder in some talukas within the cluster where there is no complementing crop residue to meet the fodder requirement. The supply chain activity of corn stalk in the pockets where it is not used as fodder would start with harvesting corn stalk using combine harvester. It will then be followed by Raker to form the windrows to collect the harvested Corn stalk more efficiently. Then Baler is mowed over the windrows to form the bales of harvested stalk. Round balers are recommended due to high compaction ratio, and good storage ability. Mechanized loading with help of forklifts is recommended to reduce the cost and expedite the loading operation. It is expected that multiple VLEs or single FMC would require taking over the entire operations of corn stalk supply chain.

Collection Centers and Storage

For collection and storage of required quantity of Corn Stalks around 3 collection centers will be required above 25 km radius. The location of proposed collection centers is selected considering the availability and distribution of net surplus quantity of Corn Stalks, and some of the proposed collection centers are as following. Around 6000 MT of baled Corn cobs would be stored in 1 Ha of land and hence capacity of CC is 24000 MT [67]. Maximum quantity to be stored in CC is around 70,000 MT and hence around 3 CCs need to be established as depicted in the next figure [66].

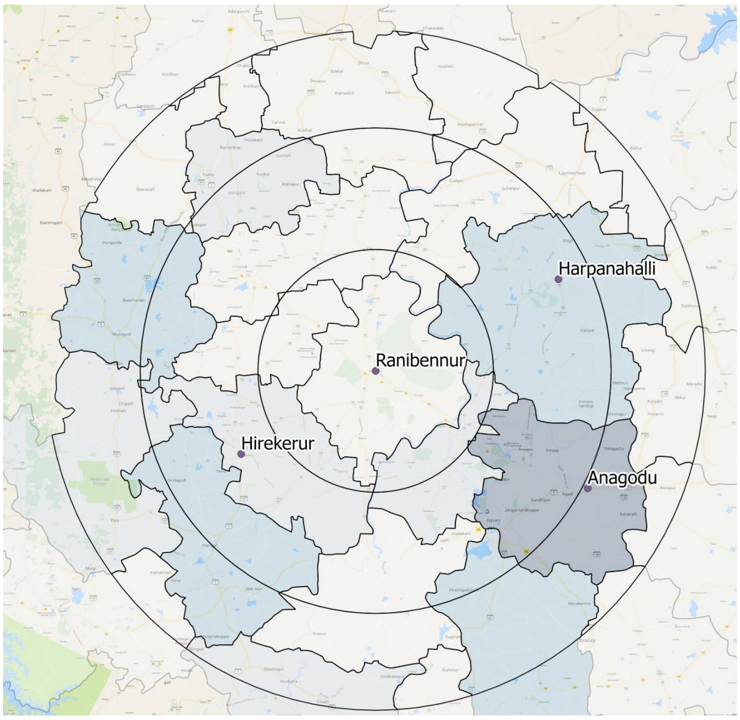


Figure 3.7 (Proposed Collection Centers - Corn Stalks)

Supply Chain of Paddy Straw

Paddy straw is expected to be available in May and then from October to December, i.e., collection window, and hence required quantity needs to be purchased and stored during this period for ensuring regular supply. The total quantity of Paddy Straw required is 150000 MT against which only 109558 MT is available within 70 km from the plant [66]. The procurement is expected to be at peak during November and May.

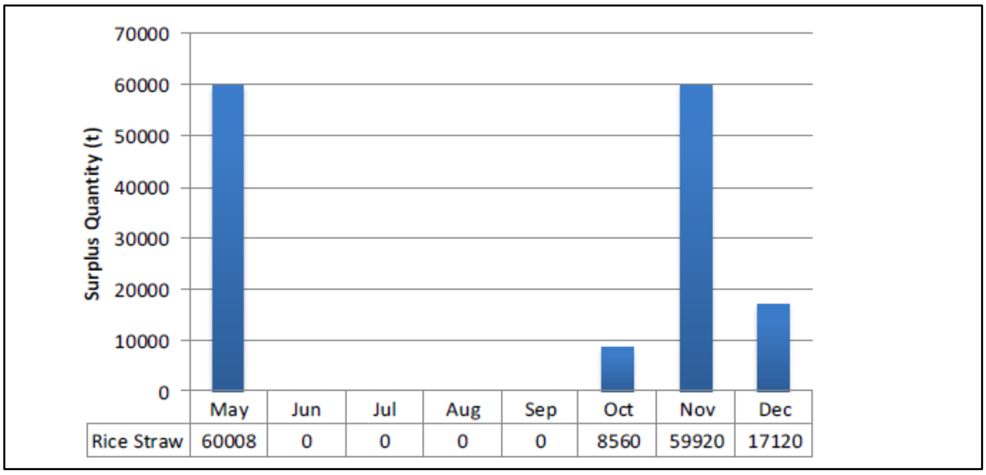


Figure 3.7.1 (Month wise Surplus Quantity - Paddy Straw) [67]

Supply chain activity

The collection system and biomass supply chain activity include shaving of stubbles that remains in the harvested paddy fields. It is done with stubble shaver/cutter. It is then followed by Raker to form the windrows to collect paddy straw. Then balers are mowed over windrows and transform it into bales. Paddy straw collection will start as soon as the paddy harvest begins.

Collection Centers and storage

For collection and storage of required quantity of paddy straw around 2 collection centers will be required. The location of proposed collection centers is selected considering the availability and distribution of net surplus quantity of paddy straw, and some of the proposed centers are depicted in the next figure.

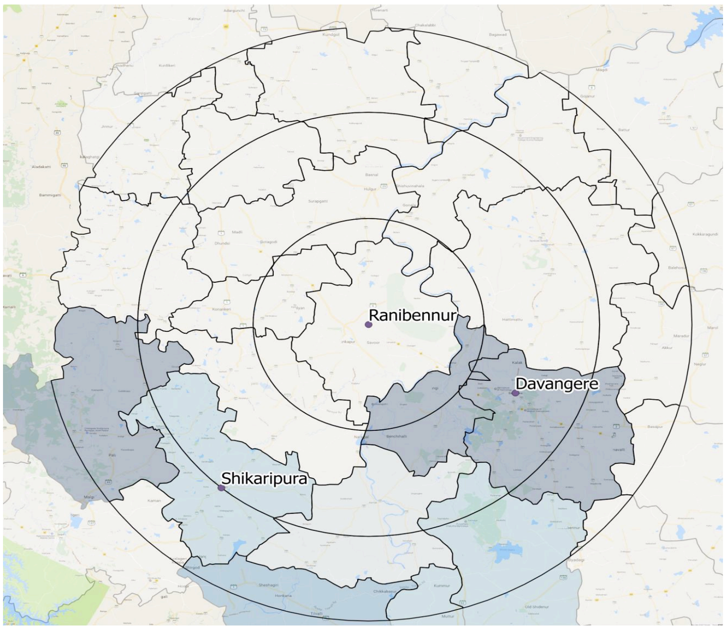


Figure 3.9 (Proposed Collection Centers - Paddy Straw)

Crops	Dry biomass In MT	Surplus Biomass In MT	Bioethanol Potential (BL)	Ash Content
Rice	225.487	43.856	12.017	18-20%
Wheat	145.449	25.07	6.919	6-12%
Corn	27.88	6.036	1.11	0.90%
Sugarcane	119.169	41.559	14.629	4-5%

Table 3.3(Ash content analysis from NREL Calculator)

The Table 3.8 provides the information about bioethanol potential from 4 of the major crops of India. The calculation of bioethanol and ash content is performed using NREL calculator [63]. Conversion efficiency in corn is very low. To deal with high ash content and to convert lignin to syngas an efficient technique is developed in IISc Bangalore [66]. The best way so far is to convert biomass to syngas in thermochemical process and syngas to ethanol in biochemical route. A detailed mass balance is given in Chapter 4.

3.4 Research problem statement

1. The proposed work emphasizes on sustainability assessment of biofuel supply chain (both upstream and downstream) by adopting the concept of circular economy.
2. Previously any product which was to be tested was undergoing cradle to grave analysis.
3. The cradle to grave analysis is a linear approach. It hardly satisfies the environment and social constraints.
4. Circular Economy has dual fold advantage 1) Technical aspect; but also, it will satisfy the Social, Economic, Environmental constraints.
5. The work will be focused on establishing biofuel sustainability by the help of a mathematical tool (optimisation technique) and concept of circular economy.

3.5 Optimisation Technique

The first mathematical model corresponds to maximization of revenue generated in the system containing 1. Harvesting area 2. Transportation linking harvest area Collection Center 3. Collection center (CC). In the analogy we have implemented a novel technology for maximization of revenue in the supply chain system. The constraints related to the system are intermittency of surplus biomass, loss in dry weight due to moisture content, rotting away of the corn due to pest attack, spillage due to the transportation, absence of proper storage area etc. In these cases, it is very difficult to arrive at an optimal solution. So, we have implemented a heuristic-based optimisation technique to evaluate the supply chain with respect to two pillars sustainability i.e., economic, and environmental. In recent years, some optimisation methods which are conceptually different from the previous mathematical programming techniques have been developed. These methods are known as non-traditional methods in the field of optimisation technique. These methods are based on characteristics and behaviour of biological, molecular, swarm of insects, and neurobiological systems. The following are the examples of such optimisation techniques:1-Genetic algorithms 2-Simulated annealing 3-Particle swarm optimisation 4- Ant colony optimisation 5- Fuzzy optimisation. These algorithms have been developed in recent years and are emerging as one of the best methods for the solution of complex engineering or mathematical problems. They require only the function values and not the derivatives. The genetic algorithm (GA) is based on the ideas of natural genetics and selection. Simulated annealing is based on the simulation of thermal annealing of critically heated solids [68]. In genetic algorithm population size is fixed since it deals with DNA; hence it is not suitable for supply chain-based problem [68]. In case of simulated annealing, it only finds out the minima; it does not address the maximization part [68]. Genetic algorithm is an evolution-based algorithm. Unlike the previous technique PSO is based on behavior-based algorithm. For this reason, particle swarm optimisation technique has been the best optimisation technique to be adopted so far.

3.6 Particle swarm optimisation

Particle swarm optimisation, abbreviated as PSO, is based on the behaviour of a colony or swarm of insects, such as ants, termites, bees, and wasps; a flock of birds; or a school of fish. The particle swarm optimisation algorithm mimics the behaviour of these social organisms.

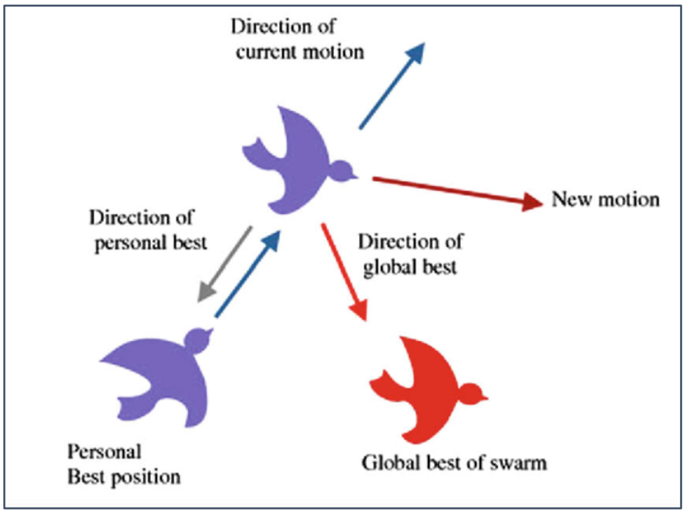


Figure 3.9 (PSO algorithm representation)

The figure 3.9 gives a pictorial representation of particle swarm optimisation technique. The word particle denotes, for example, a bee in a colony or a bird in a flock. Each individual or particle in a swarm behaves in a distributed way using its own intelligence and the collective or group intelligence of the swarm. As such, if one particle discovers a good path to food, the rest of the swarm will also be able to follow the good path instantly even if their location is far away in the swarm. Optimisation methods based on swarm intelligence are called behaviourally inspired algorithms as opposed to the genetic algorithms, which are called evolution-based procedures. The PSO algorithm was originally proposed by Kennedy and Eberhart in 1995 [66]. In the context of multivariable optimisation, the swarm is assumed to be of specified or fixed size with each particle located initially at random locations in the multidimensional design space. Each particle is assumed to have two characteristics: a position and a velocity. Each particle wanders around in the design space and remembers the best position (in terms of the food source or objective function value) it has discovered. The particles communicate information or good positions to each other and adjust their individual positions and velocities based on the information received on the good positions. As an example, consider the behaviour of birds in a flock[78].

Although each bird has a limited intelligence by itself, it follows the following simple rules:

1. It tries not to come too close to other birds.
2. It steers toward the average direction of other birds.
3. It tries to fit the "average position" between other birds with no wide gaps in

the flock. Thus, the behaviour of the flock or swarm is based on a combination of three simple factors:

1. Cohesion — stick together.
2. Separation — do not come too close.
3. Alignment — follow the general heading of the flock.

The PSO is developed based on the following model:

1. When one bird locates a target or food (or maximum of the objective function),

it instantaneously transmits the information to all other birds.

2. All other birds gravitate to the target or food (or maximum of the objective

function), but not directly.

3. There is a component of each bird's own independent thinking as well as its

past memory. Thus, the model simulates a random search in the design space for the maximum value of the objective function. As such, gradually over many iterations, the birds go to the target (or maximum of the objective function).

An algorithm can be defined to demonstrate the PSO model [68]. In the PSO model there will be two best values. p_{best} value, g_{best} value.

$p_{best} \longrightarrow$ best solution (fitness) it has achieved in the last iteration.

$g_{best} \longrightarrow$ best solution achieved by any particle in the population.

Each particle tries to modify its current position and velocity according to the distance between current position and pbest.

It tries to modify the distance between current position and gbest.

Calculation of position and velocity -:

Set the initial velocity = 0.

Velocity, $V_j(i) = wV_j(i-1) + c_1r_1[\, p_{best,\,j} - X_j(i-1)] + c_2r_2[g_{best} - X_j\,(i-1)]$ (4)

j=1, 2…… N, "i" is the iteration count

Position of j^{th} particle in i^{th} iteration is $X_j(i)=X_j(i-1) + V_j(i)$

j = 1,2, 3,.….N, "i" is the iteration count

c_1, c_2 are cognitive and social learning rates respectively. c_1 allows in defining the ability of the group to be influenced by the best personal solutions found over the iterations. c_2 allows in defining the ability of the group to be influenced by the best global solution found over the iterations. In the equation (1) "w" corresponds to inertia weight.

3.6.1 Summary of the flowchart of a constrained PSO

1. Assume the swarm size to be N.
2. Set the objective function as F(x) and iteration as i, j respectively.
3. Evaluate $F[X_1(i)]$, $F[X_2(i)]$, $F[X_3(i)]$, $F[X_N(i)]$.
4. Check whether the constraints are satisfied.
5. Generate position of each particle as $X_j(i)$.
6. Generate the velocity of each particle as $V_j(i)$
7. Set initial velocity=o
8. Find velocity, $Vj(i)= w*V_j(i-1) + c_1r_1[\, p_{best,\, j} - X_j(i-1)] + c_2r_2[g_{best} – X_j(i-1)]$, where $j = 1, 2,. N$
9. Find the position of j^{th} particle in i^{th} iteration as $X_j(i) = X_j(i-1) + V_j(i)$, $j=1,2,3…. N$
10. Check if $p_{best} = g_{best.}$ (only the points in feasible space)
11. If NO then go back to step 5, set i=i+1.
12. If YES, then stop iteration

3.7 Computational Implementation of PSO

An example of unconstrained PSO is explained in the following paragraph.
An unconstrained maximization problem is explained below.

Maximize F (**X**) ,with $\mathbf{X}^{(l)} \leq \mathbf{X} \leq \mathbf{X}^{(u)}$ (5)

where $\mathbf{X}^{(l)}$ and $\mathbf{X}^{(u)}$ denote the lower and upper bounds on **X**, respectively. The PSO procedure can be implemented through the following steps. Assume the size of the swarm (number of particles) is N. To reduce the total number of function evaluations needed to find a solution, we must assume a smaller size of the swarm. But with too small a swarm size it is likely to take us longer to find a solution or, in some cases, we may not be able to find a solution at all. Usually, a size of 20 to 30 particles is assumed for the swarm as a compromise[78].Generate the initial population of $\mathbf{X}$ in the range $\mathbf{X}^{(l)}$ and $\mathbf{X}^{(u)}$ randomly as $\mathbf{X}_1, \mathbf{X}_2, \ldots, X_N$. Hereafter, for convenience, the particle (position of) j and its velocity in iteration "i" are denoted as $\mathbf{X}_j^{(i)}$ and $\mathbf{V}_j^{(i)}$, respectively. Thus, the particles generated initially are denoted $\mathbf{X}_1(0), \mathbf{X}_2(0), \ldots, X_N(0)$. The vectors $\mathbf{X}_j(0)$ $(j = 1, 2, \ldots, N)$ are called particles or vectors of coordinates of particles.

3.7.1 Constrained PSO

Let the constrained optimisation problem be given by

Maximize $f(\mathbf{X})$

subject to $g_j(\mathbf{X}) \leq 0; j = 1, 2, \ldots, m$ (6)

An equivalent unconstrained function, $F(\mathbf{X})$, is constructed by using a penalty function for the constraints. Two types of penalty functions can be used in defining the function $F(\mathbf{X})$. The first type, known as the stationary penalty function, uses fixed penalty parameters throughout the minimization and the penalty value depends only on the degree of violation of the constraints. The second type, known as nonstationary penalty function, uses penalty parameters whose values change dynamically with the iteration number during optimisation. The results obtained with the nonstationary penalty functions have been found to be superior to those obtained with stationary penalty functions in the numerical studies reported in the literature. As such, the nonstationary penalty function is to be used in practical computations. According to the nonstationary penalty function approach, the function $F(\mathbf{X})$ is defined as :

$$F(\mathbf{X}) = f(\mathbf{X}) + C(i)H(\mathbf{X})$$

where C(i) denotes a dynamically modified penalty parameter that varies with the iteration number i, and $H(\mathbf{X})$ represents the penalty factor associated with the constraints.

The formulation of C(i) is presented by Liu and Lin [68]

$$C(i) = (ci)^{\alpha} \tag{7}$$

$$H(\mathbf{X}) = \sum_{j=1}^{m} \phi[gj(\mathbf{X})][qj(\mathbf{X})]^{\gamma[qi(\mathbf{X})]} \tag{8}$$

$$\phi[q_j(\mathbf{X})] = a\left(1 - \frac{1}{e^{q(X)_j}}\right) + b \tag{9}$$

$$q_j(\mathbf{X}) = \max\{0, g_j(\mathbf{X})\}; j = 1, 2, \ldots, m \tag{10}$$

where c, α, a, and b are constants. Note that the function q_j (**X**) denotes the magnitude of violation of the j^{th} constraint, $\phi[q_j (\mathbf{X})]$ indicates a continuous assignment function, assumed to be of exponential form, as shown in Eq. (13.29), and $\gamma [q_i (\mathbf{X})]$ represents the power of the violated function[78]. The values of c = 0.5, α = 2, a = 150, and b = 10 along with

$$\gamma [q_j (X)] = \{ \begin{matrix} 1 & \text{if } q_j (X) \leq 1\} \\ 2 & \text{if } q_j (X) > 1 \end{matrix} \qquad (11)$$

Although assessment study is the primary part of the data collection is the primary part of the proposed study.

3.8 Assessment of Sustainability Indicators

Optimisation is one of the principal methodologies used for the development of energy models. The primary concentration in optimisation models is on the current system's configuration as a starting point, and procedures are followed afterwards to identify the optimal pathway ahead. In this way, optimisation models are suitable for forecasting. Satisfying the problem's constraints in these models, the energy system's interactions create a feasible region, and the goal is to seek the optimal solution within the region. The optimal solution is explored in the direction of the objective function that is typically cost minimization. Negative environmental impacts are sometimes considered as a cost term in the objective function. The proposed circular economy framework or cradle to cradle analogy is based on three major sustainability indicators. i.e., economic, social, and environmental. The aim is to find out whether the proposed biomass supply chain within the system (biofuel supply chain) is feasible for transportation industry. The major blocks of the proposed supply chain are (i)Harvesting Site (ii) Transport (iii) Conversion Plant (iv)Oil Refinery (v)Ethanol blended with petrol in IC engine. In the sustainability assessment phase, corn cobs, paddy straw and corn stalk have been considered as the biomass or source for ethanol generation. The main tool for optimisation is the heuristic-based modelling technique which is suitable for the corresponding scenario as it can deal with the randomness and uncertainty attached to the system.

3.9 Sustainability assessment with respect to economic, environment and social indicator

Figure 3.10(Block Diagram of indicators)

The figure 5.1 gives the idea about the system where the sustainability assessment takes place. The total revenue generated which is described as total system profit has been considered as an economic indicator. The sustainability assessment is performed in relation to the upstream process.

1. The objective function and constraints attached to the supply chain including harvesting area, transportation of biomass and collection center for calculation of total system profit is:

Maximize profit

Subject to

Each harvesting area has a capacity limit.

Maximum one kind of technology is selected at one time.

Biomass can be transported unidirectionally, vice versa is not true.

Establish a link between harvesting area and collection center.

An arc is selected by considering certain no of harvesting areas.

and its flow amount is restricted by imposing arc capacity.

2. The second objective function deals with environmental indicator where the aim is to minimize the emissions:

Minimize the emissions into air

Subject to

All the biomasses should go to the collection center from harvesting site.

The availability of biomass should not exceed dry weight.

Here the seasonality,

harvesting window and geographical availability of various biomass at

harvesting areas is considered.

The logistics distance must not exceed a maximum transportation distance.

3. The third objective function deals with social indicator where the aim is to maximize the employment rate.

3.10 Model formulation

The first equation refers to the profit based objective function.

System Profit in Harvesting area = $\sum_{\mathbf{k \in K}} \sum_{\mathbf{f \in F}} \sum_{\mathbf{t \in T1}} \sum_{\mathbf{a \in A_{frt}^{+}}} \mathbf{C_k z_{ka}} - \sum_{\mathbf{f \in F}} \sum_{\mathbf{r \in R}} (\mathbf{C_{fr} x_{fr}} + \mathbf{V_{fr}\, q_{fr}}) - \sum_{\mathbf{a \in A}} \mathbf{C_T^a\, y_a} - \sum_{\mathbf{k \in K}} \sum_{\mathbf{a \in A}} \mathbf{V_T^a\, z_{ka}}$ (12)

Nomenclature

h	harvesting area.
r	technology type
t	time
b	biomass type
k	commodity type
l	layer
j	collection center

x_{hr} = 1 if harvesting area “h” of type “r” is open,0 otherwise

y_a = 1 if arc a is directed ,0 otherwise

q_{hr} = capacity of facility “f” of type “r”

P_{bh} = flow amount of biomass “b” in harvesting area “h”

3.11 Constraints

$\sum_{r \in R} x_{hr} \leq 1 \quad h \in H_{OB}$ (At most one technology type can be selected for each facility) (13)

$q_{hr} - Q_{b,h,t}^{H} x_{hr} \leq 0 \quad h \in H_{OB}\,, \; r \in R_h$ (14)

The equation above shows that, if facility is opened, the amount of flow out of it is restricted by its capacity , $Q_{b,h,t}^{H}$ otherwise the facility can sustain no flow.

$\sum_{a \in A^{+}_{hrt}} Y_a \leq 1 \qquad h \in H_{b1} \cup H_{b2}, t \in T$ (15)

Ya = 1 if there is a direct link from facility to collection center.

$\sum_{k \in K} P_{bh} - Q^{T}_{b,a} y_a \leq 0 \qquad h \in H, r \in R, t \in T, a \in A^{+}_{hrt}$ (16)

If arc a selected, then flow amount of biomass is restricted by the arc capacity $Q^{T}_{b,a}$, otherwise flow amount is zero.

$\sum_{a \in H^{+}_{rt}} P_{bh} \leq Q^{H}_{k} \qquad h \in H_{b1}, r \in R_h, t \in T, a \in A^{+}_{hrt}$ (17)

This shows the supply limit in the farm area.

The second equation refers to the emission based objective function.

We are trying to model the emissions pattern till the biomass reaches the collection center.

Total emission is divided into 2 parts.

Emissions in harvesting area (E^{ha}) and emission in transport (E^{trans}).

Total emissions = $E_T = E^{trans} + E^{ha}$ (18)

$E^{ha} = \sum_{b \in B} \sum_{h \in H} \sum_{t \in T} eab_{b,h,t} Pbh_{b,h,t}$ (19)

$E^{trans} = \sum_{b \in B} \sum_{h \in H} \sum_{j \in J} \sum_{t \in T} etb_b ds_{i,j} Fbij_{i,j,t}$ (20)

There are 3 types of constraints attached to the mentioned objective function.

$Pbh_{b,h,j} = \sum_{j \in J} Fbh_{b,h,j} \qquad \forall\, b \in B, h \in H, t \in T$ (21)

$Pbh_{b,h,j} \leq Q^{H}_{b,h,t} \qquad \forall\, h \in H, b \in B, t \in T$ (22)

$Fbh_{b,h,j} = 0, \qquad \forall\, (b,h,j,t) \mid (dsij_{i,j} > mdb_{b,t})$ (23)

$Fbh_{b,h,j}$ denotes the amount of raw biomass b shipped from harvesting site h to pre-processing facility ‘j’ in time t.

The social indicator is one of the challenging parts in the assessment study. There are many types of social indicators to showcase the assessment study. But due the scarcity of data only no of jobs generated in terms of employment rate is calculated. The indicator is calculated in the scenario in the areas where harvesting takes place, A detail analysis is provided to calculate the social indicator. The case of paddy and corn is studied by the help of the data provided by PRESPL [66].

3.12 Paddy straw

Degree of mechanization in paddy is high in this cluster. It is primarily because of the convenience, reduced cost, and effort. About 85-90% of total paddy undergoes mechanized harvesting. According to respondents, only farmers having area less than 1-1.5 acres and has own labor to cut, transport and thresh, chooses manual harvesting. Harvester charges Rs 1500-1800 per hour and covers 1-1.5 acres depending on the field size whereas the same activity requires 5-6 man-days for cutting and shifting the material to threshing base and further 4-5 man-days for threshing, it reduces if machine thresher is available. Thus, in manual harvesting the cost translates to Rs 1800-2200. Therefore, reducing the cost by about 20%, time and efforts drastically. Hence, the adoption of mechanized harvesting is high in the region. The time and efforts saved due to mechanized harvesting is put into the preparation of fields for subsequent crop increase the productivity of the harvester. Threshed straw is dispersed in the field as harvester releases the chaff while moving. This straw is collected with the help of labor and is used as fodder. The recovery of threshed straw is about 70% as some portion is lost by truncating it above the ground and some during the manual collection of dispersed straw. Farmers having surplus straw often sell it to the farmers in need. The farm gate prices of such paddy straw range between Rs 3500-4000 per tractor load. About 1.5 acres is required to complete one tractor load and 4-5 labor are required to collect the paddy straw and load the tractor.

3.13 Corn cobs and Corn stalks

After the crop reaches the maturity stage, cobs are detached from the plant manually with the help of laborers. Generally, labor charges are on the per acre basis which varies from Rs 1500-2000 depending on the degree of shortage of labor and acreage. This period faces shortage of the labor as crop of entire area reaches harvesting stage at the same time. This is mainly because the sowing of corn is rain dependent, and majority of farmers start sowing immediately after receiving the first shower. Labor must detach the cob and collect it at the threshing point, transport if required for the purpose must be arranged by the farmers. Farmer then calls the thresher service provider which most of the times is available in the village. The decision of threshing is influenced by the market price of corn. Hence, the threshing of corn cobs harvested in month of October-November is stretched till January-February. Service charges of thresher ranges between Rs 40-60 per quintal. It is less in the areas with high corn crop intensity and vice versa. Thresher owner has the team of labor and thresher machine which is either tractor driven or engine driven and visits the fields of the individual farmer.

3.13.1 Mathematical Model Formulation

The work primarily focuses on maximization of no of jobs which is calculated in the same way as employment rate. The graphs show maximization of wages and jobs (social indicator) in corn and paddy straw. Workers are the sum of people attached to baling technique, threshers etc.

The employment rate = $\sum(\text{workers in the system/laborers}) \times 100$

The constraints attached are:

Maximum wage of threshers > wage defined by the ministry of labor and employment.

Maximum wage of workers > wage defined by the ministry of labor and employment.

We can write it as:

Percentage of jobs created = $\sum \frac{\text{Wo} \times \text{Th}}{\text{La}} \times 100$ (24)

Constraints

Max (Wage Wo) - (Wage Wo) ≥ 0 (25a)

Max (Wage Th) - (Wage Th) ≥ 0 (25b)

3.13.2 Solution Method

We are implementing constrained optimisation method using PSO algorithm. We have two stochastic acceleration coefficients c_1 and c_2. Hence, proper control of these two components is very important to find the optimum solution precisely and efficiently. To incorporate better compromise between the exploration and exploitation of the search space in Particle Swarm Optimisation, time variant acceleration coefficients have been introduced in the proposed work. The approach is known as time variant PSO method where the values of c_1 and c_2 are expressed in terms of initial and final values as –

3.14 Sustainability assessment with respect to economic, environment and social indicator in conversion area (downstream area)

Figure 3.11 (Downstream area)

The fig 3.11 gives an overview of the midstream and downstream process in the supply chain. The total revenue generated which is described as total system profit has been considered as an economic indicator. The sustainability assessment is performed in relation to the downstream process.

$$\textbf{System Profit} = \sum_{k\in K}\sum_{f\in F}\sum_{t\in T1}\sum_{a\in A_{frt}^{+}} p_{kft} z_{ka} - \sum_{f\in F}\sum_{r\in R}(C_{fr} x_{fr} + V_{fr}\, q_{fr}) - \sum_{a\in A} C_T^a\, y_a$$

$$- \sum_{k\in K}\sum_{a\in A} V_T^a\, z_{ka} - \sum_{k\in K}\sum_{f\in F}\sum_{t\in T1}\sum_{a\in A_{frt}^{-}} c_k z_{ka} \qquad (26)$$

Constraints

$$\sum_{k\in K} z_{ka} - \sum_{a\in A_{frt^-}}(1-\partial_k) z_{ka} = 0 \qquad r\in R_f, t \in T \qquad (27)$$

$$\sum_{a\in A_{frt^+}} z_{k_{2a}} \sum_{k\in k_1}\sum_{a\in A_{frt^-}} \alpha_{k_1 k_{2fr}}\, z_{k_{1a}} = 0 \qquad r\in R_f, t \in T \qquad (28)$$

$$\sum_{a\in A_{frt^-}} z_{ka} \leq D_{kft} \qquad r\in R_f, t \in T \qquad (29)$$

$$x_{fr} \in \{0,1\} \qquad (30)$$

$$y_a \in \{0,1\} \qquad (31)$$

$$q_{fr} \geq 0 \qquad (32)$$

$$z_{ka} \geq 0 \qquad (33)$$

In the conversion side we have considered the case of corn cob to ethanol process. It has been described in chapter 4 already. So, the assessment is performed in concern to the corn cob to ethanol plant. The downstream process starts from the collection center/factory gate, transport, and conversion plant. The assumption is pre-processing is performed in the upstream process. In the downstream side the work is in pilot project state in a laboratory scale. Moreover, the economic, social, and environmental assessment is not performed in the conversion stage, rather a probable trend is explained. In the next section the sustainability assessment result is shown. The tool is the modern optimisation technique. First the constrained non time varying particle swarm optimisation (PSO) is implemented; but due to the sluggish performance of the algorithm, time varying PSO is used in the assessment.

3.14.1 Solution Method

We are implementing constrained optimisation method using PSO algorithm. We have two stochastic acceleration coefficients c_1 and c_2. Hence, proper control of these two components is very important to find the optimum solution precisely and efficiently. To incorporate better compromise between the exploration and exploitation of the search space in Particle Swarm Optimisation, time variant acceleration coefficients have been introduced in the proposed work [13]. The approach is known as time variant PSO method where the values of c_1 and c_2 are expressed in terms of initial and final values as –

$$c_{1t} = (c_{1f} - c_{1i})\, t/\max(it) + c_{1i} \qquad (34)$$

$$c_{2t} = (c_{2f} - c_{2i})\, t/\max(it) + c_{2i} \qquad (35)$$

max(it) refers to maximum iterations and the subscript i and f refers to initial and final values respectively. Also, a time variant inertia weight i.e., "w" is implemented here.

$$w_t = (w_1 - w_2) * (maxit - it)/maxit + w_2 \qquad (32)$$

wt decrease linearly with iteration from w_1 to w_2.max(it) is the maximum iterations and (it) is the iteration number.

3.15 Summary of a flowchart of a constrained PSO

1. Assume the swarm size to be N.
2. Set the objective function as F(x) and iteration as i, j respectively.
3. Evaluate F[X1(i)], F[X2(i)], F[X3(i)], F[XN(i)].
4. Check whether the constraints are satisfied.
5. Generate position of each particle as Xj(i).
6. Generate the velocity of each particle as Vj(i)
7. Set initial velocity = 0
8. Find velocity, $V_j(i)= w*V_j(i-1) + c_1r_1[p_{best}, j -X_j(i-1)] +c_2r_2[g_{best} – X_j(i-1)]$, where j = 1, 2 …. N
9. Find the position of j^th particle in i^th iteration as $X_j(i) = X_j(i-1) +V_j(i)$, j=1,2,3…. N
10. Check if $p_{best} = g_{best}$. (Only the points in feasible space)
11. If NO then go back to step 5, set i=i+1.

3.16 Results

While implementing the PSO model we have started with non-time varying case. All the three indicators showed same results which needed further correction. Hence, we have followed time varying PSO model.

1.13.1 Maximization of system profit

Case 1: In this plot c_1=c_2=2.05, w= 0.729. Here X-axis corresponds to no of years and Y axis corresponds to system profit in rupees for corn cobs.

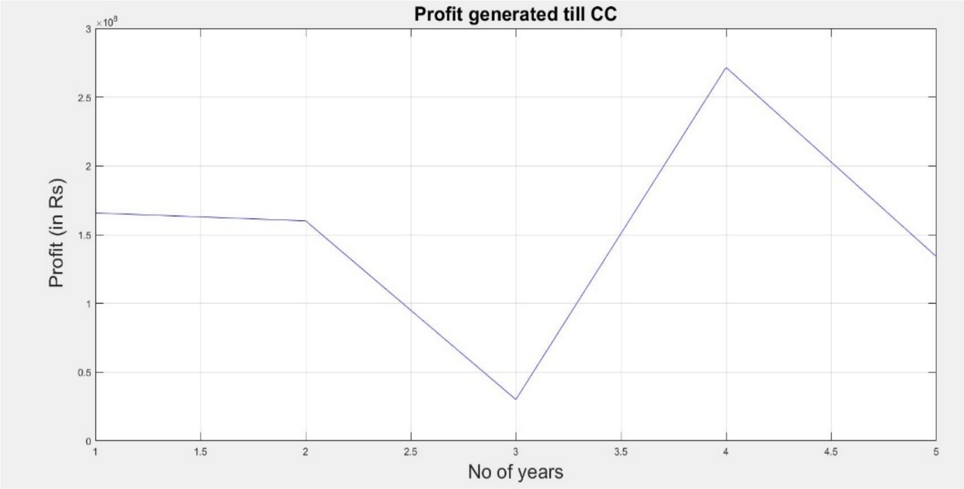


Figure 3.12 PSO with non-time varying inertia weight and acceleration coefficient

Case 2: In this plot c_{1f} = c_{2f}= 2.5, c_1i = c_2i = 0.5 and w_{max} = 0.9, w_{min} = 0.4

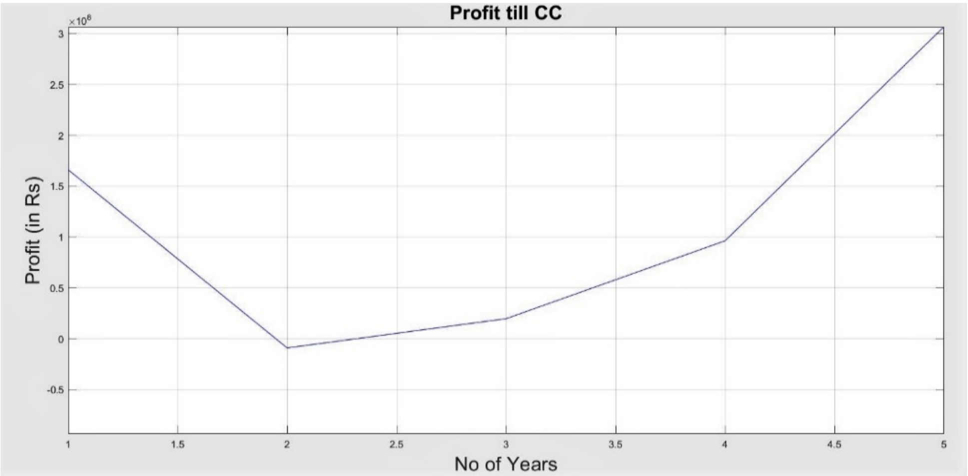


Figure 3.13 PSO with time varying inertia weight and acceleration coefficient

Case 3: In this plot $c_1=c_2=2.04$,w = 0. 719.Here X-axis corresponds to no of years and Y axis corresponds to system profit in rupees for corn stalks .

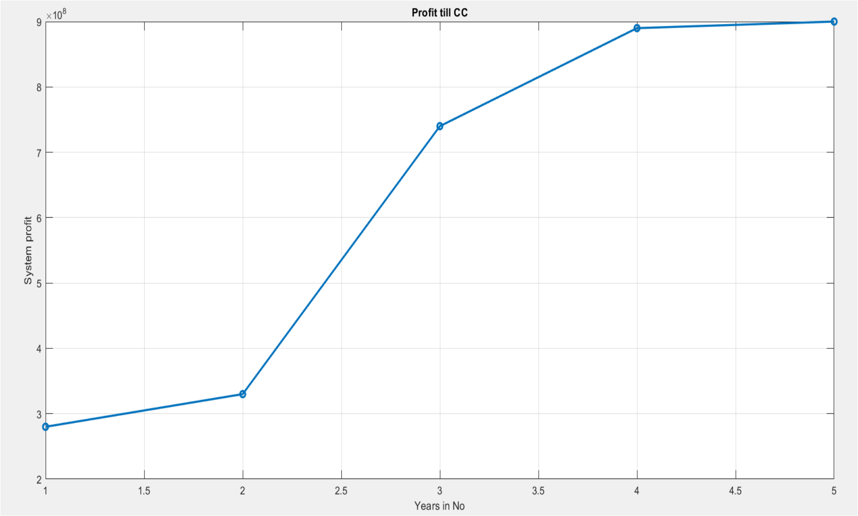


Figure 3.14 PSO with non-time varying inertia weight and acceleration coefficient

Case 4: In this plot $c_{1f} = c_{2f} = 2.5$, $c_{1i} = c_{2i} = 0.5$ and $w_{max} = 0.9$,$w_{min} = 0.4$

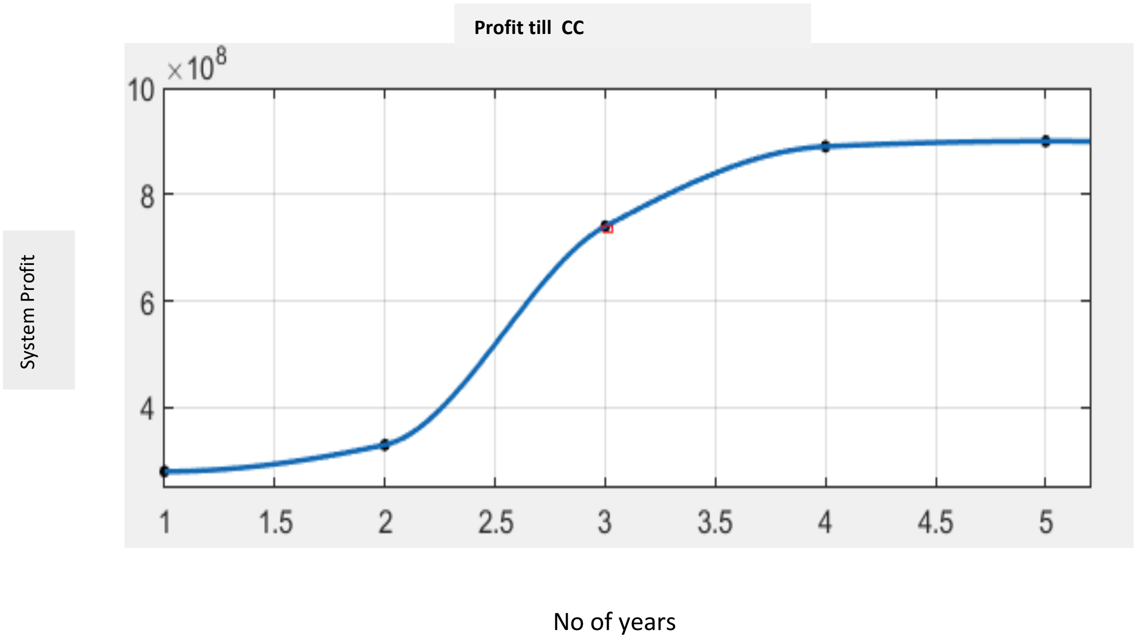


Figure 3.15 PSO with time varying inertia weight and acceleration coefficient

Case 5: In this plot $c_1=c_2=2.04$, $w = 0.719$. Here X-axis corresponds to no of years and Y axis corresponds to system profit in rupees for paddy straw.

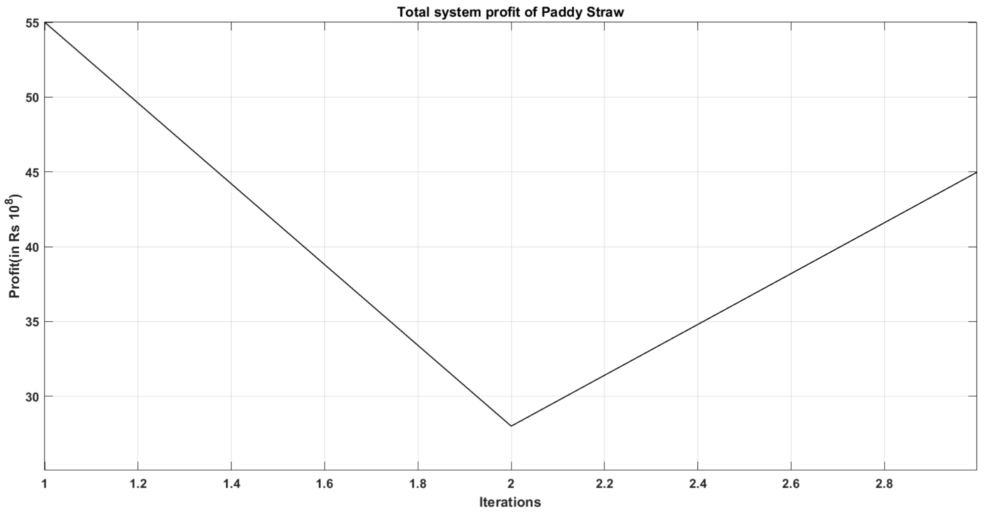


Figure 3.16 PSO with non-time varying inertia weight and acceleration coefficient

Case 6: In this plot $c_{1f} = c_{2f} = 2.5$, $c_{1i} = c_{2i} = 0.5$ and $w_{max} = 0.9$, $w_{min} = 0.4$

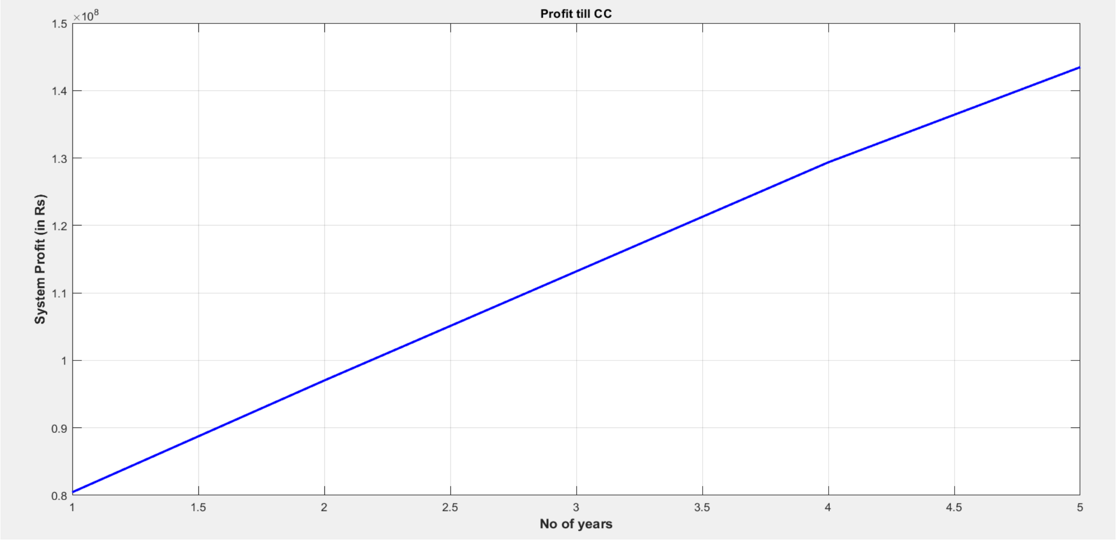


Figure 3.17 (PSO with time varying inertia weight and acceleration coefficient)

Minimization of environmental emissions

Case 1: For time varying PSO we have plotted various combinations of sets of inertia weights and acceleration coefficients. The combination which gives the optimal result is $c_{1f} = 2.0$, $c_{2f} = 2.0$, $c_{1i} = 1.5$, $c_{2i} = 1.5$, $w_{max} = 0.8$, $w_{min} = 0.4$. The X-axis corresponds to no. of years and Y-axis corresponds to emissions in tons CO_2 equivalent per kg in case of corn cobs and corn stalks.

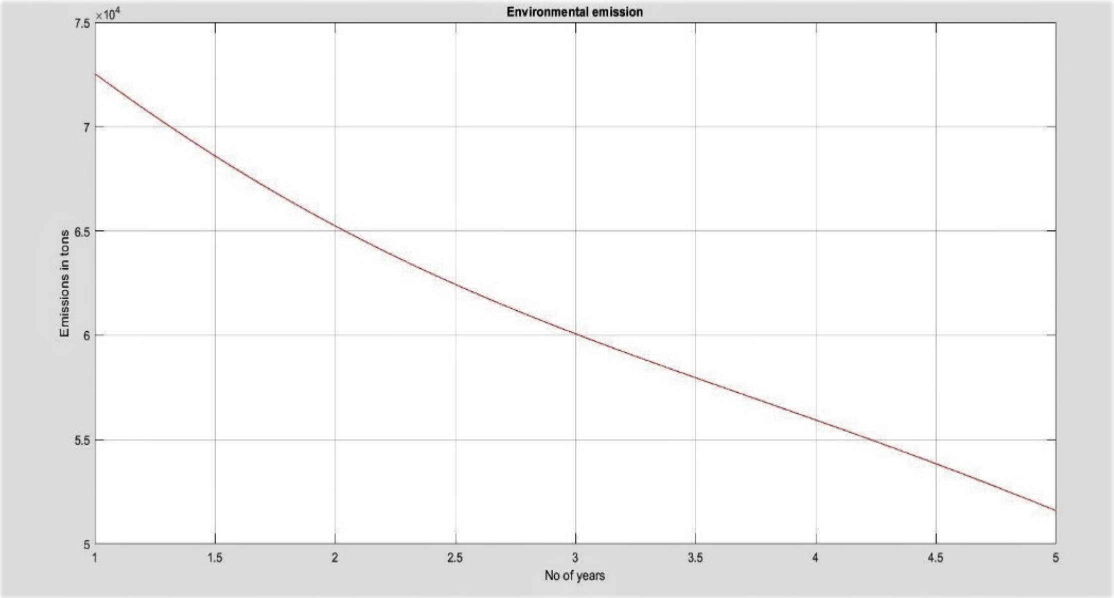


Figure. 3.18 PSO with time varying inertia weight and acceleration coefficients

Case 2: In this plot $c_{1f} = c_{2f} = 2.5$, $c_{1i} = c_{2i} = 0.5$ and $w_{max} = 0.9$,$w_{min} = 0.4$

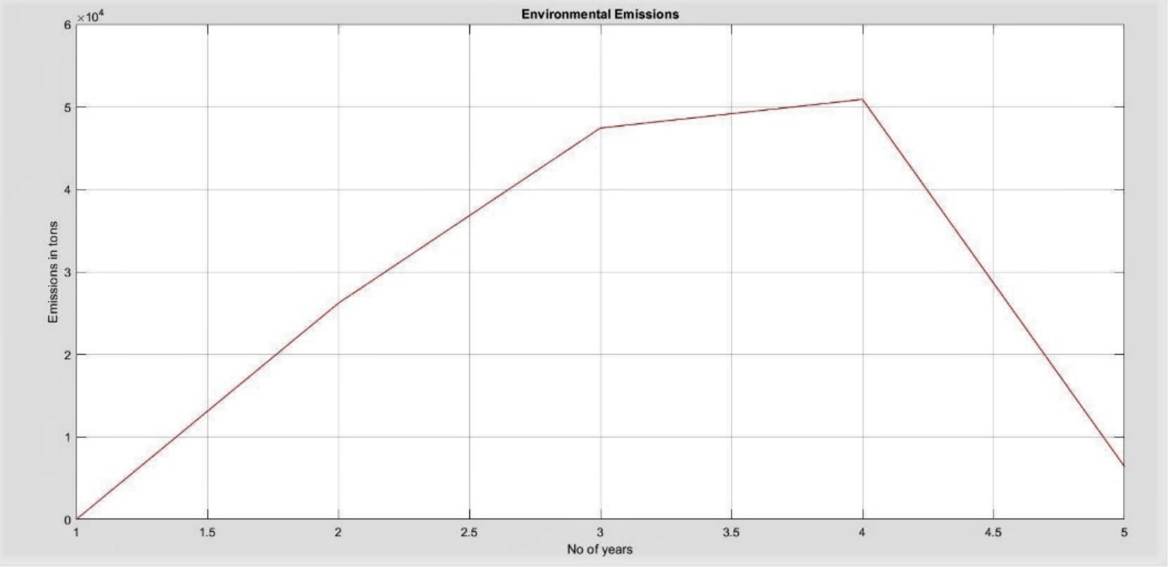


Figure. 3.19 PSO with non-time varying inertia weight and acceleration coefficient

Case3: In this plot $c_{1f} = c_{2f} = 2.5$, $c_{1i} = c_{2i} = 0.5$ and $w_{max} = 0.9$,$w_{min} = 0.4$. It is a non-time varying case which involves paddy straw.

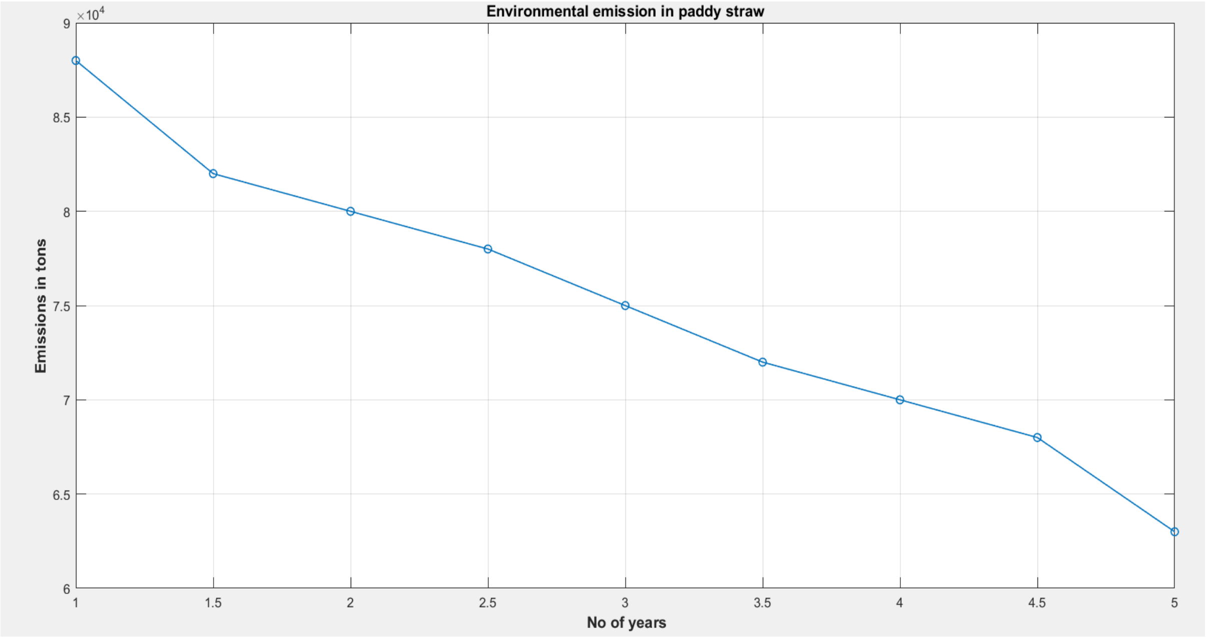


Figure. 3.20. PSO with non-time varying inertia weight and acceleration coefficient

Case 4: For time varying PSO we have plotted various combinations of sets of inertia weights and acceleration coefficients. The combination which gives the optimal result is $c_{1f} = 2.0$, $c_{2f} = 2.0$, $c_{1i} = 1.5$, $c_{2i} = 1.5$,$w_{max} = 0.8$, $w_{min} = 0.4$. The X-axis corresponds to no. of years and Y-axis corresponds to emissions in tons CO_2 equivalent per kg in case of paddy straw.

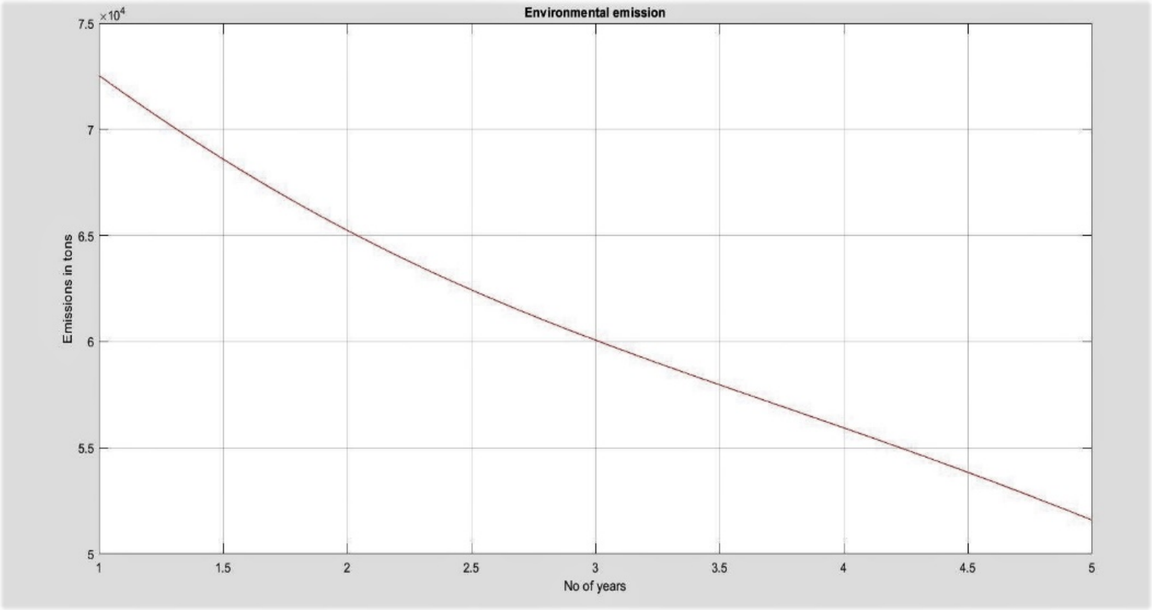


Figure. 3.21. PSO with time varying inertia weight and acceleration coefficient

Maximization of jobs

Case 1: The social indicator is expressed in terms of employment rate. For time varying PSO we have plotted various combination of sets of inertia weights and acceleration coefficients. The combination which gives the optimal result is $c_{1f} = 2.0$, $c_{2f} = 2.0$, $c_{1i} = 1.5$, $c_{2i} = 1.5$, $w_{max} = 0.8$, $w_{min} = 0.4$. The X-axis corresponds to no. of years and Y-axis corresponds to employment rate in percentage in case of corn cobs and corn stalks.

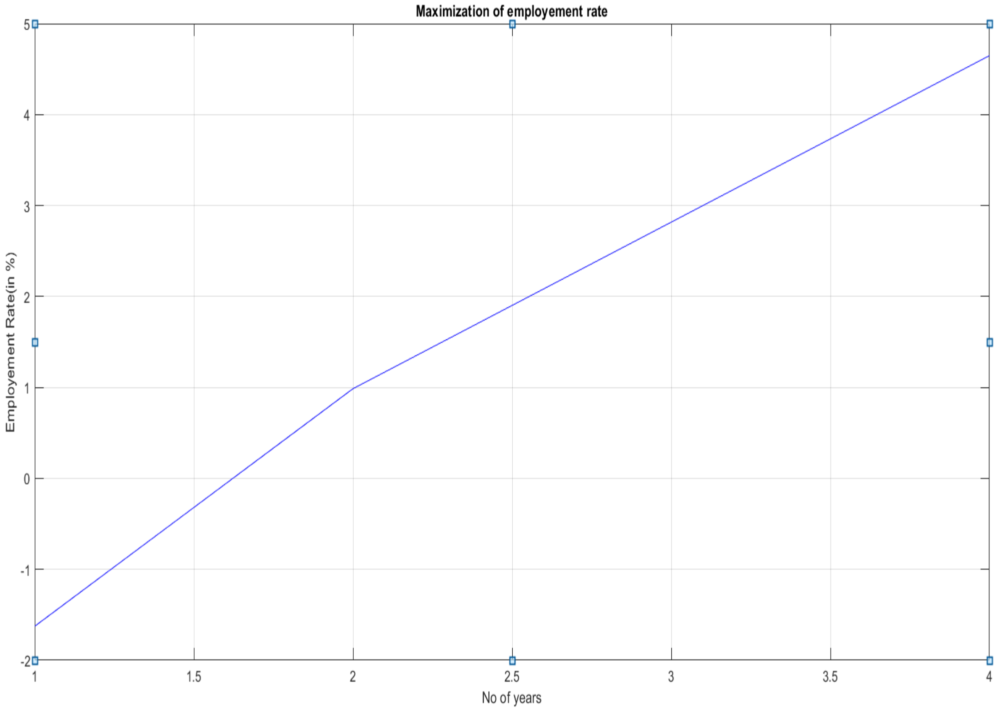


Figure. 3.22. PSO with time varying inertia weight and acceleration coefficient

Case 2: In this plot $c_{1f} = c_{2f} = 2.5$, $c_{1i} = c_{2i} = 0.5$ and $w_{max} = 0.9$,$w_{min} = 0.4$.It is a non-time varying case which involves paddy straw.

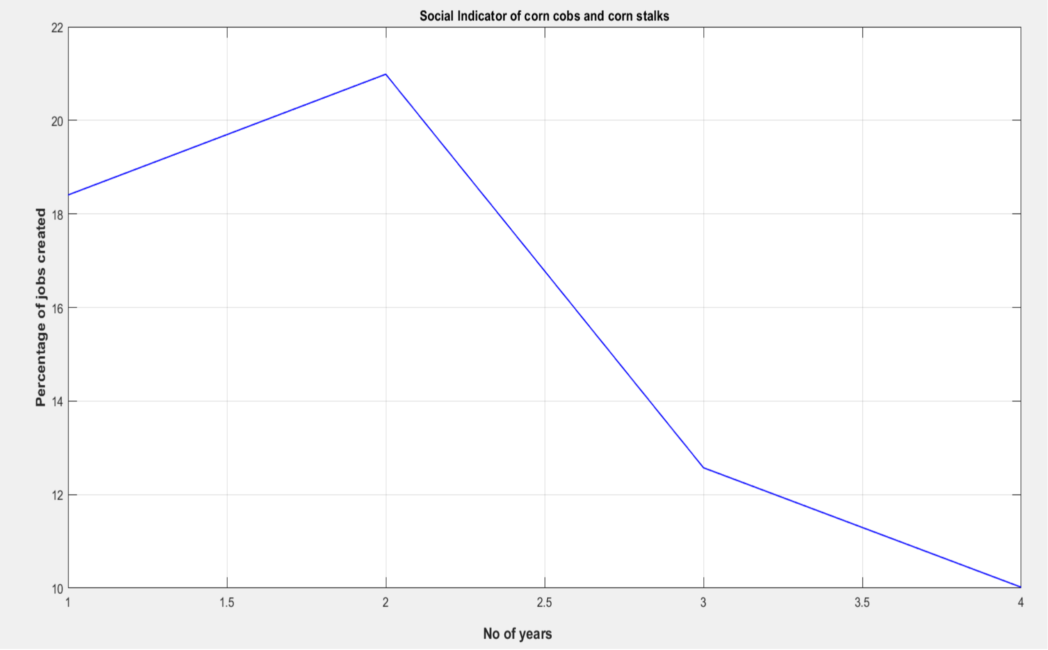


Figure. 3.23. PSO with time varying inertia weight and acceleration coefficient

Case 3: For time varying PSO case, the combination which gives the optimal result is $c_{1f} = 2.0$, $c_{2f} = 2.0$, $c_{1i} = 1.5$, $c_{2i} = 1.45$,$w_{max} = 0.8$, $w_{min} = 0.4$. The X-axis corresponds to no. of years and Y-axis corresponds to employment rate in percentage in case of corn cobs and corn stalks.

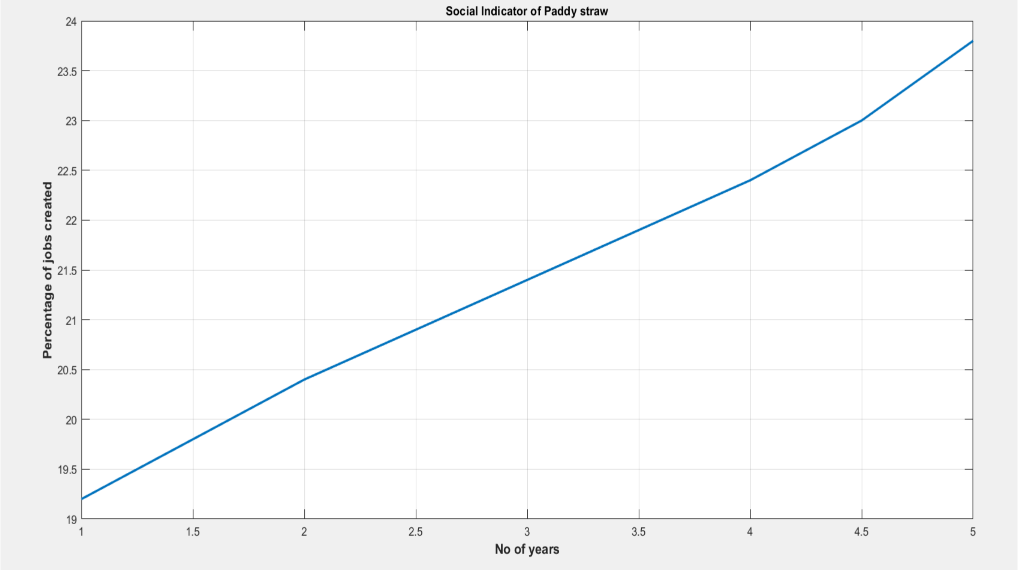


Figure. 3.24. PSO with time varying inertia weight and acceleration coefficient

Case 2: In this plot $c_{1f} = c_{2f} = 2.35$, $c_{1i} = c_{2i} = 0.5$ and $w_{max} = 0.9$, $w_{min} = 0.4$. It is a non-time varying case which involves paddy straw.

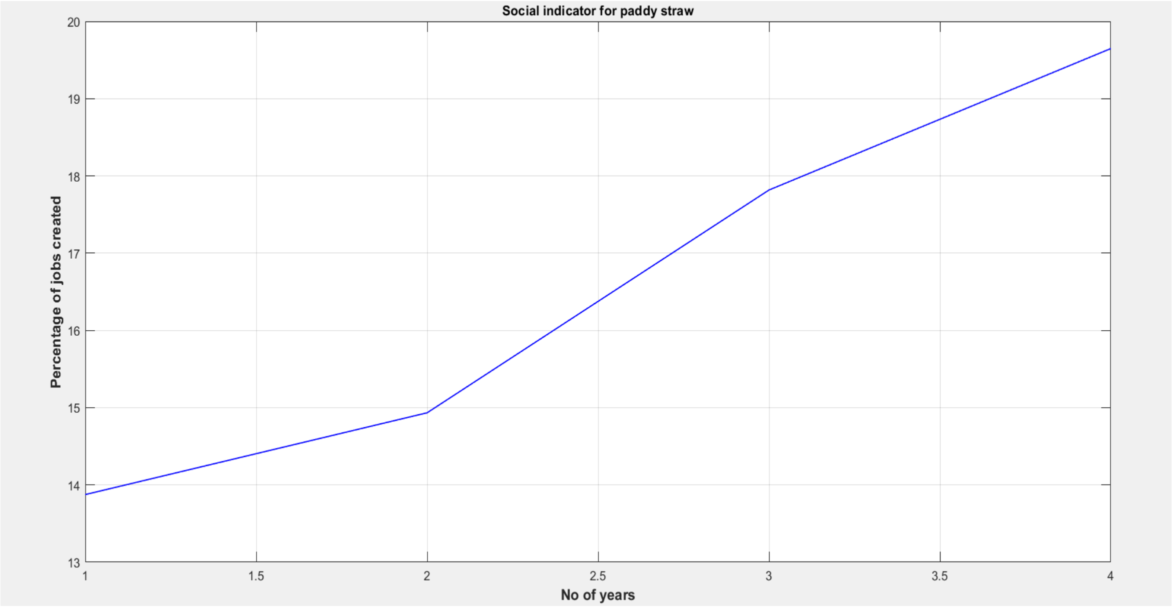


Figure. 3.25. PSO with non - time varying inertia weight and acceleration coefficient

1.14 Downstream process

As discussed in chapter 4 there are some limitations in the corn cob to ethanol conversion. As it is a hybrid process and in laboratory scale, the data for the net amount of ethanol synthesized is not clear yet; but we have the mathematical model for the economic, environmental, and social indicator. The analysis for the sustainability assessment starts from the factory gate i.e., the collection center and ends at the consumer side. If we summarize the downstream and midstream process it will start from the conversion plant and ends at the consumption site.

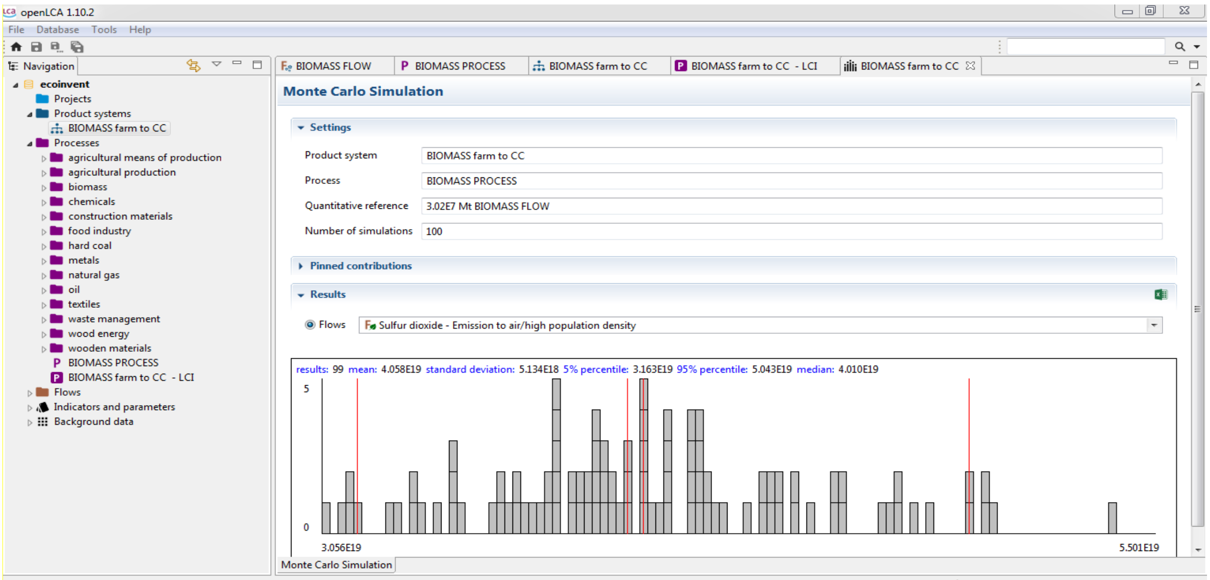
Case 1: The first part deals with the maximization of total system profit.

Case 2: The social indicator deals with maximization of total number of jobs created. The number of jobs created is classically divided into three categories: (i) Direct jobs (jobs related to conversion plant's operations), (ii) Indirect jobs (new employees in subcontractors) and (iii) Induced jobs (new employees in the local area) [82].

Case 3: The environmental indicator refers to the emissions related to carbon dioxide and nitrous oxide and sulfurous oxide emissions. Major parameters are 1) Emission in the conversion plant, oil refinery and gas station 2) Emission while transporting the biofuel and the blended biofuel 3) Emission after consumption.

3.17 Emissions from farm area by the virtue of life cycle assessment

The emissions from farm area, collection center collectively was tried to capture by the virtue of life cycle assessment technique. It was performed by the help of OpenLCA software Eco invent v 1.10.2. The plots are provided in the following paragraph. It comprises various compounds starting from acetaldehyde to zinc.



Monte Carlo Simulation

Settings

Product system: BIOMASS farm to CC

Process: BIOMASS PROCESS

Quantitative reference: 3.02E7 Mt BIOMASS FLOW

Number of simulations: 100

Results

● Flows: Sulfur dioxide - Emission to air/high population density

results: 99 mean: 4.058E19 standard deviation: 5.134E18 5% percentile: 3.163E19 95% percentile: 5.043E19 median: 4.010E19

Figure 3.26(LCA Software)

1.14.1 Scattered plots of emissions

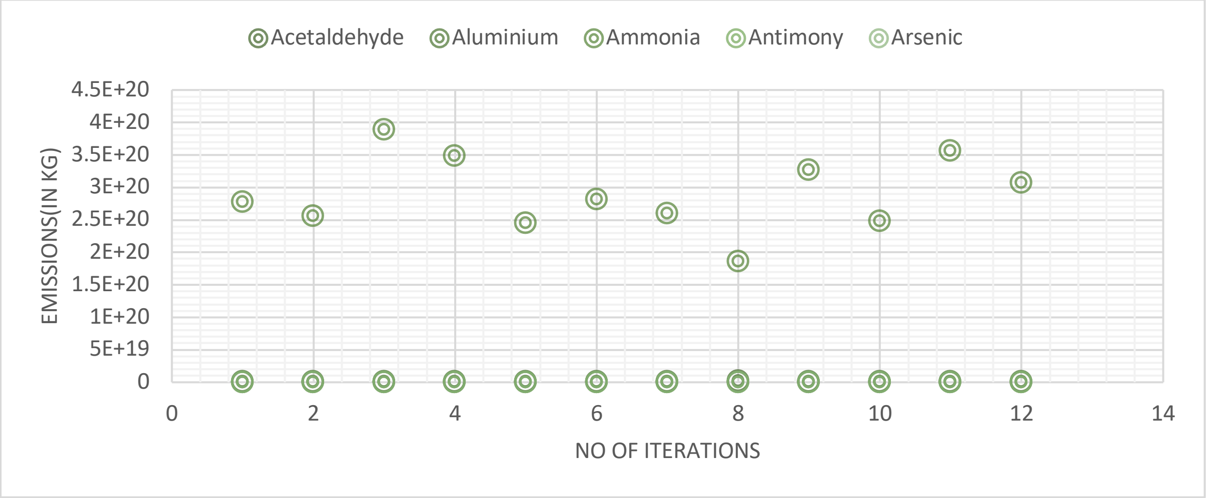


Figure 3.27(Emissions from farm till collection area)

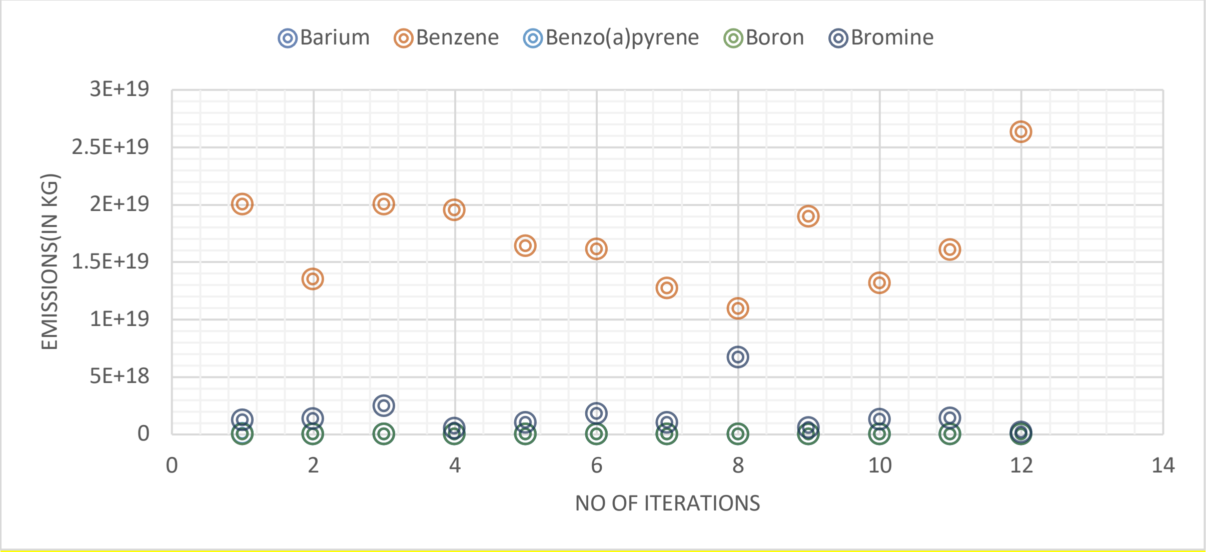


Figure 3.28(Emissions from farm till Collection area)

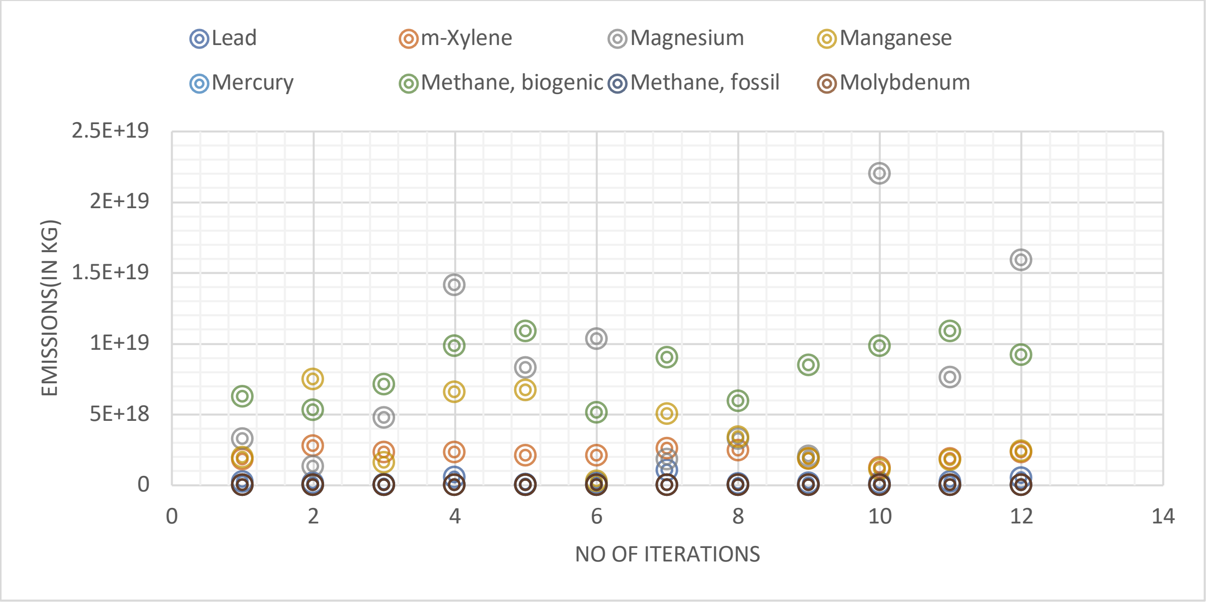


Figure 3.29(Farm to collection area emissions)

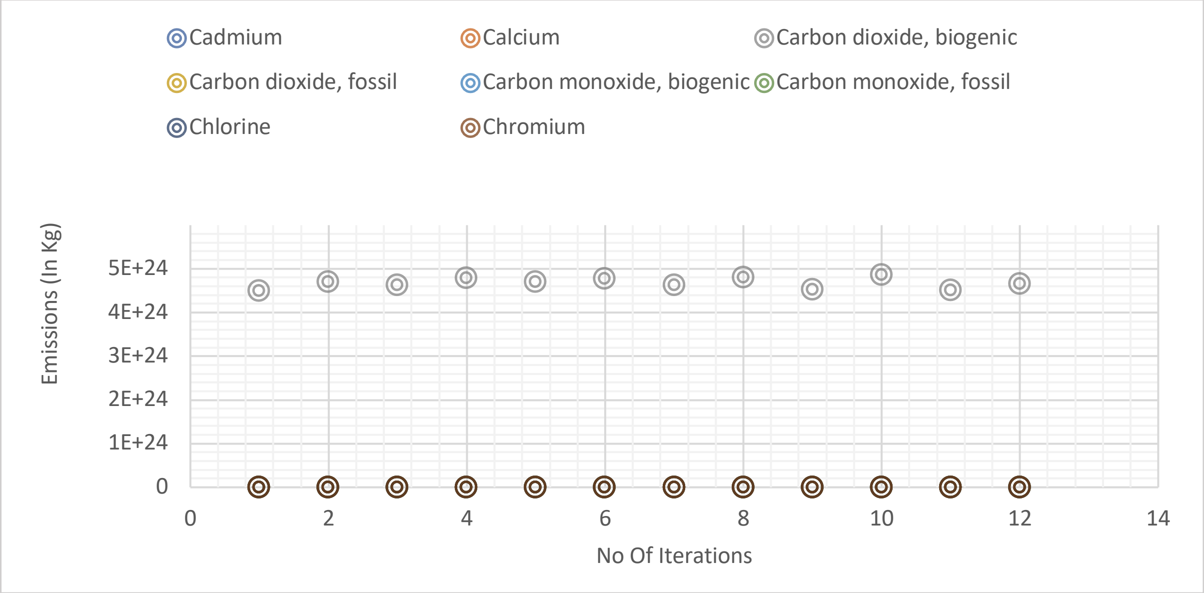


Figure 3.30 (Emissions from farm till the collection area)

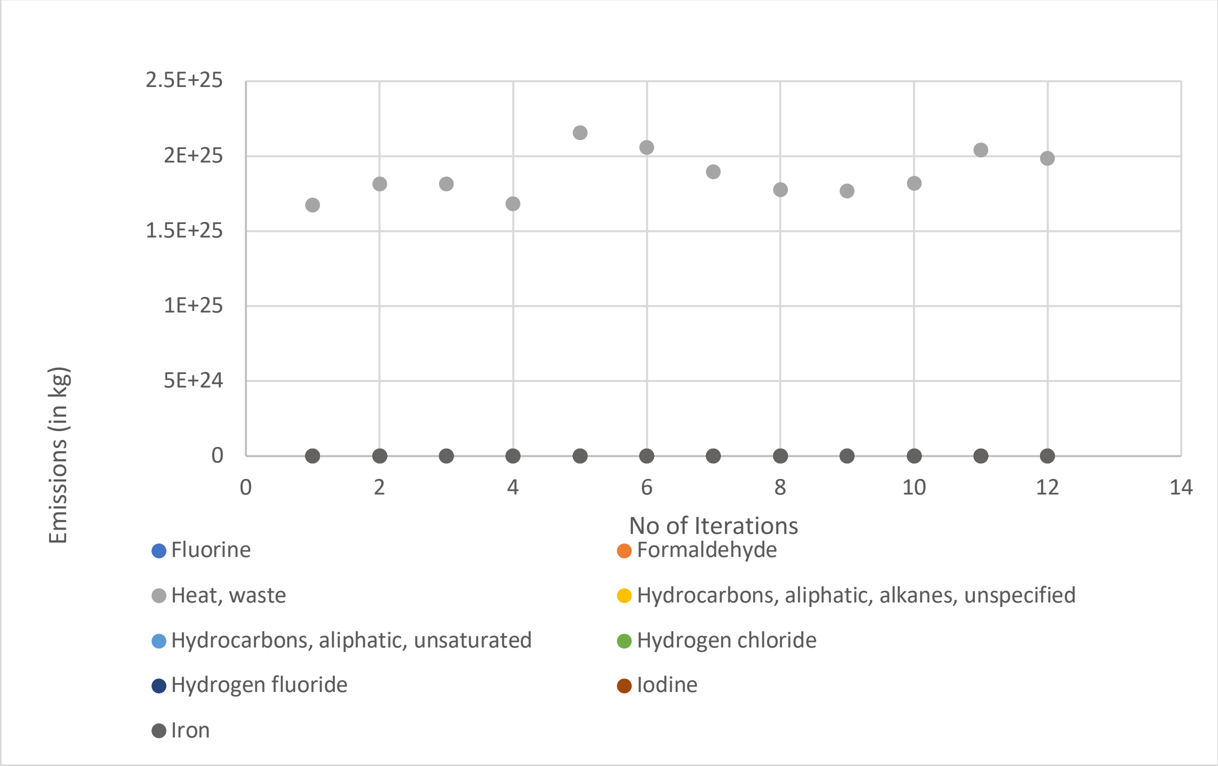


Figure 3.31(Emissions from farm till the collection area)

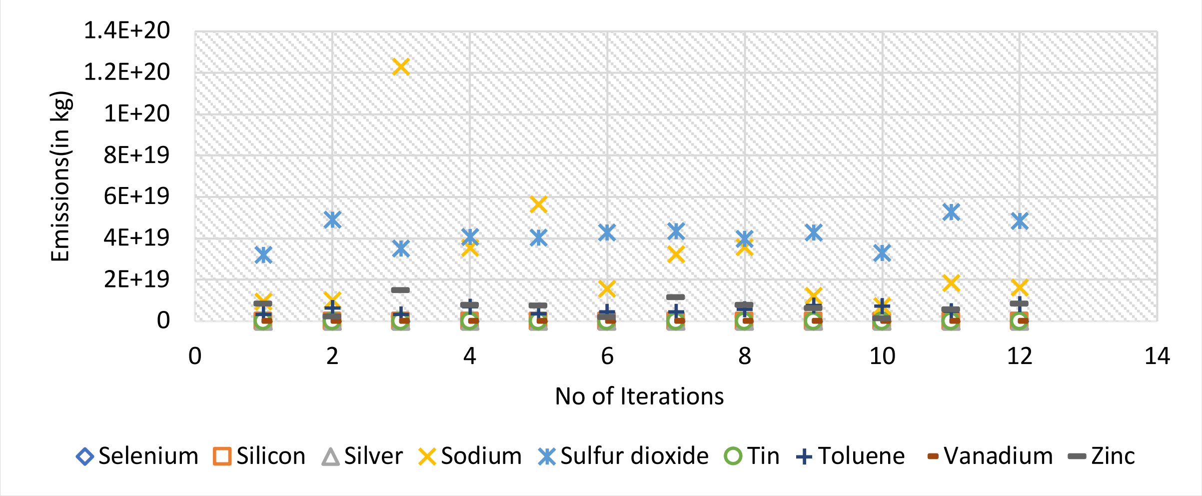


Figure 3.32 (Emissions from farm till the collection area)

3.18 Discussion

The results show that the percentage of particulate matter is low in the emission. There is a significant amount of acetaldehyde and benzene present in the emission list though. There is negligible amount of formaldehyde, lead present in the result which shows that it is less carcinogenic. But the presence of nitrogen oxide and Sulphur oxide shows that further modification is required w.r.t the chemical compounds used in the farming process. The simulation results are from a corn to ethanol supply chain. The emission values are unpractical to justify the supply chain. The reason is the limitations of inventory analysis. It was directing to Brazilian soil, water, and fertilizer. Hence, we can easily establish the previously described environmental indicator assessment methodology as one of the best methodologies to describe the emissions.

3.19 Conclusion

The sustainability analysis of the conversion plant and gas station to consumer is not performed. As the conversion is in lab scale, the conversion plant's indicator-based assessment was not possible. But in future when the results will be in terms of the industry scale, the assessment will follow the same procedure described in section 5.2.7. The constraints will change as it will be dependent on conversion plant and gas station scenario. The methodology is one of the best fits for the mentioned supply chain scenario. In future it is going to be helpful for the sustainability analyst to perform the assessment.

Appendix

The data is adapted from various sources. Few data are taken from PRESPL [66].

Data on paddy production

District	Taluka	Paddy Production (MT)							
		Kharif			Rabi			Summer	Total
		Rainfed	Irrigated	Total	Rainfed	Irrigated	Total	Irrigated	Total
Bellary	Hadagalli	0	11452	11452	0	0	0	6535	17988
Bellary	Habhalli	0	5499	5499	0	0	0	2525	8024
Bellary	Kudligi	0	928	928	0	0	0	504	1432
Chitradurga	Chitradurga	0	9	9	0	2	2	76	87
Chitradurga	Holalkere	19	143	162	0	1	1	46	208
Davangere	Channgiri	7702	38403	46106	0	0	0	42694	88800
Davangere	Davanagere	9359	69052	78411	0	0	0	65842	144252
Davangere	Harihara	10142	70368	80510	0	0	0	58305	138815
Davangere	Harpanahalli	1710	8791	10501	0	0	0	7625	18126
Davangere	Honnali	10866	26139	37005	0	0	0	24337	61342
Davangere	Jagalur	4	8	12	0	0	0	1	13
Dharwad	Kundgol	129	0	129	0	0	0	54	183
Gadag	Mudargi	57	1947	2004	0	0	0	1504	3508
Gadag	Shirahatti	79	798	877	0	0	0	758	1635
Haveri	Byadgi	442	915	1357	0	0	0	12	1369
Haveri	Hangal	10259	29545	39805	0	0	0	1608	41412
Haveri	Haveri	33	1065	1098	0	0	0	287	1386
Haveri	Hirekerur	598	5161	5759	0	0	0	1399	7158
Haveri	Ranebennur	263	12425	12688	0	0	0	10517	23205
Haveri	Savanur	4	192	196	0	0	0	27	223
Haveri	Shiggaon	7151	3139	10290	0	0	0	22	10312
Shivamogga	Bhadravati	2474	22091	24565	10618	0	10618	31973	67157
Shivamogga	Sagar	15086	18551	33637	582	0	582	422	34641
Shivamogga	Shikaripura	2068	49839	51907	2598	0	2598	3454	57959
Shivamogga	Shimoga	7661	37637	45298	6366	0	6366	39912	91575
Shivamogga	Sorab	17930	40167	58097	1459	0	1459	42980	102536
	Total	104036	454265	558301	21622	2	21624	343418	923343

Table 3.5 List of Paddy Production

Data on corn production

District	Taluka	Corn Production (MT)							
		Kharif			Rabi			Summer	Total
		Rainfed	Irrigated	Total	Rainfed	Irrigated	Total	Irrigated	Total
Bellary	Hadagalli	30983	15809	46792	185	658	842	165	47800
Bellary	Habhalli	9873	22214	32088	314	110	425	491	33004
Bellary	Kudligi	14839	13516	28355	351	188	539	1445	30339
Chitradurga	Chitradurga	64973	6288	71261	2	1134	1136	186	72583
Chitradurga	Holalkere	60817	65	60882	0	0	0	5	60887
Davanagere	Channgiri	91212	234	91447	0	0	1	6	91453
Davanagere	Davanagere	83492	18411	101902	1	178	179	441	102522
Davanagere	Harihara	21063	7817	28881	1	14	14	75	28971
Davanagere	Harpanahalli	116128	40902	157030	200	623	823	301	158154
Davanagere	Honnali	88700	2787	91487	16	766	781	841	93109
Davanagere	Jagalur	40412	12443	52855	299	2037	2337	172	55363
Dharwad	Kundgol	2321	0	2321	7	3	10	47	2378
Gadag	Mudargi	2687	9770	12456	666	2236	2902	23	15382
Gadag	Shirahatti	13094	9030	22124	119	409	528	60	22713
Haveri	Byadgi	55380	2598	57978	0	1506	1506	132	59615
Haveri	Hangal	34392	5850	40242	107	2075	2182	1536	43960
Haveri	Haveri	58900	16343	75243	58	4120	4179	2046	81467
Haveri	Hirekerur	102789	3812	106601	19	1379	1398	1117	109117
Haveri	Ranebennur	46037	12698	58735	39	1117	1156	547	60438
Haveri	Savanur	19038	2136	21174	126	338	464	266	21905
Haveri	Shiggaon	19973	24	19997	48	148	196	471	20664
Shivamogga	Bhadravati	7167	15	7183	0	0	0	77	7260
Shivamogga	Sagar	7491	11	7502	0	0	0	95	7597
Shivamogga	Shikaripura	65735	7646	73381	0	1158	1158	4899	79438
Shivamogga	Shimoga	37849	8744	46593	0	4	4	1015	47612
Shivamogga	Sorab	17356	5064	22419	125	0	125	4968	27512
Total		1112701	224228	1336928	2683	20203	22886	21430	1381244

Table 3.6 List of Corn Production

Chapter4

Mass and Energy balance of Agro-waste Biomass Supply Chain

The aim of this work was to produce a set of baseline mass balances for a range biomass feedstock. These are systems where there is a continuous flow of feed material, some (at least) of which is converted to a desired product, which then flows continuously out of the system, together with any by-products and unused feed material. The basic calculations performed on such a process (as distinct from the design of the individual units) are the mass balance, and the energy balance. The mass balance is an important aspect while assessing the environmental sustainability of the proposed supply chain. In the previous chapter the assessment of the supply chain is thoroughly explained while the emissions have been analysed. The objective function addresses the mass balance constraint in the upstream of the supply chain. Although in the formulation the mass balance has been considered as a constraint, the significance of mass balance has not been addressed. This chapter gives a descriptive idea about mass balance.

4.1 Basic mass balance equation

The mass balance equation simply stated says that at steady state, the mass in is equal to the mass out (conservation of mass). This is also true for energy balance. A schematic diagram is represented below to visualize the mass in and mass out in a system.

Figure 4.1 (A schematic diagram of mass energy balance)

Mass In = Mass Out

Thus $M_{consumed} - M_{generated} = M_{In} - M_{Out}$ (36)

The scenario described here is based upon two parts. The first part deals with the mass balance in the biomass side. The second part deals with mass balance in the conversion side. Both the types of mass balance have been demonstrated in the preceding paragraphs.

4.1.1 Harvesting/Farm area

The biomass is of 3 types.1. Paddy straw, 2. Corn Cobs ,3. Corn stalk

These three agro residues come from paddy and corn. So, the mass balance is performed with respect to the paddy and corn crops. The agricultural profile of both the crops is necessary to analyse as we are dealing with the biomass in this sector. The main reason of selecting corn and paddy for the study is their abundance in Karnataka.

4.1.2 Corn

After the crop reaches the maturity stage, cobs are detached from the plant manually with the help of laborer. Generally, labour charges are on the per acre basis which varies from Rs 1500-2000 depending on the degree of shortage of labour and acreage. This period faces shortage of the labor as crop of entire area reaches harvesting stage at the same time. This is mainly because the sowing of corn is rain dependent, and majority of farmers start sowing immediately after receiving the first shower. Labour must detach the cob and collect it at the threshing point, transport if required for the purpose must be arranged by the farmers. Farmer then calls the thresher service provider which most of the times is available in the village. The decision of threshing is influenced by the market price of Corn. Hence, the threshing of Corn cobs harvested in month of October-November is stretched till January-February. Service charges of thresher ranges between Rs 40-60 per quintal [91]. It is less in the areas with high Corn crop intensity and vice versa. Thresher owner has the team of labour and thresher machine which is either tractor driven or engine driven and visit the fields of the individual farmer.

Thus, grains, hull and husk are separated in threshing where grain is taken to market, hull required by domestic purpose is stored while remaining is either given to traders or remains in field while husk is stored as fodder. The decision to harvest Corn stalk is influenced by cropping pattern and amount of rainfall received.

4.1.3 Paddy

Degree of mechanization in paddy is high in this cluster. It is primarily because of the convenience, reduced cost, and effort. About 85-90% of total paddy undergoes mechanized harvesting. According to respondents, only farmers having area less than 1-1.5 acres and has own labour to cut, transport and thresh, chooses manual harvesting [91]. Harvester charges Rs 1500-1800 per hour and covers 1-1.5 acres depending on the field size whereas the same activity requires 5-6 man-days for cutting and shifting the material to threshing base and further

4-5 man-days for threshing, it reduces if machine thresher is available. Thus, in manual harvesting the cost translates to Rs 1800-2200 [91]. Therefore, reducing the cost by about 20%, time and efforts drastically. Hence, the adoption of mechanized harvesting is high in the region. The time and efforts saved due to mechanized harvesting is put into the preparation of fields for subsequent crop. Harvester cuts the paddy stalk 9-12 inches above the ground. It is mainly to avoid the risk of any boulders, stones or hard material damaging the cutting blades of harvester and to increase the productivity of the harvester. Threshed straw is dispersed in the field as harvester release the chaff while moving. This straw is collected with the help of labor and is used as fodder. The recovery of threshed straw is about 70% as some portion is lost by truncating it above the ground and some during the manual collection of dispersed straw. Farmers having surplus straw often sell it to the farmers in need. The farm gate prices of such paddy straw range between Rs 3500-4000 per tractor load. About 1.5 acres is required to complete one tractor load and 4-5 labour are required to collect the paddy straw and load the tractor [91].

The agro-residues collected from paddy and corn are of various kinds. Such as rice husks, paddy straws, corn cobs, corn stover, corn stalk etc. Paddy straw is a rice by-product produced when harvesting paddy. Each kg of milled rice produced results in roughly 0.7–1.4 kg of paddy straw [91] depending on varieties, cutting-height of the stubbles, and moisture content during harvest. Paddy straw is separated from the grains after the plants are threshed either manually, using stationary threshers or, more recently, by using combine harvesters. Paddy straw, as a lignocellulosic biomass, is comprised of three components: lignin, cellulose, and hemicelluloses. The characteristics of rice husk compared with other solid fuels can be summarized as follows:

- High silica content wears out the components in processing machines, such as conveyers or grinders, and hampers digestibility for livestock. Content of volatile matter in paddy straw is higher than that in wood and much higher than in coal. On the other hand, fixed carbon is much lower than that in coal. Ash content in paddy straw is much higher than that in wood and coal, which causes barriers in energy conversion.
- High content of ash, alkali, and potassium causes agglomeration, fouling, and melting in the components of combustors or boilers.

Similarly, some of the features of corn cobs and corn stalks can be summarized as: -

- One of the advantages of corn cobs as a biofuel feedstock is that they are a by-product of corn grain production, and no additional production inputs are required above those needed for cob collection and transport.
- On a dry matter basis, cob yields average about 14% of grain yields and represent about 16% of the total stover biomass in a field. Cob moisture is a logistical and storage challenge as cobs are typically wetter than the corn grain. At corn grain moisture levels of 20%, cobs may still be retaining 35% moisture [92].
- Lignocellulosic waste, such as corn stalks, is a potential biofuel source.
- Corn stalk is thick and strong; it is about 0.8–3 m long and 2–4.5 cm wide (diameter) with obvious nodes and internodes [92].

4.2 Mass Balance in Ranebennur (Karnataka) for Paddy

The first case mass balance is deduced for paddy straw as paddy straw is one of our major biomasses assessed. The mass in and mass out typically denotes the left-hand side and right-hand side equation. The 'mass in' is the mass input to the system and mass out is the output from the system.

Let the total production of paddy in Ranebennur area = m kg per ha

$$\text{Mass In} = x + y + z + (f+f') + x_p \qquad (37)$$

x: amount of soil required per 'm' kg of paddy

y: amount of water required per 'm' kg of paddy

z: amount of seeds required per 'm' kg of paddy

f: amount of organic fertilizer required per 'm' kg of paddy

f': amount of non-organic fertilizer required per 'm' kg of paddy

p: amount of pesticides required per 'm' kg of paddy

B: amount of biomass

A: amount of ash present per kg of "B"

S: amount of Si present per kg of "B"

U: amount of useful Biomass per kg of "B"

Stubble

Useful: $(U \times B)$

Ash: $(A \times B)$

Silica: $(S \times B)$

4.2.1 Mass balance of paddy straw

Mass In (in kg)

$x + y + z + (f+f') + (x_p)$ (38)

Mass out (in kg)

$1+ B = 1+ ((U \times B) + (A \times B) + (S \times B))$ (39)

Case study has been done in Ranebennur taluka Karnataka

Average production (2014), $m = 2787$ kg

Hence soil required, $x = 27.98$ kg

y: 323.292 kg of water is required.

$z = 19.80$ kg

$f = 150:60:60$ (NPK) (per kg of paddy)

Mass Out

$B = 31.80$ kg

$U = 17.49$

$A= 3.498$ kg

$S = 2.62$ kg

f and f' are assumed to be equal to 'f' in the calculation as organic fertilizer utilization varies from farmer to farmer.

4.2.2 Mass balance in Ranebennur (Karnataka) for corn cobs and corn stalk

Mass In

Let the total production of corn in Ranebennur area = m kg per hectare area = 3,24 t/ha

Mass In $= x + y + z + (f+f') + x_p$ (40)

x: amount of soil required per ha

y: amount of water required per ha

z: amount of seeds required per ha

f: amount of organic fertilizer required per ha

p: amount of pesticides required per ha

B: amount of biomass

A: amount of ash present per kg of “B”

S: amount of Si present per kg of “B”

U: amount of useful Biomass per kg of “B”

Idea is a crop requires certain mm of water.so calculate kg of crops requirement

Z = 20 kg/ha

X= 2 * 10^6 kg(million)

Y = 181.89 liter/day/mm

f = 9 tons/ha

P = 3.1 kg /ha

Mass Out

B= 1.70 tons/ha

A= 2.2%,

S = 47.8%

Mass In is same for corn cobs and corn stalks; mass out is different in both the cases.

Since the Mass In is same for corn stalk as in the case of corn cobs; only Mass out is demonstrated in the next paragraph.

Mass Out

B = 1.237 tons (came from 500 kg of dry stalks/acre)

A= 6 % * 1.237 tons= 74.22 kg

S = 58.75 % * 1.237 tons = 723.76 kg

The difference in mass in and mass out values are due to following reasons:

1)Biomass for food

2)Drainage before harvesting (12 days before)

3)Run off

4)Percolation

5)Evapotranspiration

4.3 Mass Balance in conversion area

The conversion stage is assumed to be a two-step process in this proposed supply chain. The first step is the thermochemical process of conversion of biomass to syngas. The next step is a biochemical process where ethanol is synthesized from syngas in a catalyst -based reaction environment. In the first step, the gasification of corn cobs is performed in a fixed-bed downdraft gasifier to generate syngas, which is further conditioned to adjust the gaseous mixture mole ratio to produce feed suitable for catalytic methanol synthesis. Conditioning involves a packed bed containing commercial type 4A sodium zeolites, where carbon dioxide adsorption takes place. The adaptation of a low-pressure operation to selectively adsorb carbon dioxide is a key feature of the separation process. A 10 kg/h biomass gasification system is operated at molar steam to biomass ratio of 2.3 and an equivalence ratio of 0.24. After gas separation, syngas with an average module value of 2.48 is obtained with total tar (phenol, benzofuran, naphthalene, 2-methyl naphthalene) and trace gases (HC_l, HF, and H_2S) being about 1.66 ppmV and less than 1.6 ppmV, respectively [79].

The mass balance and the energy balance of the corn cobs corresponding to the superheated steam temperature of 655 °C is tabulated below [93].

Component	Mass(kg/hr)	Energy (MJ/hr)
Input		
Biomass	11.7	190
Steam	20.9	86.1
Oxygen cryogenic separation	3.4	2.5
Auxiliary Output	-	5.4
Syngas	16.5	158.0 (LHV basis) 176.6 (HHV basis)
Efficiency	55.6% (LHV basis)	62.2% (HHV basis)

Table 4.1(Composition of biomass)

4.3.1 Conversion Area

Chemically, biomass is a carbon, hydrogen, and oxygen complex resulting from photosynthesis. In the presence of sunlight, CO_2 and H_2O combine to form the C–H–O complex. The C–H–O complex is composed of molecules of sugars resulting in cellulose and hemi-cellulose, in combination identified as holo-cellulose. Lignin is a non-carbohydrate, poly-phenolic that binds the cells together. The structural formula for cellulose, hemicellulose, and lignin are $C (H_2O)0.83$, CH_2O, and CH (1.3) O(0.3) respectively. It is evident that the hydrogen to carbon ratio (H: C) is 1.66 for cellulose, 2 for hemi-cellulose, and 1.3 for lignin. While all these are organic fractions in biomass, the inorganic content forms ash [93].

Cellulose is a glucan polymer. It is a linear chain formed by D-glucopyranose units linked by glucosidal bonds. Cellulose in wood is highly crystalline. It forms intra and extra-molecular hydrogen bonds and aggregates into bundles, which in turn form microfibrils. Microfibrils constitute the main component of the cell wall. Cellulose provides strength to the tree and is insoluble in most solvents. Hemicellulose is a collection of polysaccharide polymers. They are branched polymers without crystalline structure. Hemicellulose has little strength and is easily hydrolyzed by acids. It is intimately associated to cellulose in the structure of the cell wall. Lignin are three-dimensional, highly complex, amorphous, aromatic polymers. Lignin does not have a single repeating unit like cellulose, but instead consists of a complex arrangement of substituted phenolic units. Lignin is an encrusting material. It fills the spaces in the cell wall between cellulose and hemicellulose. It is also the main component of the middle lamella, the binding layer between the wood cells. The thermochemical conversion process, as the name suggests, is an activity involving both heat and chemistry. During the thermochemical process, the fuel undergoes several sub-processes involving degradation of the solid fuel [93].

4.3.2 Drying

Drying is a physical process, during which the moisture in the biomass is removed. Typical moisture content in a freshly cut biomass is up to about 50%, depending upon the species of biomass. With an increase in the biomass temperature, the moisture is removed. The processes that occur during drying process are the thermal and mass diffusion processes. With heat penetration into the particle, change of phase takes place and the water molecules diffuse out through the pores. Moisture content of biomass is usually expressed as the moisture content by weight per unit weight of the dry or wet biomass. It is important to understand the significance of the two bases. Wet-weight basis expresses the moisture content in the biomass as a percentage of the weight of the wet biomass, whereas the dry-weight basis expresses the moisture in the biomass as a percentage of the weight of the bone-dry biomass. Thus 50% moisture on wet basis (w/w) signifies 50 parts by weight of water per 100 parts by weight of wet biomass. On the other hand, biomass containing 50% moisture on a dry-weight basis will contain 50 parts by weight of water per 100 parts by weight of bone-dry material (b/d). The importance of the basis is evident if the wet-basis is converted to dry-basis or vice versa. A moisture content of 100 on bone-dry basis would represent 33.3% on wet basis. The relationship between the two can be expressed as $W_w = W_d / (1 + W_d)$ and $W_d = W_w / (1 - W_w)$ where W_w is the grams of moisture per gram of wet material and W_d is the grams of moisture per gram of dry material [93].

4.3.3 Pyrolysis

Pyrolysis is defined as the process of thermal degradation of biomass, that is decomposition or transformation of a compound caused by heat. The complex chemical mechanisms involved in pyrolysis are not completely understood and the degradation pathway is a function of heating rate, temperature, gaseous environment, pre-treatment, extent of inorganic impurities, and catalysis. Based on the heating rate, pyrolysis is classified as slow and fast. As the name suggests, during slow pyrolysis the biomass particles are subjected to heating rates of the order about 100 K/s while in fast pyrolysis it is in the range of 1300 K/s [93].

4.4 Combustion

This thermochemical process converts the energy content in the fuel to sensible heat with the aim of extracting all the chemical energy in the fuel to the product of combustion. Combustion is an exothermic chemical reaction between the fuel, in this case biomass, and an oxidant that can be air, accompanied by the production of heat and conversion of chemical species. The release of heat can result in the production of light in the form of either a glowing or luminous flame. In a complete combustion reaction n, a compound reacts with an oxidizing element, such as oxygen, and the products are compounds of each element in the fuel with the oxidizing element. During the process of combustion, earlier identified sub-processes like drying and pyrolysis also occur in the presence of the oxidizer [93].

For typical hydrocarbon fuel burning in air,

$CH_n + (1 + n/4) (O_2 + 79/21\ N_2) \rightarrow CO_2 + n/2\ H_2O + 79\ n/84\ N_2$, where the stochiometric ratio, s is given by $(32 + 3.76 \times 28) (1 + n/4)/ (12 + n)$ (41)

For diesel/gasoline, $n \approx 1.8$, $s = 14.4$

For methane, $n = 4$, $s = 17.1$. For a typical fuel with CHNO components in the fuel, the stochiometric chemical equation is given by $CH_nO_mN_p + (1 + n/4 - m/2) (O_2 + 79/21N_2) \rightarrow CO_2 + n/2\ H2O + [3.76(1 + n/4 - m/2) + p/2)]\ N_2$ (42)

where air is used as the oxidizing medium.

The stochiometric ratio is, $s = [(32 + 3.76 \times 28) (1 + n/4 - m/2)]/ [(12 + n + 16m + 14p)]$. For a typical biomass,

$CH1.4O.7N.002 + 1.00 (O_2 + 79/21\ N_2) \rightarrow CO_2 + 0.7\ H_2O + 3.949\ N_2$, $s = 6.0$. (43)

From the above chemical equations, one can get the stochiometric (or chemically correct or theoretical) proportions of fuel and air, that is, there is just enough oxygen for conversion of all the hydrocarbon fuel during combustion into completely oxidized products like carbon dioxide and water vapor. These values are presented as stochiometric (fuel/air) or stochiometric (air/fuel) ratios depending upon the notation used. Depending upon the air to fuel ratio, the combustion process can be identified as rich or lean. Under rich conditions, the air available for combustion is less than the stochiometric air required, while in lean conditions the air available is more than the stochiometric requirement [95].

4.4.1 Gasification

Gasification is sub-stoichiometric combustion of fuel with oxidant. The process is not simply pyrolysis of biomass but involves stoichiometric combustion of pyrolysis products (oxidation) which further react with char (reduction) leading to typical products – hydrogen, carbon monoxide, methane, carbon dioxide, some higher molecular weight compounds, water vapor, and remaining nitrogen – in proportions depending on the feedstock and reactant used. In the case of gasification, the chemical equation is:

$CH1.4O0.74N0.005$ (Fuel) + 0.337 (O_2 + 3.76 N_2) (Air) $\Rightarrow$ 2.7(0.211 CO + 0.18 H_2 + 0.0105 CH_4 +0.1275 CO_2 + 0.471 N_2) +0.157 H_2O + 0.028 C (44)

The air/fuel ratio is 1: 1.8. Overall A/F tends towards fuel rich condition (less air) and the energy in biomass is realized in the form of combustible gases (CO, CH_4, and H_2) because of gasification [93].

The useful product of gasification is thermochemical energy, while it is pure thermal energy for combustion [93]. Biomass gasification involves an initial pyrolysis process depending upon the temperature, followed by complex heterogeneous reactions where char reacts with combustion products of pyrolysis (CO_2 and H_2O) with the reaction kinetics playing an important role in the gasification process. Typical reactions in the reduction zone are:

Oxidation: $C + O_2 \Leftrightarrow CO_2$ + 393.8 kJ/mole (45)

Water gas reaction: $C + H_2O \Leftrightarrow H_2 + CO$ − 131.4 kJ/mole (46)

Boudouard reaction: $C + CO2 \Leftrightarrow 2CO$ − 172.6 kJ/mole (47)

Water gas shift reaction: $CO + H_2O \Leftrightarrow CO_2 + H_2$ + 41.2 kJ/mole (48)

Methane reaction: $C + 2H_2 \Leftrightarrow CH_4$ + 75 kJ/mole

Based on the sequencing of the above process, two major types of gasification systems can be identified: namely, updraft and downdraft. In this case open top-down draft type gasifier has been used.

4.5 Conclusion

The mass balance of the proposed sources i.e., biomass is described in terms of providing the adequate energy and mass for the second-generation ethanol supply chain. The mass balance was performed for paddy and corn around Ranebennur. The results are comprehensive to support the proposed research work for generating second generation ethanol pathways. In addition to that a summary of the thermochemical processes has been described for the extraction of syngas from biomass. It consists of the traditional route of open top downdraft type gasifier developed in the CGPL lab of Indian Institute of Science, Bangalore.

Chapter 5

Circular Economy of 2G Biofuel Supply Chain – A Financial Assessment

5.1 Introduction to Circular economy Framework

The linear economy is characterised in terms of valorisation of waste: instances where components, products or materials reach their end-of-use/life prematurely, or where their capacity for value creation is under utilised. To address this, the circular economy (CE) concept proposes a range of efficiency and productivity enhancing activities collectively known as circular strategies, such as reduce, reuse, repair, recycle, restore, cascading, etc. In this sense, CE is an umbrella concept: it groups a range of sub-concepts and imbues them with a new meaning by highlighting a shared feature of the sub-concepts . This new meaning revolves around the notion that through the application of circular strategies both more value can be created as well as value loss and destruction reduced. Although CE has widely been recognised as an idea with potential merit, it has yet to be widely implemented and embedded within business and industry. This is in line with the progression of umbrella concepts: when the transformative potential of an idea has been recognized, the attention then turns to operationalize it through frameworks, tools, methods, and approaches. This, in turn, allows for further examination of the concept.

5.2 Research Objectives

Previous academic work focuses on the definition of the circular economy and how to promote it. However, supporting the early stages of the circular economy framework through establishing a CE vision, i.e., answering why to perform CE, has so far achieved relatively little scholarly attention. The proposed framework is based on finding the 'why' for a CE transition requires understanding the type of structural waste in the system. The tools implemented are impact assessment by means of sustainability indicators, mass and energy balance and system optimisation techniques. A 9R framework is proposed to justify the work in the 2G ethanol supply chain.

5.2.1 Description of Circular Economy

In a circular economy, value is created using loops using biological as well as technical cycles. In the technical cycle, product repair and maintenance are the most important block followed by reuse (it comes in between disassembly and technical nutrients), while in the biological block, biodegradation and biological nutrients are the important blocks. As it is a circular economy, any anomalies/dysfunctionalities in a block will affect the previous and next one in the cycle. The butterfly diagram adapted from Ellen Mc Arthur foundation is described in figure 5.1.

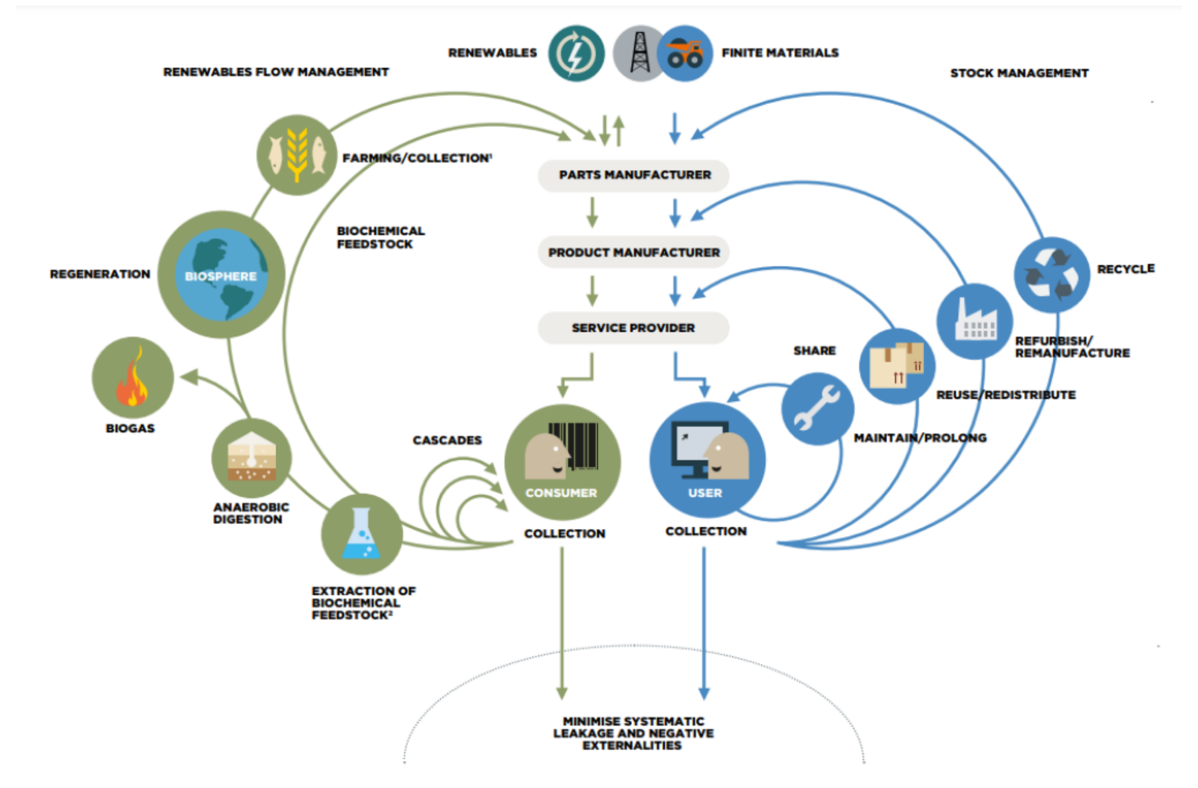


Figure 5.1 (Butterfly Diagram demonstrating CE approach by Ellen Mc Arthur foundation)

The Butterfly Diagram is a powerful tool that helps us to understand the application of the Circular Economy model in practice. In a single image, we have a holistic view of the main assumptions of the model, the proposed changes, and the several solutions that facilitate the transition. There are 3 guiding principles that must be considered in the transition to the CE which we'll explain in more detail in this article: The first one is "preserving natural capital", promoting the effective use of finite resources and balancing the use of renewable resources.

Second is to enhance the usefulness of products, components, and materials, keeping them circulating in the Economy up to the capacity limit. The last one is to develop effective systems that minimize the volume of waste that ends in landfills and negative externalities.

5.2.1.1 Preserving natural capital

At the top of the diagram, we can see that there is a separation between renewable feedstocks, called biological nutrients, and finite materials or technical nutrients. There are very clear features that distinguish these two cycles: The biological nutrients, in addition to being renewable, can decompose when returned to nature (e.g.: wood, paper, cork, cotton, etc.); the technical nutrients, in addition to being finite, do not decompose, which is why their useful life should be prolonged to the limit of their capacity (e.g.: aluminium, iron, plastic, etc). This model can only be effectively regenerating and restoring, if the energy that feeds the entire process is a "clean" energy, from renewable sources. Additionally, processes and products must be thought and designed in alignment with the Circular Economy principles. The design of the products must be rethought in order to facilitate the separation of each of its components so that it can be sent to the correct cycle. For this purpose, the products must be designed with a modular structure, avoiding glues or other types of joints, which make the separation and reuse of its components difficult. The choice of materials is also of high importance: toxic components must be eliminated, to ensure the safety and effectiveness of the processes and to protect public health and the environment. The digitization of processes is also relevant as it promotes greater efficiency in the use of resources and in the activities carried out[101] .

5.2.1.2 Enhance the usefulness of products, components, and raw materials

When analyzing the existing processes between the extraction of resources and the buyer, we can verify that: there is a separation between the parts manufacture and the product manufacture, as this separation promotes a uniformity of the components, which facilitates their continuous reintroduction in the system economic. There is also a distinction between consumer and user, as the name indicates the biological nutrients are consumed (ex: food items, paper, etc.) and the technical nutrients are used, and this use can be shared (ex: tools, bicycles, appliances, etc). As mentioned in the technical nutrients cycle, the alternatives proposed aim to restore the stock of finite resources. In this sense, there is a set of solutions that allow extending the life cycle of products and components. In the first instance, alternatives that allow the maintenance and repair of products should be facilitated, to extend their useful life.

Solutions that promote shared use of products should also be favored, enhancing their usefulness. When a user no longer wants a particular product, there must then be made available channels that allow its collection, maintenance, and redistribution. When a product becomes obsolete, or can no longer be repaired, it must be sent out to be disassembled, and its components used to produce new products. When none of these solutions is feasible, then the resources must be directed to the appropriate recycling processes. On the side of biological nutrients, the solution closest to the consumer is the cascade, where the resources are cyclically reused for several purposes, depending on their applicability. This alternative can be applied in many cases as is the example of fabrics of natural origin: clothes made of organic cotton can be reused to produce new pieces or accessories, which in turn can be reused to produce insulation material for construction or filling for pillows or bean bags. The same applies to materials such as cork or wood. Biochemical materials can be extracted from biological nutrients to produce biogas. The remaining nutrients can be safely returned to the biosphere in the form of compost, thus regenerating the soil and its fertility and closing the nutrient cycle. In both cycles, whenever possible, the alternatives closest to the user/consumer should be favored, since the closer to the user these are, the smaller the resources, time, money, and people needed and the greater the integrity and quality of the materials are maintained and respected. In addition, measures must be applied to extend the time that each component remains in each cycle, thus reducing the need to produce new components, which leads to a continued reduction in the dependence of "virgin" resources.

5.2.1.3 Develop effective systems that minimize negative externalities

With the continuous, integrated, and systemic application of this model by the industries and their communities, it's possible not only to minimize the volume of resources that end in a landfill, but also the negative externalities that are generated with the activities of the industries. For a long time, organizations have been focused on doing less harm and on the efficiency of processes. The problem is that "less harm" is still doing harm, but to a lesser extent, a situation that does not solve the problem and does not contribute to the current environmental challenges that lie ahead, due to the unsustainable system that has been applied in recent decades. The focus should be on doing well (effectiveness) and building resilient systems, which effectively serve the needs of communities and contribute to their evolution. Doing well involves creating value for all parties involved, including organizations, communities, living beings, and the environment [101].

5.3 Reason of implementing waste to energy valorisation

The matter of agro-waste has become increasingly crucial for the Indian subcontinent. In recent studies, various reports reveal that stubble burning of crop residues in India generates nearly 150 million tons of carbon dioxide (CO_2), more than 9 million tons of carbon monoxide (CO), a quarter-million tons of sulphur oxides (SO_X), 1 million tons of particulate matter and more than half a million tons of black carbon. These contribute directly to environmental pollution, as well as the haze in the Indian capital, New Delhi, and the diminishing glaciers of the Himalayas. Although stubble burning crop residue is a crime under Section 188 of the Indian Penal Code (IPC) and the Air and Pollution Control Act (APCA) of 1981, a lack of implementation of these government acts has been witnessed across the country. Instead of burning, crop residues can be utilized in various alternative ways, including use as cattle feed, compost with manure, rural roofing, bioenergy, beverage production, packaging materials, wood, paper, and bioethanol, etc. This review article aims to present the status of stubble-burning practices for disposal of crop residues in India and discuss several alternative methods for valorisation of crop residues. Overall, this review article offers a solid understanding of the negative impacts of mismanagement of the crop residues via stubble burning in India and the other more promising management approaches including use for bioenergy, which, if widely employed, could not only reduce the environmental impacts of crop residue management, but generate additional value for the agricultural sector globally [100].Stubble burning can be defined as the intentional incineration of stubbles by farmers after crop harvest. Stubbles are the cut stalks left on the field after the grains of cereal plants or stems of sugarcane are harvested. Other biomass burning activities such as wood burning for domestic cooking, open field incineration of municipal waste, and wildfire also contribute to the emissions, however; in Asian countries such as China, around 60% of the total biomass emissions comes from the burning of stubble [100]. On a global scale, stubble burning constitutes about one-fourth of the total biomass burning [100]. India is blessed with fertile agricultural farmlands and a diverse ecosystem. Most of the farmers in this region use combine harvesters for planting and harvesting the crops thereby generating a significant quantity of stubble. The use of combine harvesters for harvesting grains is common among Indian farmers especially in the northern parts of the country. This machine can combine three different tasks, i.e., reaping, threshing, and winnowing into a single operation. They are reported to be efficient in harvesting different types of grains, however; they generate a huge amount of stubble consisting of tall stalks, about 15cm high, which are difficult to be incorporated into the soil . A significant amount of the stubble generated is set to fire on the field. According to the Indian Agricultural Research Institute (IARI), approximately 14 million tons (Mt) out of the 22 MT of the rice stubble (about 63.6%) generated each year in India is set to fire [110]. Rice is usually planted in the summer season, around May/June, and harvested around October/November. On the other hand, wheat is normally planted during the winter, mostly in December and harvested during the summer of the subsequent year, around April/May.

5.4 Research Objective

The burning takes place immediately after harvest in each season. From the farmers' perspective, it is easier to burn the crop stubble after harvest to quickly prepare the farmland for the next sowing (of rice or wheat as the case may be). The farmers' eagerness to quickly prepare the farmland for the next planting compels them to simply burn the stubble on-field thereby emitting many hazardous pollutants [111]. Another rationale behind the burning of the stubble is the shortage of time between the harvest and the sowing of the next crop [112]. The average time interval between the harvest of rice and sowing of wheat was reported to be 15 days, and that of rice sowing after wheat harvest was relatively higher, up to about 46-48 days. The farmers, therefore, do not have sufficient time to appropriately manage the crop stubble especially after rice harvest [112]. From the farmers' perspective, it is easier to burn the crop stubble after harvest to quickly prepare the farmland for the next sowing. The farmers' eagerness to quickly prepare the farmland for the next planting compels them to simply burn the stubble on-field thereby emitting a large number of hazardous pollutants [112].Another rationale behind the burning of the stubble is the shortage of time between the harvest and the sowing of the next crop [112].The average time interval between the harvest of rice and sowing of wheat was reported to be 15 days, and that of rice sowing after wheat harvest was relatively higher, up to about 46-48 days. The farmers, therefore, do not have sufficient time to appropriately manage the crop stubble especially after rice harvest. The impact of stubble burning may increase in the coming years with the increase in population and food demand. A report by the United Nation pointed out that the world population may rise to 10 billion by 2050, which will in turn lead to increased food demand. In India, crop production is projected to increase by 45% by 2050, i.e., from 619 MT (million tons) in 2017 to 899 Mt in 2050 [112]. This will necessitate the production of more food and consequently the generation and burning of more stubble. Several efforts have been made by the government to provide alternative management techniques for the farmers to manage their crop stubble.

5.4.1 Research Methodology

One of the ways to handle the issue is converting the residual agro waste or biomass into a useful energy resource. This can be achieved by converting biomass into 2G ethanol .For the conversion of biomass to ethanol an entire supply chain must be formed where in each step waste to energy conversion ,environmental impact assessment ,socio-economic condition of the stakeholders etc is to be considered. So, the role of circular economy is inevitable in such case.

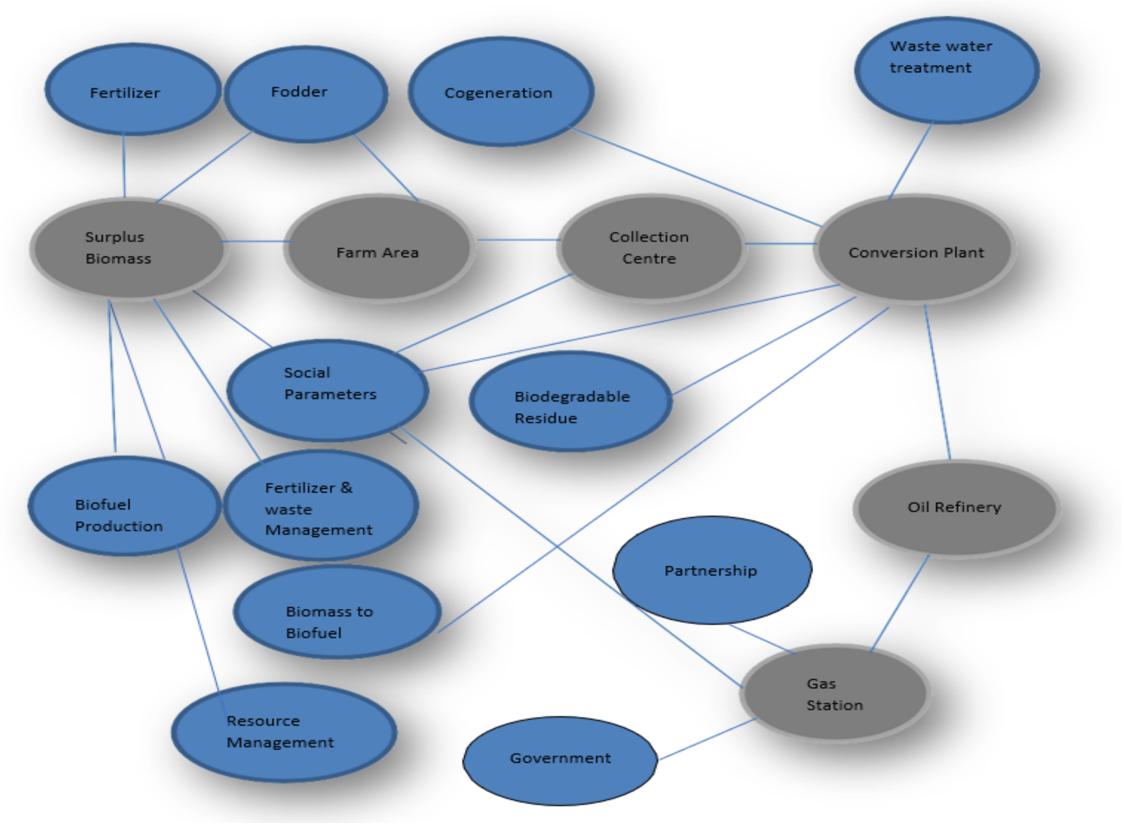


Figure 5.2(Updated approach for circular economy framework)

The figure is drawn to signify the framework we have adapted in the supply chain.

Harvesting area/Farm: It consists of crops and waste. The waste is utilized to feed the cattle, sometimes it gets utilised as a cooling material in rooftop of houses. The residual agro waste would have gone to stubble burning; rather it will be utilised in producing ethanol. The process takes many companies, village level entrepreneurs into account. Thus, it creates jobs for many sectors.

The farming technique can also be circular by making organic waste as manure and the agro waste can be used as manure in many other farming or gardening purposes.

Collection Centre - The collection centre is the place to store the biomass. Sometimes it takes part in pre-processing like shredding, briquetting etc. The importance of the collection centre is not only about storing the biomass, it also makes the local people employed. The employment rate increases by introduction of the upstream of supply chain

Conversion Plant – it is the hub of circular economy-based framework. The most important job done is the conversion of biomass into ethanol.

The process is not direct in the proposed case. Rather it's a hybrid one.

1- Thermochemical process: In this process biomass is converted to syngas.
   There are many co-products arising in this technique which can be beneficiary to other industries. Like from syngas we can not only synthesize ethanol; but we can derive many biofuels such as methanol, dimethyl ether and hydrogen etc. So, each category of biofuel gives rise to a new industry.
2- Biochemical process: The technique in thermochemical and biochemical processes are not same. So, it requires collaboration giving rise to number jobs. In this case the local people are employed along with the skilled technicians, engineers, scientists, and consultant. The biggest benefit is it produces less CO_2 in comparison to any fossil fuel-based refinery or mining activities. The conversion centre is a block in the supply chain where co-generation can take place adding a parameter to the CE parameter.

Oil Refinery: The oil refinery in the proposed supply chain is one of the secondary blocks ;but it is an integral part. In general, the oil refinery changes crude oil into petroleum products for use as fuels for transportation, heating, paving roads, and generating electricity and as feedstocks for making chemicals. In the proposed model the responsibility of the refinery will increase as blending of ethanol will take place. Thus, a greater number of people will get jobs and the company's net revenue will increase.

Consumer: The consumer defines to one who will be using the 2G ethanol in transport sector. For the consumer there are 2 major benefits.1- As ethanol will be blended in petrol or diesel ,prices will go down making the transport more affordable.2- The emissions in ethanol -based transport will be lesser than the fossil fuel-based transport making the air cleaner and healthy.

The closing of loop in the proposed model is dependent on social parameters and environmental parameters. The complexity of the model is it's a supply chain and the products have been changing in each block. So, till the conversion stage waste to energy valorisation takes place; but from oil refinery till consumer the framework is based on social and environmental factors. The major connection between the first and last block of the supply chain is the social parameters which will be better such as employment will rise, people will access to clean energy. Due to rise in affordability the laborers and farmers will have access to better healthcare system, the malnutrition problem will reduce. Hence, we can that many sustainability development goals can be addressed through the work. The major SDG is SDG 12 which deals with sustainable production and consumption and the second-generation ethanol supply chain clearly imbibes it. It does not give rise to food versus fuel problem. The other way of justifying the circular economy approach is done via the 9R framework. An illustration of 9R framework is given below [112].

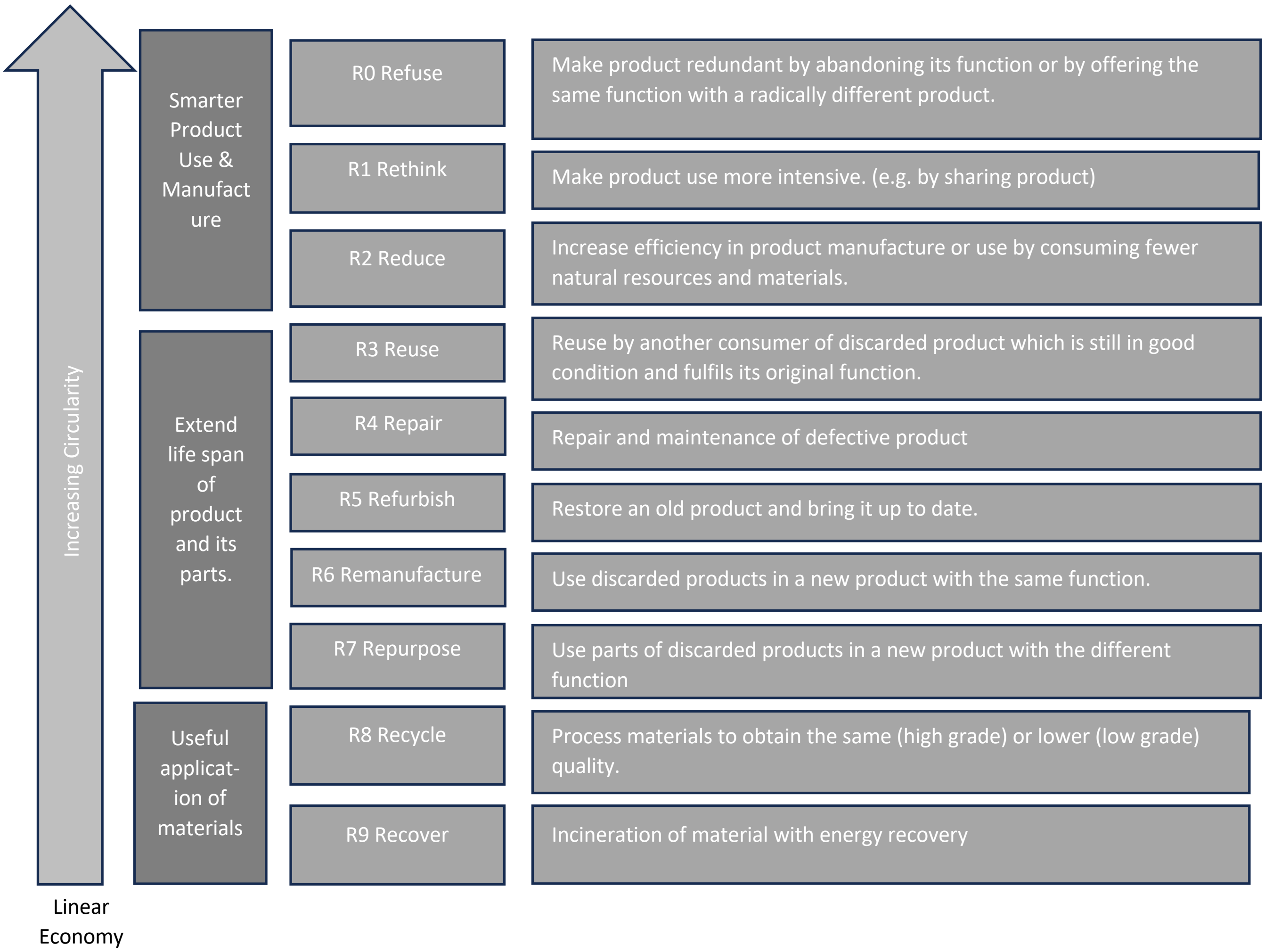


Figure 5.3 (9R Framework demonstrating CE framework)

The aim of the research is to showcase and prove the existence of circular economy framework while illustrating the second - generation ethanol supply chain. The description of the work is validated by using 9R framework. The reuse, recycle, reduce, and refurbish strategy has been well explained in the previous paragraph. In the 9R framework it is integrated with the existing frameworks of linear economy. The entire work is a gradual shift from the linear to circular economy. Hence, the 9R framework is established.

Apart from sustainability analysis a business model is developed for the corresponding biomass supply chain. In first scenario harvesting area/farm area is considered. The details of the harvesting site along with the sensitivity plot is given in the preceding paragraphs. The data regarding total output biomass, biomass cost, operational expenses, capital expenses are adapted from the PRESPL paper [66] . The rate and other financial parameters are adapted from the established literatures [112]. The table 4.2 gives an idea on the Net present value (NPV) and Internal Rate of Return (IRR) which has been found out by detailed analysis using MS Excel sheet. The internal rate of return is associated to financial rate of return and net present value is a tool of capital budgeting to find out the profitability of the project. Further sensitivity analysis is done in excel environment which gives us the idea regarding the relationship between surplus biomass, NPV and IRR. Figure 5.4 gives an idea on sensitivity analysis of surplus biomass, NPV and IRR. Figure 5.5 is based on sensitivity analysis of biomass selling price, NPV and IRR.

Business Model		
Interest Rate	%	14
Inflation Rate	%	5
Discount Rate	%	10
Depreciation Rate	%	20
Salvage value of machinery and building	%	10
Equity	%	25
Debt repayment period	Years	7
Corporate Income Tax rate	%	30.9
CER Price	INR/CER	0
Total Project Investment	INR Million	110.00
Equity Component	INR Million	27.5
Capital Subsidy	INR Million	15
Output Biomass per MT	INR	2183.00
Capital Expenses	INR Million	385.00
Operational Expenses	INR Million	3.51
Total depreciable investment (Rs)	INR Million	275.00
Loan Amount	INR Million	188.51
Annual Repayment (Rs.)	INR Million	26.93

Table 5.2 Business model of harvesting area

The NPV (Net present value) was found to be INR 82.96 and IRR (Internal rate of return) is 15%. A sensitivity plot is drawn to observe the relationship between biomass, NPV and IRR.

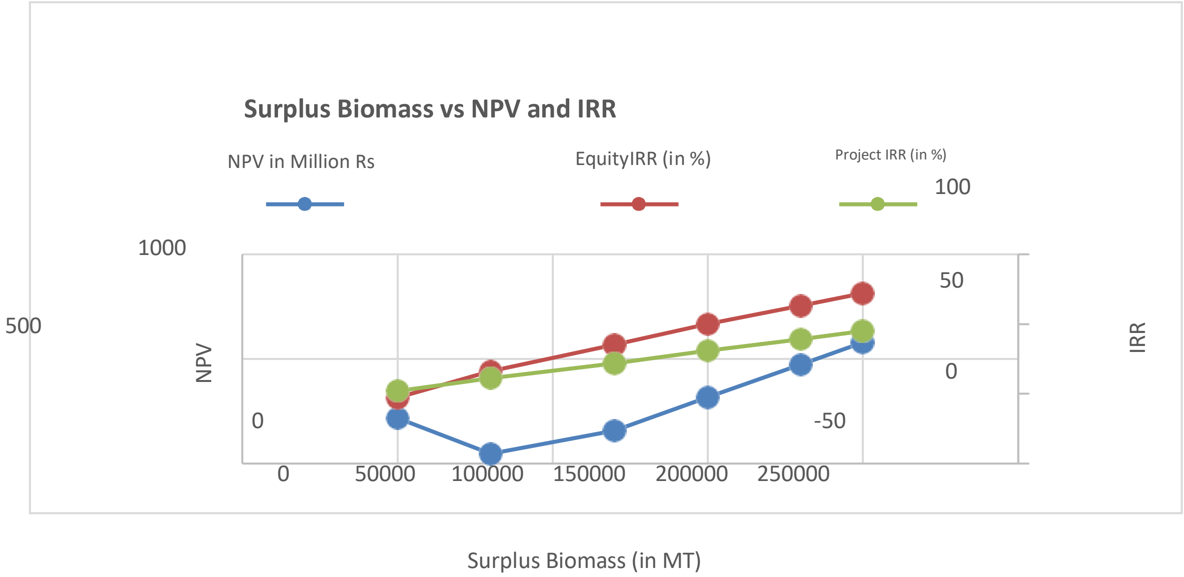


Figure 5.4. Sensitivity analysis of Surplus biomass, NPV and IRR

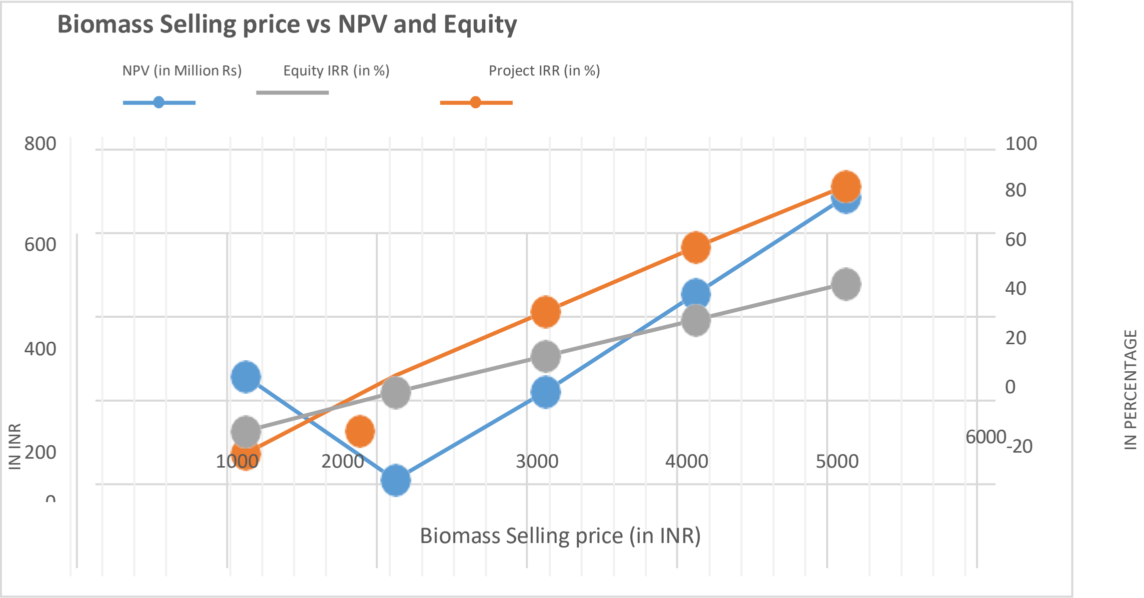


Figure 5.5. Sensitivity analysis of biomass selling price, NPV and IRR

A sensitivity analysis of the biomass selling price, NPV and IRR is performed to know the economic indicators of the biomass supply chain. The business model helps to determine the economic feasibility of the proposed model.

Surplus Biomass (In MT)	NPV (in Million INR)	IRR (in %)
50000	216	2
80000	46.12	11
120000	156.57	22
150000	314.67	31
180000	472.78	39
200000	578.18	45

Table 5.3. Inference from the sensitivity analysis of surplus biomass

Biomass Selling Price (INR/MT)	NPV (in Million INR)	IRR (in %)
1000	258.25	-1
2000	10.76	13
3000	221.78	26
4000	454.48	39
5000	686.87	52

Table 5.4. Sensitivity analysis of biomass selling price

The motivation behind the sensitivity model was to prove the circularity of the proposed supply chain in terms NPV, IRR. The net present value is determined by the minimally expected yield (calculated interest rate). It shows the amount of capital growth has been accumulated by the investment during its duration, but it does not inform about the real profitability of capital investment [76]. However, the investment's internal rate of return informs the decision maker that how works the real yield of long capital investment. Hence these two indicators are incorporated in this section to show that the investment in the proposed work is a profitable idea as the IRR increases with the increase in surplus amount of biomass and biomass selling price.

5.5 Conclusion

The chapter 5 highlights the potential of the circular economy to bring about more sustainable lifestyles and green industrial development in the India, while also making explicit that the CE is contested terrain with complex societal structures and government policies. It shows that some of the core arguments and issues of the politics of green transformations–multiple pathways, different narratives of transformations, institutional contexts, and political alliances–also pertain to the circular economy. The chapter shows the many possible synergies between the circular economy and the sustainable development goals which can contribute to creating integrated strategies. It discusses how CE practices are being realised in varied domains, ranging from traditional agricultural practices of small- or large-scale agriculture in India and big revenue-based oil refineries. The proposed framework helps think through the roles and interests of the different actors.

Chapter 6

Summary and Conclusion

The research objective is to establish a model which will assess the economic, environmental, and social indicators for a 2G ethanol supply chain and incorporate the concepts of circular economy in the supply chain. It utilized particle swarm optimisation technique-based decisions to assess the sustainability of the biofuel supply chain in the transportation sector. It has adapted data from Karnataka, India. Since paddy and corn are one of the major crops in the state, the second-generation biofuel assessment study is based on corn cobs, corn stalks and paddy straw as biomass. In the downstream process and upstream process, mass balance is performed. On the downstream side, the conversion of corn cobs to ethanol is discussed along with the sustainability assessment. The invocation of circular economy has helped to perceive waste valorisation as a possibility in the Indian scenario while keeping the clean energy concept intact. Another objective of the study is to make the farmers and other stakeholders gain from the discussed supply chain. Hence business models have been derived to show the NPV and IRR values in both the upstream and downstream cases. The proposed research is innovative and a primary attempt to assess sustainability. The study inputs will benefit the researchers working in the 2G ethanol domain.

6.1 Summary

To provide a broader view of the studies, we have provided a systematic analysis of the biomass in the supply chain system, the upstream and downstream process, uncertainty in the methods and assessment technique. The dependency on fossil fuel in IC engines is a factor where 100% blending is impossible; hence E20 is the vision by 2025. Also, a significant shift is required due to the incapability of linear economy as it directly affects the environment. The first objective was to decide the biomass type, and in this phase, the biomass required for fodder and other activity was calculated, and finally, surplus biomass was measured. Corn cobs, corn stalks and paddy straw were the biomass decided for the study. The data enabled us to determine the profit, net CO_2 emissions and total no of jobs generated in the assessment stage.

The second objective is one of the crux parts of the proposed work. Mathematical modelling is done in the sustainability assessment for both the upstream and downstream processes. A heuristic-based optimisation technique is a tool for evaluating economic, environmental, and social indicators. The methodology also involves a business model followed by sensitivity analysis where we have found the NPV, and IRR.

The third objective is to balance the mass and material flow in the supply chain, majorly in the collection site and conversion stage. A thorough analysis is done concerning the biomass, and the reasons for inequality have been stated with proper explanation. However, in the conversion stage, the mass balance adapted from the corn cob to syngas gasification work in Combustion Gasification and Propulsion Laboratory, IISc.

The final work is based on developing the circular economy framework for the entire supply chain system. The smaller the loop, the more efficient it is. The concept of circular economy has emerged to be a powerful concept in our analysis.

6.2 Major Research Findings

The significant findings from the research are listed as follows:

i. Three kinds of biomass, such as paddy straw, corn cobs and stalks, have been considered. The study area covers the Ranebennur cluster, which comprises 26 talukas from 7 adjoining districts of Bellary, Chitra Durga, Davangere, Gadag, Haveri and Shimoga. All the cultivated crops from the mentioned talukas were listed. Paddy and corn were found to be the major crops in these talukas.

ii. Unlike lithium and fossil fuel, abundant biomass resource is present in India. Hence the geographical location of these types of biomasses makes the country a potential biofuel manufacturer. A detailed study on the potential yield of the biomass in the Karnataka region is done while doing the research and the research findings is shared in the present work.

iii. The detailed study of the biomass yield after food, fodder requirements was not done before and through this study one can get a comprehensive idea on how to determine the amount of potential biomass yield for ethanol conversion.

iv. The Harvesting area is the first significant system in the upstream process. So, it is necessary to know the net system profit, including transportation, until the biomass reaches the factory gate. In the case of paddy straw, the net system profit is nearly Rs.

14 million at the end of 5 years. Similarly, the net system profit is Rs. 30 million and Rs. 90 million for corn cobs and corn stalks, respectively.

v. In the emission domain, the total emission is 52 kilo tons of CO_2 in the case of paddy and 65 kilo tons of CO_2 in the case of corn.

vi. The social indicator gives one of the most significant values for the biomass types. In the case of corn cob and stalk, the employment rate is zero or negative before introducing such ideas. After presenting the biomass to the biofuel conversion concept, employment has increased to 4.5% in corn. However, in the case of paddy, employment has risen to 24%.

vii. In the economic indicator domain, the sensitivity analysis was done, and IRR was found out for corn cobs. In the downstream process, due to the technical challenges, only the case of corn cobs is being taken into consideration.

viii. A systems thinking approach is followed while analyzing the entire work, and it was achieved through 9R framework. The implementation of 9R framework in the biomass to biofuel conversion supply chain is an innovative approach.

ix. The normal procedure to determine the economic, social, and environmental indicators are using life cycle assessment methodology which are backed by user friendly software like SimaPro, GaBi and Ecoinvent. Unlike the traditional approach, proposed idea is based on mathematical formulation of the three indicators and solving it through a heuristic based optimisation algorithm. This kind of approach is not only precise and novel; but also, an effective way to prove the efficacy of the supply chain.

x. The current market is dominated with electric vehicle, but the main source of the lithium is imported to India. Hence ethanol blending has a potential market for the Indian customers. The blending option is better than a battery-based vehicle as it doesn’t require any change in the engine design.

6.3 Major contributions of the research

i. This research implements a new methodology based on heuristic-based optimisation technique. The algorithm is behavioral, and it satisfies all the constraints. In general, unconstrained optimisation is easy to implement; but we have proposed a constrained particle swarm optimisation technique. This technique helps to solve all the mathematical models with accuracy.

ii. The traditional way of finding the environmental indicator, i.e., the emission, is a life cycle assessment technique. At first, we tried to use the LCA methodology using Ecoinvent software. The drawback was the location, the soil type, the water availability etc., were all based on either Europe or Latin American scenarios. So, the fundamental analysis of CO_2 emissions, employment rate, and net system profit is performed by virtue of the particle swarm optimisation technique, which has included the uncertainty and randomness of the supply chain and provided solutions with accuracy.

iii. The proposed research is one of the earliest attempts to combine a modern optimisation technique as a tool to assess sustainability.
iv. The scenarios developed and validated in this research proved that the modelling approach and circular economy concepts proposed here could be effectively employed for studying the implications of the second-generation ethanol supply chain.
v. The research is based on the “National Determined Contributions” known as NDCs.The NDCs should adhere the 2030 climate goal commitments both in national and international level.

6.3.1 Inputs for decision-making and policy formulation

The proposed research aims to establish commercially viable projects for 2G ethanol production. Also, remunerative income to farmers will be provided for their waste agriculture residues. Climate change mitigation and net zero carbon targets are the key issues worldwide. So, it is essential to address the concerns of environmental pollution caused by burning biomass residues/waste. The goal is to help meet the targets envisaged in the blended ethanol petrol (EBP) program promoted by the government of India. The vision is to reduce fossil fuel imports by 10% [2]. Creating rural & urban employment opportunities is one of the factors the Indian government should look for and diligently contribute to maintaining the ecology cleaner by reducing food waste and landfills and burning biofuel feedstocks such as waste biomass and urban waste.

The other benefit of the proposed supply chain is the indigenization of second-generation biomass to ethanol technologies. As one option for countering cost competitiveness obstacles, some national and local governments have implemented tax credits to reduce EV purchase prices and make them more competitive with comparable IC engine vehicles [1]. Hence a subsidy for the farmers and customers using the ethanol blended petrol-based vehicle should be proposed.

6.3.2 Scope for further research

There is a considerable scope and many possibilities for this work's extension. In this section, we have presented some of those.

i. The proposed study's biofuel supply chain is based only on paddy and corn-based waste. In future, there will be an addition to the biomass types. Hence a broader idea can be developed regarding the sustainability assessment.
ii. In the downstream process, the corn cob to ethanol process has only been demonstrated in future. This technology will be extended to paddy straw and other biomass types, producing more yield.
iii. The intervention of IoT, data analytics or artificial intelligence is one of the aspects that has not been discovered in the present study. Each sub-system can be operated by one of the mentioned techniques, making the circular economy model an innovative circular economy model. The intervention of AI will enable the farmers and consumers to know the updated price of agro-residual yield, biofuel price. Such type of cloud-based interactions could be a future scope of the present study.
iv. The work will be collaborative as it tries to take the policymakers, decision-makers, and private and non-private organizations as a single entity and propose inputs that will benefit society.
v. Finally, the proposed research will not only be limited to ethanol. Instead, it will extend to the sustainability assessment with respect to methanol, dimethyl ether, and hydrogen.

6.4 Conclusion

The necessity for a cleaner fuel has given rise to alternate fuels like ethanol. In future, the ethanol produced by the scheme beneficiaries will be mandatorily supplied to Oil Marketing Companies (OMCs) to further enhance the blending percentage under the ethanol blending program (EBP). Apart from supplementing the targets envisaged by the government under the EBP program, the scheme will also have several benefits, such as meeting the vision of reducing import dependence by way of substituting fossil fuels with biofuels. Moreover, to achieve the GHG emissions reduction targets through progressive blending/substituting fossil fuels. They are also addressing the environmental damage caused due to the burning of biomass/ crop residues & improve the health of citizens. The farmer's income can be enhanced by providing them remunerative income for their otherwise wasted agriculture residues. One of the other goals is to create rural & urban employment opportunities in 2G ethanol projects and biomass supply chain and indigenize of second-generation biomass to ethanol technologies.

This work describes the importance of closing the loop for the second generation - based ethanol supply chain. An energy modelling is performed to find out the viability of the project by implementing data science. It is one of the innovative work in the areas of sustainability where the analysis has been established through data science. We believe the present research has made a strong beginning and produced exciting findings and insights. These will motivate future researchers to contribute more significantly to this specific research agenda.

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