An Empirical Study on Factors Influencing Purchase Intention of Ethanol Blended Fuel Leading to Promoting Sustainable Cities

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Thesis submitted in partial fulfilment for the Award of Degree

Doctor of Philosophy

by

SANTANU GUPTA

RAJIV GANDHI INSTITUTE OF PETROLEUM TECHNOLOGY
Jais, India - 229304

PM1910 **2024**

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CERTIFICATE

It is certified that the work contained in the thesis titled "***An Empirical Study on Factors Influencing Purchase Intention of Ethanol Blended Fuel Leading to Promoting Sustainable Cities***" by "***Santanu Gupta***" has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

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Supervisor

Professor Sanjay Kumar Kar

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I, "Santanu Gupta", certify that the work embodied in this thesis is my own bona fide work and carried out by me under the supervision of Prof. Sanjay Kumar Kar from August 2019 to May 2024, at the Rajiv Gandhi Institute of Petroleum Technology, Jais.

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It is certified that the above statement made by the student is correct to the best of my/our knowledge.

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Prof. Sanjay Kumar Kar

Supervisor

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Dr. Jaya Srivastava

Head of Department

Department of Management Studies

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CERTIFIED that the work contained in the thesis titled "***An Empirical Study on Factors Influencing Purchase Intention of Ethanol Blended Fuel Leading to Promoting Sustainable Cities***" by ***Mr. Santanu Gupta*** has been carried out under my supervision. It is also certified that he fulfilled the mandatory requirement of TWO quality publications that arose out of his thesis work.

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ABSTRACT

India currently satisfies 87.7% of its crude oil requirements through imports. Despite comprising 17.84% of the global human population, India possessed only 2.4% of the global surface area and accounted for about 6% of global primary energy consumption as of 2022. As conventional energy reserves continue to deplete, there has been a concerted effort to explore alternatives to fossil fuels in multiple sectors including transport sector. Recognizing the imminent energy challenges, Indian policymakers have implemented multiple strategic initiatives to integrate renewable energy into the country's energy systems.

India has undergone rapid industrialization, elevating it to the status of the world's third-largest energy consumer. Among the sectors propelling this heightened energy consumption, the transportation industry assumes a significant role. In the fiscal year 2023-24, India experienced a notable upswing in petroleum consumption, reaching a record high of 233 million metric tonnes (MMT). However, the country's crude oil production remained at 29 MMT during the same period, resulting in a substantial dependence on imports.

To reduce its reliance on crude oil imports, the Indian government has been actively promoting ethanol as a renewable fuel alternative for several years. India started blending ethanol in petrol on a pilot basis in 2001. It mandated the blending of 5% ethanol in nine states and four union territories with a Rs 0.75 excise duty exemption in 2002. Despite the introduction of policies supporting the ethanol blended petrol program since 2003, India struggled to meet the targets until the introduction of the National Biofuel Policy in 2018. This policy incorporated several modifications and aimed to address the shortcomings of previous efforts. National Biofuel Policy-2018 created provision for a viability gap funding scheme for 2G ethanol Bio refineries of Rs.5000 crore in 6 years in addition to additional tax incentives and a higher purchase price as compared to 1G biofuels. Such incentives were critical for removing ethanol production and supply constraints. The Central Government

has taken steps on pricing, incentives, and an opening alternate route for ethanol production to increase the availability of domestic ethanol. Remunerative prices of ethanol to suppliers have resulted in manyfold increase of ethanol, giving a significant boost to farmers' income.

India achieved 10% ethanol blending with petrol in 2022 and target of 20% ethanol blending on sight by 2025-26. India has already made the crucial start to reach 10% ethanol blends and can learn from various public and private endeavours in Brazil to push for a higher share of ethanol in the transportation sector.

The global population has undergone a significant shift towards urban living, surpassing the 50% threshold in 2007. In 2022, the urban population constituted 56.5% of the global total, and the United Nations projects that by 2050, this figure will reach 68%. Higher urban population puts severe pressure on facilities and amenities of the cities. Especially, the city transport system faces incredible stress.

Despite accommodating most the world's population, urban areas occupy a mere 2% of the total land area. Cities wield substantial economic influence, contributing to approximately 70% of the global gross domestic product. However, this economic weight comes with notable ecological impacts. Cities are responsible for the consumption of about 70% of global resources and energy production, emitting 70% of all greenhouse gases, and generating approximately 70% of global waste. Therefore, cities should be sustainable as per the UN SDG-11.

The UN Department of Economic and Social Affairs recognizes that development trends associated with urbanization are "crucial to the implementation of the 2030 Agenda for Sustainable Development". Similarly, the European Union acknowledges the pivotal role of cities in the transition to sustainable, low-carbon societies and in addressing the challenges posed by urbanization.

The literature on ethanol fuel is largely focused on engine efficiency measurement, feasibility studies, compression ratio and performance issues, combined use of ethanol and hydrogen among others. This shows that studies on behavioural perspective of consumers are missing. Ethanol fuel is ultimately used by general consumers mostly in transport sector. Benefits and issues of ethanol fuel adoption are directly faced by them. Higher adoption of ethanol requires deeper understanding of the challenges associated with the fuel and the consumers intention to use. Therefore, researchers should focus appropriately on the consumer aspect of the same. This may uncover significant findings and help bridge the gap between policy and consumer's issues, needs and wants. Therefore, to fill this gap in the literature, we focus on consumers intention to use ethanol.

As policies are important to the ethanol blended fuel consumption, therefore, we incorporated this construct in the study to examine the role of policy in consumers intention to use ethanol. Further, the dependent variable of promoting sustainable cities was employed as usage of Ethanol fuel may also result in consumers intention to promote sustainable cities which is fundamentally important to achieve sustainable development goals (SDGs). Concept of sustainable cities is futuristic in nature and may be seen as an ideal scenario but its inception in minds of consumers is crucial. This may result in multiple behavioural changes. Therefore, promoting sustainable cities is studied. Further, any technological change is perceived as risk among consumers due to inexperience with it. Therefore, we incorporate risk perception as a construct in the study to analyse its dynamics with purchase intention.

Infrastructure is crucial for widespread use of any new fuel. Multiple changes in machines like fuel dispensers maybe along with the changes in engines especially the older vehicles which may lead to challenges to generate sufficient efficiency levels compared to the non-blended fuel. Therefore, we incorporate infrastructure construct. Further, purchasing ethanol blended fuel may also be influenced by consumers view of promoting United Nations SDGs. Therefore, this construct is also included. As using ethanol fuel may result in lower fuel efficiency, analysing cost perception and purchase intention becomes important. The linkage between consumers cost concerns and purchase intention was examined. Consumers may or may not get motivated to adopt ethanol blended fuel despite policy implementation. Therefore, motivation for consumers intention to use ethanol needed an investigation, so this construct was included in the model. Motivation is important and may be useful for future policy measures.

Research objectives:

- To identify factors influencing purchase intention of ethanol blended fuel.
- To provide policy recommendation for stakeholders for faster adoption of ethanol.
- To analyse the linkage between purchase intention and promoting sustainable cities.

The data was collected using a structured questionnaire with quantitative approach on potential adopters of ethanol blended fuel in India. A sample of 309 respondents were collected from Indian consumers using a convenience sampling. All geographical region of India were given proportional representation. The sample also adequately represented all age group above the age of 18. We employed the partial least square - structural equation modelling (PLS-SEM) to analyse the data using Smart PLS-4 software.

The results confirm that motivation is a significant predictor of purchase intention signifying that consumers motivation to use ethanol blended fuel results in purchase intention. Further, policy initiatives also significantly influenced the purchase intention. Therefore, policy plays an important role in shaping consumers purchase intention of ethanol blended fuel. SDGs positively influenced purchase intention depicting its importance among consumers. Purchase intention of ethanol blended fuel significantly influences promoting sustainable cities.

Dedicated To

My Parents, family and Teachers

For their never-ending blessings

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(Santanu Gupta)

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ABBREVIATIONS

S. No.	Abbreviation	Description
1	BPCL	Bharat Petroleum Corporation Limited
2	CO	Carbon Monoxide
3	COP	Conference of Parties
4	DFPD	Department of Food and Public Distribution
5	EMS	Engine Management System
6	EBP	Ethanol Blended Petrol
7	1G	First-Generation
8	FFV	Flexible Fuel Vehicle
9	GVA	Gross Value Added
10	HTMT	Heterotrait- Monotrait Ratio
11	HC	Hydrocarbons
12	IOCL	Indian Oil Corporation Limited
13	IPO	Initial Public Offering
14	INDC	Intended Nationally Determined Contributions
15	ICCT	International Council On Clean Transportation
16	ITC	Investment Tax Credits
17	MMT	Million Metric Tons
18	NPB	National Policy On Biofuels
19	OMCs	Oil Marketing Companies
20	Nox	Oxides Of Nitrogen
21	PLS	Partial Least Square
22	PLS-SEM	Partial Least Square Structural Equation Modelling
23	PM JI-VAN	Pradhan Mantri Jaiv Indhan -Vatavaran Anukool Fasal Awashesh Nivaran
24	PTC	Production Tax Credits
25	PI	Purchase Intention
26	RFS	Renewable Fuel Standard
27	2G	Second Generation
28	SC	Sustainable Cities
29	SDG	Sustainable Development Goals
30	TRQ	Tariff-Rate Quota
31	WEFL	Water-Energy-Food-Land

CHAPTER 1

INTRODUCTION

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INTRODUCTION

1.1 Context to the research

Climate change concerns have been increasing getting prominence across the globe. In the context of climate risk and energy transition, cleaner energy options are seriously explored across the continents. Clean energy transition is no longer a buzz word rather operating principles for numerous economies. In the context of Intended Nationally Determined Contributions (INDC) multiple nations like India are fully committed to implement strategies and policies to cut down emissions. Recently, in the Conference of Parties (COP) 28, the stakeholders fully appreciated the standpoint of transitioning away from fossil fuel. Even under the presidency of India the G20 countries agreed to focus on renewables. Energy transition pathways clearly identifies role of cleaner fuel like biofuel to reduce emissions. Recognizing the importance biofuel, the G20 countries advanced the idea of International Biofuel Alliance. Economies like United States of America and Brazil have made considerable progress to fast-track integration biofuel into the energy systems, especially in the transport sector. In the ambitious global biofuel economy, ethanol plays a very important role. For instance, Brazil has created a successful business model for biofuel adoption. Brazil has successfully implemented its Biofuels program to such an extent that more than half of its Gasoline requirement is satisfied by Ethanol. A review of the available literature points out that the success of Ethanol in Brazil can be accredited not only to the policies and regulations of the government but also to the fervent participation of the auto manufacturers in developing the technology to drive flex-fuel technology. The auto part suppliers had a decisive role in developing and implementing this technology in the country. They persuaded not only the government but also other silent members of the industry.

India has already made the crucial start of introducing low-level ethanol blends and can learn from various public and private endeavours in Brazil to push for a higher share of Biofuels in the transportation sector. Riding on the success story of the biofuel integration into the energy systems, India ambitiously targeted to replicate Brazilian biofuel success story, albeit in an indigenous way. India has an immense potential to harness domestic biofuel resources and increase share of biofuel adoption in the country. A greater adoption of biofuel in the transport sector would address several challenges associated with India's energy value chain. In India's emerging biofuel economy, the promising options like bioethanol, bio-methane, and biodiesel must be fully explored and capitalized. The untapped opportunities for biofuel production and consumption are plenty.

The gross value added (GVA) through agriculture and allied sectors in total economy has been steadily declining through financial years 2020-2023. Still in 2022-2023, GVA agriculture and allied sectors was 18.3%. Renewed emphasis on biofuel economy could boost agriculture and renewable energy production in the country.

In the biofuel economy, role of ethanol requires scientific examination. The extant literature lacks scientific examination of factors influencing ethanol adoption in an emerging and growing economy like India. Further, empirical studies on the subject matter are far and few. Ethanol blending is key to success of greater integration of ethanol in the transport system. Therefore, the motivation of the study is to examine factors affecting consumers ethanol blended fuel purchase intention.

1.2 Research objectives and questions

The demand for ethanol blended fuel can be unpredictable, influenced by factors such as consumer preferences, global energy markets, and government policies. Consumer acceptance and willingness to pay a premium for ethanol blended fuel also play a crucial role in the success of the supply chain. Therefore, this study set the following objectives: (1) exploring key factors influencing consumers purchase intention of ethanol blended fuel; (2) examining the linkage between purchase intention and sustainable cities; and (3) discussing policy implications for stakeholders for greater adoption of ethanol blended fuel for sustainable cities. The motive behind this study is to identify and analyse the dynamics of ethanol blended fuel and sustainable cities. This includes assessing the impact of cost awareness, infrastructure knowledge about ethanol blending and sustainable cities, the role of policy incentives, risk perception and SDGs. With an objective to address challenges of sustainable city fuel consumption through effective policy measures, this novel research is the first of its kind to carry out a real-time survey of the Indian consumers to unearth the critical factors impacting consumers purchase intention of ethanol blended fuel.

To achieve the research objective, we developed following set of research questions:.

1. What are the important factors impacting consumers purchase intention of ethanol blended fuel?
2. How do the consumers purchase intention influence sustainable cities?
3. What role policy incentives play in consumers purchase intention of ethanol blended fuel?

1.3 Thesis overview

Subsequently Chapter-2 presents ethanol economy with broad coverage on evolution of ethanol economy, ethanol economy in India, challenges and opportunities associated with ethanol economy. Chapter-3 lucidly presents a critical assessment of the current body of knowledge with critical examination of the existing gaps in the extant literature. Further, the chapter presents theoretical framework, research model and formulation of hypotheses. Chapter-4 explains the research methodology adopted to conduct this research. Chapter 5 analyses the responses collected from the survey and presents the research findings. Section 6 advocates various policies which would enhance ethanol purchase intention leading to support sustainable cities. Finally, Chapter-9 highlights the limitations that future researchers could further address. Further, the chapter outlines topics for guiding future research.

CHAPTER 2

ETHANOL ECONOMY

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ETHANOL ECONOMY

2.1 Evolution of ethanol economy

India has become the 5th largest economy globally and is slated to become the 2nd largest by 2050. With the fast-expanding economy, the country's energy demands will continue to rise with the population growth, expansion of urbanisation, ever changing lifestyles and increasing disposable income. India currently imports about 87.7% of its oil. India's net import of crude oil was 233 million metric tons (MMT) at $ 132.4 billion in 2023-24. Crude oil import registered a nominal decrease growth of rate of 0.1% over the previous financial year. By the end of February 2024, crude oil import reached 212.6 MMT valued at $120 billion. Indigenous biofuels offers an opportunity for the country to cut down fossil fuel import dependency. To fulfil the Prime Minister’s ambition to reduce crude oil import and increase farmer’s income, indigenous energy solutions are yet to be fully explored and exploited. Biofuel is considered as a renewable, sustainable, and indigenous solution to address sustainability as well as energy security challenges. Biofuel could play a great potential solution to deal with surging fossil fuel import. Further, biofuel could strengthen utilization domestic resource, support agriculture, boost farmer’s income, and create millions of direct and indirect employments across its value chain and associated industries. Biofuel certainly poised to play a critical importance in the, “Atmanirbhar Bharat”, “Make in India” and “Swachh Bharat” initiatives. It promote ‘Waste to Wealth’ generation with added advantage of clean environment and creating circular economy.

Predominant and popular biofuels are: (1) Ethanol, (2) Biogas, and (3) Biodiesel. There green fuels are not only environmentally desirable but also these are extremely useful for boosting GDP. The biofuel economy strongly supports the growth of the energy crops in the country. Further, biofuel economy favourably supports additional market opportunities for sugarcane, corn, oil seeds, and rice straw, and wheat straw. For an energy import dependent country, the prosperity of the biofuel economy is strongly linked with the international fossil fuel prices, global/regional geopolitical dynamics, domestic agricultural productivity, and supporting national/state government policies.

Ethanol: This is the most extensive form of biofuel used worldwide. It is generally produced from crops such as corn, sugarcane, wheat, and foodgrains. Ethanol could be blended to petrol/gasoline. Generally, as ethanol a fuel additive could be blended (E10, E15, E20, etc.) or could be used as a standalone fuel in flex-fuel vehicles.

Ethanol naturally produced by the fermentation of sugars by yeasts or via petrochemical processes such as ethylene hydration. Ethanol has multiple applications including medical applications as an antiseptic and disinfectant. It has use in the chemical industries as a chemical solvent and in synthesising organic compounds. Ethanol's application as a fuel or feedstock makes one of the most desired products in the market. Its simpler production processes make it acceptable across the value chain.

2.2 First generation ethanol

First-generation ethanol is produced from sugar and starch. Ethanol is generally produced by enzymatic reaction through the fermentation of sugars or starches, or cellulose. First-generation bioethanol is produced via "yeast (*Saccharomyces cerevisiae*) fermentation of plant sugars and starches obtained from crops such as sugarcane, sugar beet, and corn". First-generation ethanol faces the challenge of food security. Many researchers argue that first-generation ethanol is less cost-competitive compared to fossil fuel. First generation ethanol production is too dependent on food crops (i.e., corn and wheat), which pose serious threats to food security and rising food prices. Further, first generation ethanol activates a debate of food-water-energy nexus. Despite several benefits first-generation ethanol interfaces multiple roadblocks, therefore hindrances in faster adoption. The ffirst-generation ethanol faces increasing resistance from environmentalists and social activists. Therefore, focus gradually shifts towards more sustainable bioethanol.

2.3 Second generation ethanol

Second Generation (2G) bioethanol is produced from agricultural residues (i.e. wheat straw, rice straw, and barley straw) and by-products, organic wastes, etc. Second generation ethanol production has potential benefits for many beneficiaries like farmers, producers, and consumers. The 2G ethanol is poised to boost rural development through employment and additional revenue generation for farmers. The use of second-generation technologies for bioethanol production is a much better sustainable option that potentially offer the advantages of additional employment generation, addressing energy security concerns, improved socioeconomic development, and access to affordable energy services to consumers with efficient land utilization (Prasad and Ingle, 2019). Therefore, bioethanol production chain should successfully integrate the water-energy-food-land (WEFL) Nexus proposal (Machado and Abreu, 2024).

Government of India has notified the "Pradhan Mantri JI-VAN (Jaiv Indhan - Vatavaran Anukool fasal awashesh Nivaran) Yojana" for providing financial support to integrated bio-ethanol projects for setting up Second Generation (2G) ethanol projects in the country using lignocellulosic biomass and other renewable feedstock. Under the PM JI-VAN Yojana, commercial project developers could avail financial support of Rs. 150 crore per project. Similarly, an eligible project developer could avail central financial assistance of Rs. 15 crore per demonstration project.

Central Public Sector Enterprises are setting up paddy straw based 2G ethanol bio-refineries at Panipat (Haryana), Bathinda (Punjab), and Bargarh (Odisha). Assam is rich with bamboo resources, so bamboo based biorefinery is set up in Numaligarh (Assam). Indian Oil Corporation Limited (IOCL), the leading refiner and oil marketing company has set up a 100 kilolitres per day 2G Ethanol Plant at Panipat. The project has been set up using indigenously technology which convert paddy straw to ethanol. During the harvesting season of 2023, IOCL has collected more than 100,000 tons of paddy straw as feedstock for the Plant.

2.4 Third generation ethanol

Thus third-generation ethanol has the power to eliminate the food vs energy nexus. Algae emerged as a vital source of production of third generation biofuels, such as bioethanol, biohydrogen, and bio-propane (Sachin Powar *et al.*, 2022). Microalgae are photosynthetic microorganisms which uses sunlight, water, and carbon dioxide to produce sugars, which would be a useful feedstock for producing bioethanol. Ethanol produced from off gases through the gas fermentation process is also termed as third-generation ethanol. A plant has been set up at IndianOil's Panipat refinery to process refinery off-gases to produce 128 kilolitres per day of ethanol.

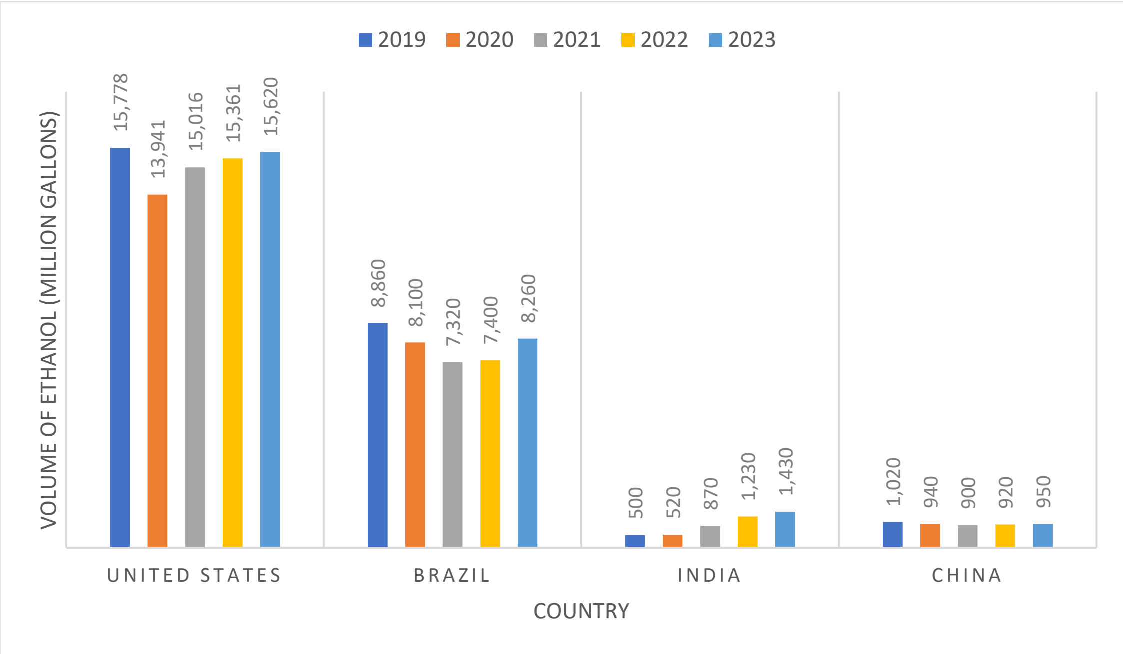
2.5 Global ethanol production

United States dominates the global ethanol production with a share of 53% of the global production in 2023 (***Table 2.1)***. Brazil occupies the 2nd position with 28% share followed by European Union, India, China, Canada, Thailand, and Argentina. India has overtaken China in terms of ethanol production (***Figure 2.1***). Global push for low carbon fuel is clear from renewed interest in biofuel like ethanol. Global ethanol production is gradually returning to the pre-covid levels. Ethanol industry strives to achieve reduction in emission levels. Ethanol can help to cut down emission by 52 percent compared to gasoline. Therefore, ethanol is an immediate solution for decarbonizing transport sector.

Table 2.1: Global ethanol production during 2019-2023 (million gallon)

Region	2019	2020	2021	2022	2023	% of World Production
United States	15,778	13,941	15,016	15,361	15,620	53%
Brazil	8,860	8,100	7,320	7,400	8,260	28%
European Union	1,380	1,330	1,410	1,460	1,440	5%
India	500	520	870	1,230	1,430	5%
China	1,020	940	900	920	950	3%
Canada	497	429	434	447	460	2%
Thailand	430	390	350	370	370	1%
Argentina	290	210	270	310	300	1%
Rest of World	645	620	680	722	760	3%
Total	**29,400**	**26,480**	**27,250**	**28,220**	**29,590**	

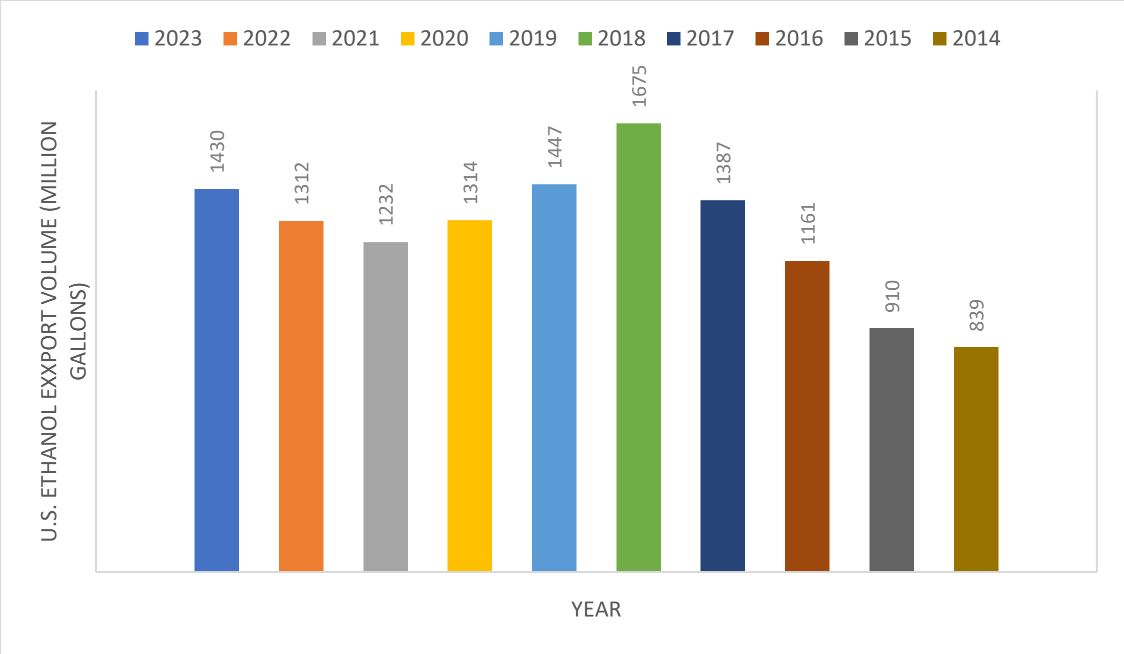
Source: Renewable Fuels Association



Source: Prepared by the author based on the data of Renewable Fuels Association

Figure 2.1: India among the top ethanol producers.

United States commitments to reducing GHG emissions and improving air quality created plethora of opportunities for U.S. ethanol on a global scale. Global ethanol demand recovery was driven by new normal in the transport sector. in 2023, United States exported 1.43 billion gallons ***(Figure 2.2)*** valued at $3.82 billion.



Source: Prepared by the author based on the data of Renewable Fuels Association

Figure 2.2: Ethanol export from United States

Brazil has fairly established its bioethanol applications especially in the transport sector. Bioethanol has been an integral part of energy policy of multiple nations like Brazil, United States, and India. Ethanol features in Brazil's National Energy policies over several decades. Brazil an ethanol mandate of 27% ethanol blended gasoline (E27) which supports faster adoption of ethanol in the country. The light-duty fleets use Pure E100 "hydrous ethanol". There is absolutely no market for unblended gasoline in Brazil. Further to support import of ethanol import to Brazil, "no tariff-rate quota (TRQ) and import duty are applied to ethanol imports". Just behind United states Brazil remains as the 2nd largest producer and consumer of ethanol in the world. Brazil national energy policy purposefully promotes production and consumption of biofuel with special focus on continuous of fuel supply. RenovaBio incentivizes the producers of biofuel to support the biofuel economy in Brazil.

The U.S. being the largest producer of the ethanol means it is one of the world's largest producers of high-protein, low-cost feed for livestock, poultry, and other animals. In 2023, biorefineries were responsible for supplying 35 million metric tons (MMT) of distillers grains and corn gluten feed/meal. United States exported 10.8 MMT of distillers grains ***(Figure 2.3)*** valued at $3.3 billion in 2023. About 5.4 MMT of distillers grains shipped to "Mexico, South Korea, Vietnam, and Indonesia".

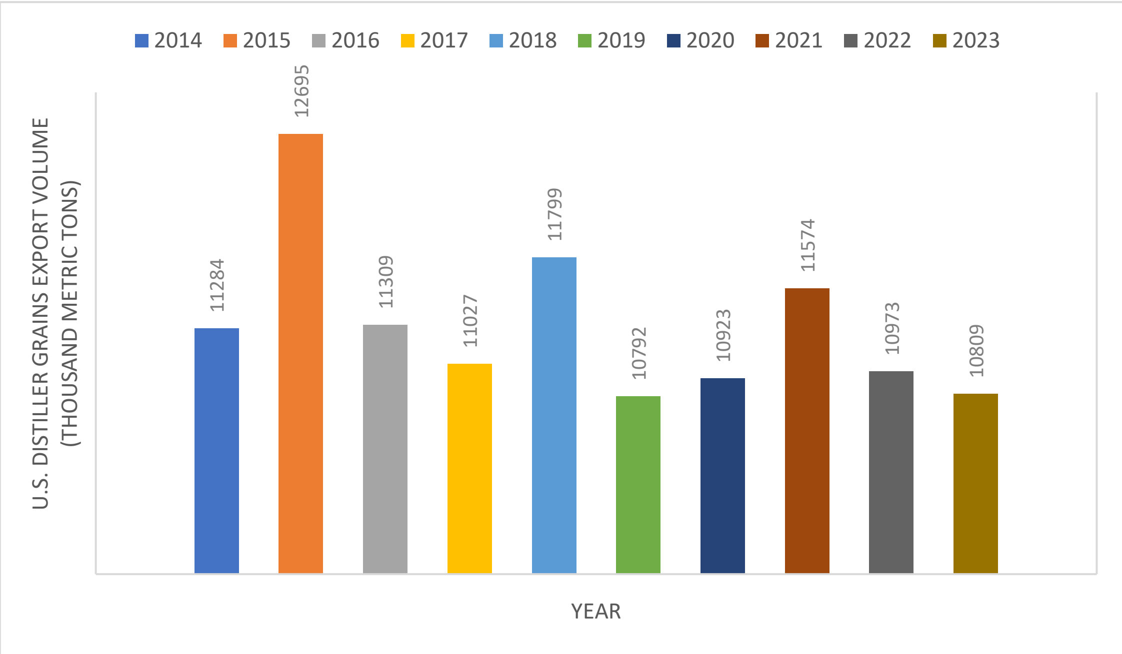


Figure 2.3: Distiller grains export from U.S (2014-2023)

Canada was the single largest ethanol export market for United States in 2023. The United Kingdom occupied the 2nd position followed by European Union, South Koreas, India, Colombia, Mexico, Peru, Philippines, and Jamaica. The United Kingdom's introductory mandatory ethanol blend policy forced them to import more to meet the domestic demand resulting in higher imports from U.S. Owing to a greater push for ethanol blending, India emerged as the 5th largest ethanol export market for the United States (***Table 2.2***). In 2023, India registered a 27% growth of ethanol import from the

United States over the previous year. Indian ethanol market is expected to prosper in the years to come. India's appetite for ethanol will continue to excite exporters from U.S.

Gulf of Mexico was the major export route in the United States. It was observed that the shipments to Canda was significantly routed through the Detroit gateway. Shipments were also channelled through the Pacific Northwest, Northern Tier, and East Coa.

Table 2.2: Top ten ethanol export market for U.S.

	Den. Fuel	Und. Fuel	Den. Other	Und. Other	2023 Total	2022 Total	Change (%)
Canada	590.6	1.6	34	12.4	638.6	503.5	26.8
United Kingdom	87.1	72.9	0	0	160	66.8	139.5
European Union	63.4	50.9	0.4	12.9	127.6	125.3	1.8
South Korea	34.5	35	7.2	17.8	94.5	153.8	-38.6
India	27.2	24.7	5.9	34.9	92.7	72.8	27.3
Colombia	18.9	45.3	1.7	7.3	73.2	10.3	610.7
Mexico	1.1	25.2	4.6	22	52.9	63.3	-16.4
Peru	21.9	26	4.5	0	52.4	38.9	34.7
Philippines	5.5	20.7	0	3.8	30	41.7	-28.1
Jamaica	1.3	19	5.3	0	25.6	24.2	5.8

All figures are shown in the table are millions of gallons, unless otherwise noted.

Source: Renewable Fuels Association

Biodiesel: It is made from vegetable oils, animal fats, or recycled cooking oil. Biodiesel can be used in diesel engines without modification and is often blended with diesel (B20, B5, etc.). Brazil mandated 10% biodiesel blending to support adoption of biodiesel. Brazil is the 3rd largest biodiesel producer just seating behind Indonesia and the United States. Brazil has over 316 biofuel plants (269 sugarcane ethanol plants, 6 sugar and corn ethanol plants, 01 cellulosic ethanol plant, 05 corn ethanol plants, 32 biodiesel plants, and 03biomethane plants). Another 12 plants were expecting required certification. Brazilian government regulates biodiesel production.

Biogas: Produced from the anaerobic digestion or fermentation of organic matter, such as agricultural waste such as rice straw/wheat straw, coconut fibres, sewage, press mud, organic waste, landfill waste, energy crops like Napier grass, animal waste, etc. Biogas is primarily methane and can be used for heating, electricity generation, or as a vehicle fuel (known as Compressed Bio Gas - CBG)). Like ethanol biogas has immense potential to transform the energy value chain in India. Considering, the importance and role of biogas, government strongly pushes for integration of biogas into the existing energy system. Biogas offers sustainable and indigenous energy solutions that strengthens the local ecosystem with immense scope for employment and entrepreneurship. However, biogas faces multiple challenges like availability of feedstock, management feedstock supply chain, technology, trained manpower, investment for risk capital, and desired policy support. Managing multiple stakeholders with varied interest and expectation is big challenge. On the contrary, it offers immense opportunity to diversify energy mix with fair amount of control over the value chain. Further, biogas has higher economic and social impact with potential energy independence, rural employment, job creation.

2.6 Status of ethanol economy in India

Learnings from Brazil offers vital takeaway points for India to make its ethanol Blending Programme successful. India started blending ethanol in petrol on a pilot basis in 2001. It mandated the blending of 5% ethanol in nine states and four union territories with a Rs 0.75 excise duty exemption in 2002. Before the mandate, studies on the feasibility of ethanol blending with petrol started in the 1970s, while IOC initiated trials in 1980.

The ethanol was produced from molasses, a by-product during the process of making sugar from sugarcane. However, despite the potential, no significant progress was made under the ethanol programme, and ethanol production stagnated until recently, when transformative reforms were carried out. The results are set to help not only the economy but transform farmers' income and recharge the rural economy. The critical policy that substantially boosted ethanol production was the introduction of the "National Policy on Biofuels in 2018".

India's biofuel policy reflects the government's long-term commitment to expanding sustainable and renewable energy sources. It aims to build a favorable business environment for attracting investment, encouraging research, and development in the biofuels sector.

Salient features of the National Policy on Biofuel-2018 are listed below-

- ***Categorisation***: The Policy categorises 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., to enable the extension of appropriate financial and fiscal incentives under each category.

- ***Scope of raw materials:*** The Policy expands the range of raw materials for ethanol production by allowing the use of Sugarcane Juice, Sugar containing materials like Sugar Beet, Sweet Sorghum, Starch containing materials like Corn, Cassava, Damaged food grains like wheat, broken rice, Rotten Potatoes, unfit for human consumption for ethanol production.

- ***Protection for farmers:*** Farmers are the most vulnerable link in the biofuel value chain. They are concerned about suitable and timely offtake of their produce with attractive price. Therefore, interest of the farmers should be adequately addressed. Taking this into account, the Policy permits ethanol production from surplus food grains for blending with petrol with the approval of the National Biofuel Coordination Committee.

- ***Viability gap funding:*** With a thrust on Advanced Biofuels, the Policy calls for greater integration of biofuel into the energy system. To induce interest of the biorefineries the policy indicates a viability gap funding scheme for 2G ethanol producers. The policy provisions for Rs.5000 crore in 6 years to support biofuel production. The policy creates attractive tax incentives and a higher purchase price of 2G ethanol as compared to 1G ethanol.
- ***Boost to biodiesel production:*** The Policy encourages the establishing a strong supply chain for biodiesel production from "non-edible oilseeds, Used Cooking Oil, and short gestation crops".

The Government of India also fixed differentiated ex-mill prices, revised year-on-year basis, which were based on raw materials utilised for ethanol production. The government has also formulated several policies like the "Interest Subvention" scheme (2018) for augmentation of domestic ethanol production capacity. Oil marketing companies (OMCs) published an EOI to enter into a long-term bipartite agreement with dedicated ethanol plants in ethanol deficit states to procure Denatured Anhydrous Ethanol to further augment the production from grain-based distilleries. One hundred thirty agreements were signed under the EOI with supply capacities of 429 Crore Litres.

The National Policy on Biofuels (NPB) – 2018, further amended in May 2022, provides an indicative target of 20% ethanol blending under the Ethanol Blended Petrol (EBP) Programme in India by ESY 2025-26. Currently, petrol with a 10% ethanol blending (E10) being sold by various OMCs in India. The country has already achieved the 10% Ethanol Blending PAN India ahead of its schedule and is well on its way to achieving the 20% target by ESY 25-26.

2.6.1 Drivers of ethanol economy

The world is slowly transitioning to a 'Net-Zero Carbon emissions' era, especially after the recent COP28 summit in Saudi Arabia. Biofuels, particularly Ethanol, are a key alternative to replace carbon-intensive fossil fuels in the transportation sector. Ethanol is not only a cleaner fuel but is also plentily available in India and boosts the rural economy. The key drivers of the ethanol economy are: (a) energy transition, (b) availability of raw material, (c) employment opportunities, and (d) government policies.

(a) Energy Transition: India's emissions level of 2.7 Gt CO2e is primarily due to the industrial and power sectors. Around one-third of emissions come from the steel and cement sectors, followed by one-third from the power sector, and the rest from transportation and other sectors.

In the transportation sector, emissions are likely to peak by 2025, with cars, trucks, light commercial vehicles, and buses emitting high levels of CO2. Decarbonization in the transportation sector could happen through changes across three dimensions: economics and market variables, changes to the regulatory environment and vehicle parc, and the technology timeline. Across the mobility system, the biggest GHG producer, by far, is road transportation. Tailpipe emissions from cars, trucks and other vehicles make up 75% of all emissions from transportation activity, compared with 13% from aviation, 11% from maritime transport, and 1% from rail transport.

Decarbonizing the power, industrial, and transportation sectors are thus crucial for emissions abatement in India, as they constitute a significant portion of emissions. Shifting to renewable power generation, electrification of heating in industries, clean fuel (such as biofuels), better energy efficiency, and circularity in plastics can contribute to significant emissions reductions. The global transportation sector faces three significant challenges such as fossil fuels depletion, high volatility in crude oil prices and ever rising strong environmental regulations. Alternative fuels such as biofuel could partly address these issues. Due to ethanol's inherent advantages like lower emissions and a higher-octane number it is considered one of the most compatible alternative fuel for blending in petrol.

Ethanol as an automotive fuel reduces vehicular emissions, which is a crucial driver for the Ethanol economy. In India, vehicular emissions such as "Carbon Monoxide (CO), Hydrocarbons (HC) and Oxides of Nitrogen (NOx)" are regulated and monitored by the pollution control board. The use of ethanol-blended gasoline reduces these emissions. A summary of emission benefits with E10 and E20 fuels compared to neat gasoline is presented in ***Table 2.3***.

Table 2.3: Emission reduction for ethanol blended fuel

Emissions	**Unblended MS**	**Two-wheelers**		**Four-wheelers**	
		E10	**E20**	**E10**	**E20**
Carbon Monoxide	Baseline	20% lower	50% lower	20% lower	30% lower
Hydrocarbons	Baseline	20% lower	20% lower	20% lower	20% lower
Oxides of nitrogen	Baseline	No significant trend	10% higher	No significant trend	Same

Source: Compiled from published sources

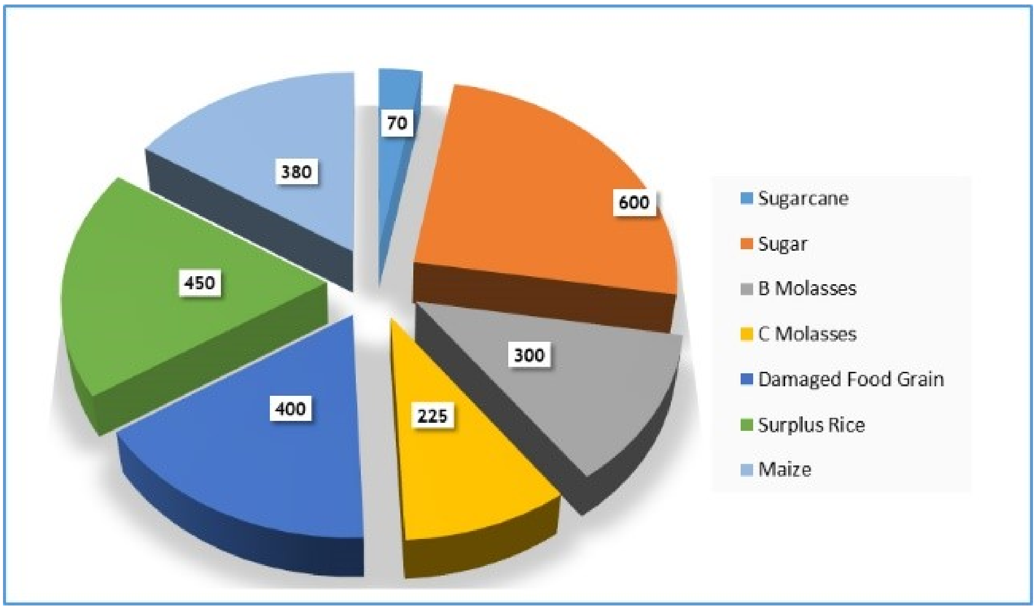
E20 ethanol blending achieves 50% lower CO emissions in two wheelers compared to unblended petrol/motor spirit. Four wheelers achieve 20% CO emissions reduction while using E20 over unblended petrol. Two wheelers and four wheelers registered 20% lower CO_2 emissions compared normal petrol.

Overall, ethanol blending program can help reducing emissions of road transport. As per a paper by International Council on Clean Transportation (ICCT), ethanol saves 52 g CO_2 eq/MJ of emissions. So, using the predicted value of 1016 Cr Litre of ethanol in 2025-26 will save around 11 MT CO_2 eq of emissions.

(b) Availability of raw material

First-generation (1G) ethanol is primarily produced from sugar cane juice, molasses, and sugar beet, etc. and starchy materials like corn, cassava, potatoes, rice, wheat, etc. 1G ethanol production is well supported by the country's large sugarcane industry. Easy convertibility of molasses into ethanol makes 1G ethanol production the most attractive option. Therefore, from commercial viability and raw material accessibility point of views molasses-based ethanol production is convenient and affordable. Sugarcane is a well-established cash crop in India, which lends strong support to feedstock availability for 1 G ethanol production. A 100 kilo liters per day plant utilizes annually 2 lakh tonne feedstocks to produce around 30 million litres of ethanol per annum.

The Department of Food and Public Distribution (DFPD) is the nodal department for promoting fuel-grade bioethanol refineries in the country. The government allows and supports sugarcane-based raw materials procurement for ethanol production. Ethanol production from various feedstocks such as sugar, surplus rice, damaged food grains, molasses and maize are given in ***Figure 2.4***. Sugar gives the best yield followed by surplus rice and damaged food grains.



Source: Expert Committee Report on "Roadmap for Ethanol Blending in India: 2020-2025"

Figure 2.4: Ethanol quantity (in Litre) per metric tonne of feedstock

As per the data provided by the Indian Sugar Mills Association, there are about 500 operational sugar mills which have capacities to provide around 440 Crore Litres of Ethanol. A brief on the Sugar mill industry in India is presented in ***Table 2.4***.

Table 2.4: Sugarcane and molasses production in India

Particulars	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21
No. of factories in Operation	526	493	525	532	461	506
Cane acreage (000 HA)	5284	4945	5042	5502	4841	5288
Sugarcane Production (Lakh Tonnes)	3369	3036	4110	4142	3440	4018
Molasses Production (000 Tonnes)	10873	9026	14063	13788	11526	14906

Source: Indian Sugar Mills Association

Currently, around 85% of ethanol is provided by the sugarcane industry. Efforts are being made to increase the capacities of grain-based distilleries to shift from water-guzzling crops of sugarcane and rice. As per the data published by the Ministry of Agriculture and Farmers' Welfare, the country has an excess of rice (2.43 MT) and foodgrains (5.45 MT) which can be utilised for ethanol production. ***Table 2.5*** presents target and achievements of major crop productions in India.

Table 2.5: Major crop productions in India

[Million Tons]

Crops	2016-17		2017-18		2018-19		2019-20*	
	Target	Achievement	Target	Achievement	Target	Achievement	Target	Achievement
Rice	108.5	109.7	108.5	112.76	114	116.48	116	118.43
Wheat	96.5	98.51	97.5	99.87	102.2	103.6	100.5	107.59
Nutri Cereals	44.35	43.17	45.65	46.97	48.1	43.06	48.3	47.48
Pulses	20.75	23.13	22.9	25.42	25.95	22.08	26.3	23.15
Foodgrains	270.1	275.11	274.55	285.01	290.25	285.21	291.1	296.65
Oilseeds	35	31.28	35.5	31.46	35.999	31.522	36.1	33.423
Sugarcane	355	306.07	355	379.9	385	405.416	385.5	355.7
Cotton#	36	32.58	35.5	32.81	35.5	28.042	35.75	35.491
Jute & Mesta@	11.7	10.96	11.7	10.03	11.2	9.82	11.2	9.906

**4th Advance Estimates* *@Million Bales of 180 kg. each* *#Million Bales of 170 kg each*

Source: Pocketbook of Agricultural Statistics 2020

(c) Employment opportunities

The government has taken several initiatives to increase ethanol production capacity. In the EOI scheme Dedicated Ethanol Plants alone 130 new plants are planned to be commissioned by end of FY-2024 which will contribute to the creation of thousands of direct and indirect employments. In another scheme, PM JI-VAN Yojana, 12 2G based Ethanol plants have been planned which will create hundreds of jobs in direct employment in the plant but thousands more in the entire value chain of biomass collection. Biomass collection is an enormously challenging task that requires efficiency across the supply chain. In the private sector also, the Indian Sugar Mills Association and Maharashtra Sugar Association have also planned several new and augmentation ethanol projects that will create new job opportunities.

According to the TIFAC 2018 report on "the estimation of surplus crop residues in India for Biofuel production", India generates 683 MT dry biomass from the major 11 crops. Out of this, 178 MT (26%) of biomass was found to be surplus, and of this 72% was generated in the Kharif season, 27% in rabi and 1% in the summer season. The surplus biomass provides an enormous opportunity to advance biofuel production, supply, and consumption in India. Agricultural states with surplus biomass have huge potential to convert waste-to-wealth. Biomass surplus states such Uttar Pradesh (17.68%), Punjab (17.31%), Maharashtra (14.22%), Gujarat (7.6%) and Haryana (5.6%) constituted 62.48% of the total annual surplus crop biomass in India. Therefore, these states have immense scope for advancing biofuel economy. Therefore, opportunities for investment in biofuel value chain in these states. Further, new avenues for developing biofuel industry that could support the conventional energy industry. Proper planning, investment, and policy support are crucial for harnessing this potential in a sustainable and efficient manner. It is suggested that a holistic approach involving stakeholders' government, industries, academia, and communities to realize the full potential of biomass for sustainable development. As usual the government should take the lead to engage the stakeholders in a productive manner to advance the biofuel economy for harnessing the domestic resources. Season-wise generation of surplus biomass from major crops in different states is given in ***Table 2.6***.

Table 2.6: Agri residue availability in India

Season	Crop	States
Kharif	Rice	Punjab, UP
	Sugarcane	UP, Maharashtra, TN, AP, Karnataka
	Cotton	Maharashtra, Telangana, Gujarat
	Soybean	Maharashtra, M.P, Rajasthan
Rabi	Wheat	Punjab, UP, MP
	Gram	Maharashtra, Karnataka, Rajasthan
	Rice	Bihar
	Rapeseed & Mustard	Rajasthan, Haryana

Source: Indian Sugar Mills Association

The total 178 MT of surplus crop biomass could be utilized to produce 51.35 billion liters (BL) of 2G ethanol. The ethanol production potential in the country ranged between 0.06 million liters (ML) and 9941 ML across the States. Out of the total annual bioethanol potential, 38.04 BL can be produced in the Kharif season and 13.08 BL in the rabi season. The maximum potential was found in the State of Uttar Pradesh , Punjab, Maharashtra, Gujarat, MP and Haryana have promising potential to produce ethanol. These 6 states account for approximately 69 % of the total annual bioethanol potential. During Kharif season UP, Punjab, Maharashtra and Gujarat show higher potential. On the other hand, Punjab, UP, MP, and Maharashtra possess higher potential in the rabi season.

Table 2.7: Potential for ethanol production from Agri wastes

Crop	Area (Mha)	Dry Biomass (MMT)	Surplus biomass (MMT)	Bioethanol Potential (Billion Liters)
Rice	44.360	225.487	43.856	12.017
Wheat	30.838	145.449	25.070	6.919
Maize	8.781	27.880	6.036	1.346
Sugarcane	5.037	119.169	41.559	14.629
Gram	8.484	26.515	8.724	2.172
Tur	4.113	9.167	1.755	0.446
Soyabean	10.694	27.779	9.950	2.935
Rapeseed & Mustard	5.869	17.085	5.157	1.495
Cotton	12.158	66.583	29.740	7.405
Ground Nut	5.474	12.900	3.873	0.848
Castor	1.185	4.604	3.017	1.134
All Crops	**136.994**	**682.618**	**178.738**	**51.348**

Source: TIFAC 2018 report

The potential for 2G ethanol presented in the TIFAC report estimates (***Table*** *7*) 51.35 billion liters of 2 G ethanol which translates 22% (w/w) for ethanol conversion in 2G plants. But the yield of 2G ethanol from fermentation of cellulosic sugars is dependent on the cellulose & hemicellulose content of biomass feedstock and technology. 2G ethanol licensors offer yields as low as 17%. Hence, considering 17%-22% yield, the ethanol production potential may fall in the range of 39 – 51 billion liters.

(d) Government policy

Government's commitment to clean energy transition automatically transpires proactive policy formulation, implementation, and monitoring to facilitate energy transition. Therefore, timely introduction of policies act as a driver to biofuel adoption. Policy has been a significant driver for ethanol blending in India, playing a crucial role in promoting the production and use of ethanol as a biofuel. The Indian government has formulated and implemented important policies and initiatives to encourage ethanol blending in petrol. These policies are primarily aiming for achieving energy security, reducing import dependence on fossil fuels, mitigate climate challenges, and supporting the agricultural sector. Here are some key policies that have driven ethanol blending in India:

National Biofuel Policy (NBP), 2018:

Mandated blending of ethanol with petrol to increase to 10% (E10) across the country. NBP-2018 sets targets to achieve 20% ethanol blending with petrol and 5% biodiesel blending with diesel by 2030, which was subsequently preponed to 2025-26. NBP-2018 created provisions for necessary fiscal incentives and supportive pricing mechanisms to promote ethanol production and blending. NBP-2018 encouraged the use of second-generation (2G) ethanol produced from biomass and crop residues.

Ethanol Blending Program (EBP)

EBP was introduced by the Government of India in 2003 to promote ethanol use in transport sector. Initially, EBP mandated 5% ethanol blending with petrol (E5) by 2006. The program has been progressively expanded, with targets increasing over the years.

EBP has been continuously monitored and revised to promote increased mandated blending percentages.

Pricing and Procurement Policies:

The government has fixed the price of ethanol to make it attractive for blending with petrol. Introduced a mechanism to link the price of ethanol with the price of petrol to ensure ethanol remains economically viable. Provided long-term purchase contracts to ethanol producers, offering stability and certainty in sales.

Ethanol Procurement by Oil Marketing Companies (OMCs):

OMCs are required to procure a certain percentage of ethanol for blending. Regular tenders are issued for the procurement of ethanol from domestic producers. The government has ensured timely payment to ethanol producers to maintain their financial viability.

Flex-Fuel Vehicles (FFVs):

Government introduced policies to promote the manufacturing and sale of FFVs capable of running on higher ethanol blends (such as E85). FFVs provide consumers with the choice to use higher blends of ethanol, encouraging the demand for ethanol.

2.6.2 Barriers to ethanol economy

Ethanol economy faces multiple barriers such as (a) technology, (b) investment, (c) rudimentary raw material supply chain, (d) stakeholders' alignment, and (e) lack of coordination between government bodies.

(a) Technology

The flex-fuel vehicles are intended to operate on any blend of ethanol and gasoline without distinction. Therefore, a **fuel recognition system** is required to accomplish this task. The **Engine Management System** (EMS) evaluates and automatically tunes the engine parameters for efficient operation. The **greatest challenge** in flex-fuel operation compared fix blends of E25 or E100 is to quickly detect and adjust the engine parameters according to changes in the gasoline-ethanol ratio. The first flex-fuel solutions used a **capacitive sensor** to detect this ratio before combustion, but these sensors were too expensive. A definitive answer was found in post-combustion detection of the gasoline-ethanol balance through an O2 sensor (also known as a **lambda probe**) installed in the exhaust system.

This technology was realised by a change in fuel flow (no fuel return), ensuring a smoother transition between the composition of "new" and "old" fuel, improving engine adjustment times. In addition, fuel detection without a capacitive sensor **reduced the total cost** of the fuel injection system. But the software that controls engine variables had to be significantly revamped. As a result, EMS contains approximately 20% more lines of code for learning algorithms, which adjust the operation to any use case not predicted during lab testing. Therefore, control software competence became the **main differentiating factor** of flex-fuel technology. Through this competence, manufacturers of flex-fuel injection systems compete among themselves, each with its own solution.

Ethanol has a higher knock resistance and thus can be utilised to enhance engine performance**. In addition**, its higher specific energy, flame speed, and molar ratio to reactants also contribute significantly to improving performance. Ethanol's high-octane benefit has permitted auto manufacturers to develop engines with **better compression ratios**, redesign pistons and cylinder heads, optimise combustion chamber geometry and design a new camshaft profile and phase which enhances thermal output. In this case, the ignition advance control calibration must also be optimised for ethanol. This requires spark plugs with a higher capacity battery and a colder heat range.

The maintenance requirements of ethanol engines are like gasoline engines and can even be lower due to ethanol's cleansing properties that reduces deposit formation. However, due to the **lesser calorific value** of ethanol, the engine requires a supply system with an increased flow capacity, fuel injectors with bigger holes and a fuel pump with an increased flow rate.

Ethanol places exceptionally high demands on fuel delivery components as its corrosive nature pose a risk to plastics, metals, and rubber parts. Therefore, **anti-corrosion materials** are used in any part that may come in touch with the fuel. The components include fuel injectors, pressure regulators, fuel tank, pump, and filter. In addition, the intake and exhaust valves and valve seats use new surface materials. The hoses, connectors and seals also need resistant materials, while the intake manifold and tail pipe need protection on internal surfaces.

The engine oil may also need to be reconfigured and a new additive package. **Special lubricants** can ensure long term durability, despite the harshness of ethanol and its combustion products. In addition, a specific catalytic converter, wash coating closer to the tailpipe manifold, and a recalibrated canister for higher purge flow may be needed.

Given the lower evaporative pressure of ethanol, the engine may require an auxiliary gasoline-assisted cold start system (for 85% & beyond) when **cold starting** the vehicle at temperatures below 15 °C. The system will have its own temperature sensor, gasoline reservoir, extra fuel injector and pump and a higher capacity battery.

During the years, advanced innovations have been incorporated into new ethanol-fuelled vehicles. The developments include new electronic fuel injection, electronic ignition control, engine designs, engine management, exhaust gas recirculation, catalytic converters, evaporative emission control, crankcase vapour recycling, turbocharging, and an on-board-diagnosis.

(b) Investment and Financing

Investment is a major concern in bioethanol value chain. A 2nd generation bioethanol plant size of 200 KL per day generally costs around Rs. 1800-2000 crore. Grain based 1st generation ethanol plant of the same capacity requires capital expenditure of Rs. 170 to 200 crores with a land requirement of approximately 20 acres. Considering India's 20 percent ethanol blending requirements a massive capital investment of around Rs.18,000-Rs.20,000 crore is required by 2025. Considering standard debt-equity ratio, capital requirement will be in the range of Rs. 10800 crores to Rs. 12000 crores. Large part of the investment is expected from the private players. Depending on the rising ethanol blending needs the investment in the bioethanol value chain will keep on increasing. An estimate of the government indicates that the investment may go up to Rs.40,000 crores in the near future.

The project developers traditionally have access to financing through debt funds and equity providers.

The debt financing could be accessed through banks, project financers, and bond market. Securing bank loans for risky long-term projects is challenging. Therefore, government brought in schemes such as interest rate subvention to reduce burden on the developers. Ethanol producers could approach the banks for funding their projects. So far, the ethanol production doesn't fall priority lending sector. Borrowers from the priority lending sector enjoy multiple advantages including lower interest rates, flexible terms, and government subsidies/incentives. Banks often offer loans at a lower rate to the borrowers from the priority sectors. Even such borrowers may get the flexibility of more time to pay the loan with lower collateral. Borrowers from the priority lending sector enjoy additional subsidies or incentives from the government.

Project Finance, specifically designed for large projects like ethanol plants. Project financers provide debt primarily based on the project's cash flow. The financers ignore don't assign much importance to the creditworthiness of the borrower.

Bonds: The ethanol project developers can access the bond market, by issuing bonds to raise capital to manage capital requirements. Revenue bonds are backed by the revenue generated from the ethanol plant.

Equity Financing:

Private Equity: Investors can provide equity funding in exchange for ownership stakes in the ethanol project. Established business houses may invest in the new projects through this route. The newer project developers or startups may look for such arrangements to meet their capital requirement.

Venture Capital: The venture capitalists look for promising opportunities for good return on their investments. They look for a strong management team, unique value proposition, scalability, and potential to exit. The ethanol producers are less likely to attract the venture capitalist. The startups in the technology domain are attracting many venture capitalists. However, for innovative 2G ethanol technologies, venture capital firms might be interested in investing.

Initial Public Offering (IPO): The IPO route is an option for raising fund, but it is not the not easiest mode for lesser-known firms. But for a large enough company venturing into ethanol production may opt this route.

Government Grants and Incentives:

Grants: Government agencies at the federal, state, or local levels may offer grants for renewable energy projects, including ethanol production.

Tax Credits: Renewable energy tax credits can significantly reduce the cost of ethanol production. These may include Production Tax Credits (PTC) or Investment Tax Credits (ITC).

To ease the capital requirement load and facilitate the operation of ethanol plants, the government offers interest subvention schemes. Current interest subvention scheme provides "interest subvention @ 6% per annum or 50% of rate of interest charged by banks/financial institutions, whichever is lower, on the loans to be extended by banks/financial institutions is being borne by the Central Government for five years including one-year moratorium".

Loan Guarantees: Government-backed loan guarantees can lower the interest rates on loans, making financing more affordable.

Strategic Partnerships and Joint Ventures:

Partnerships: Collaborating with other companies in the ethanol supply chain, such as feedstock suppliers, technology providers, or distributors, can bring in additional capital.

Joint Ventures: Sharing costs and risks with other companies through joint ventures can be an attractive financing option.

Crowdfunding and Peer-to-Peer Lending:

Crowdfunding Platforms: Online platforms allow individuals to invest in projects they believe in. The ethanol project developers may look at this innovative funding mechanism for meeting capital requirements or meeting operating expenses, including renewable energy projects like ethanol production.

Peer-to-Peer (P2P) Lending: Platforms that connect borrowers directly with lenders can be an alternative source of securing funds.

Investing in bioethanol production process is enterprising. The producers are careful about investing in bioethanol plants. The potential investors assess the ethanol demand, technology availability, feedstock availability at competitive price, and supportive government policies. Further, the potential investors critically examine the return on investment and profitability of the project.

The producers are guaranteed 60 percent offtake by the government, which can support the plants in their cashflow management. Further, assured offtake of bioethanol adds to the viability of the bioethanol plant.

(c) Rudimentary raw material supply chain

Supply chain of the bioethanol is rudimentary, which creates an immense challenge for the producers. Especially for the second-generation ethanol production, feedstock collection, storage, transportation, pre-processing, distillation, and purification are at very early stage. The supply chain is rudimentary stage; therefore, it lacks maturity and efficiency. Further, storage and distribution of ethanol demands better efficiency too. Feedstock collection from farmers is extremely challenging due to many factors. Efficient transportation and storage of feedstocks are crucial to cut down delays and spoilage. Therefore, the ethanol producers tend to achieve integration across the supply chain partners (e.g., farmers owning or contracting with biomass processing facilities). Efficient feedstock management impacts the financial feasibility of 2G ethanol production.

Therefore, every bit of improvement in the rudimentary ethanol supply chain would add to betterment of the ethanol economy.

(d) Stakeholders' alignment

In last 10 years, sugar mills generated additional revenue of more than ₹ 94,000 crores from ethanol sales which strengthened the financial conditions of the of sugar mills. Further, ethanol blending program resulted in sales of about 502 crore litres of ethanol, which led to saving of about ₹ 24,300 crores of foreign exchange. In the context of India's energy security and the role of bioethanol, the alignment of all the stakeholders like farmers, ethanol producers, oil marketing companies, and consumers. The government is well poised to bring this alignment in the common interest of the nation.

(e) Coordination between government bodies

The bioethanol production and marketing are connected to multiple ministries and government bodies. For example, production of sugarcane or any feedstock (i.e., food grains such as rice, wheat, maize, etc.) falls under Ministry of Agricultural and Ministry of Consumer Affairs, Food and Public Distribution. Ethanol production and marketing is directly related to the Ministry of Petroleum and Natural Gas. Also, other ministry like the Ministry of Environment and Forests relates to Bioethanol. Considering a complex bioethanol value chain and jurisdiction of multiple ministries and government departments, the level of coordination becomes a bottleneck. Successful ethanol blending requires coordination among the stakeholders at central and state levels, which is incredibly challenging.

2.7 Scope of ethanol as a fuel

By 2025, mandatory E20 blending, ethanol demand rise to 1016 crore litres. Therefore, the worth of the ethanol industry will jump by over 500% from around Rs. 9,000 crores to over Rs.50,000 crores. The ethanol requirement year on year is projected progressively with the increased blending of 10% from ESY 2020-21 to 20% by ESY 2020-25 (***Table 2.8***).

Table 2.8: Projected Ethanol Demand in India

Ethanol Supply Year (Dec to Nov)	Projected Petrol Sale (Crore Litre)	Blending (in %)	Ethanol Requirement (Crore Litre)
2021-22	4374	10	437
2022-23	4515	12	542
2023-24	4656	15	698
2024-25	4939	20	988
2025-26	5080	20	1016

Source: Expert Committee Report on "Roadmap for Ethanol Blending in India: 2020-2025"

Due to extremely supportive government policies, the supply of ethanol to Oil Marketing Companies (OMCs) has jumped 502 crore litres in Ethanol Supply Year (ESY) 2022-23 from 38 crore litres in ESY 2013-14. The blending percentage has increased significantly from "1.53% in ESY 2013-14 to targeted 12% in ESY 2022-23". Long term offtake agreement with producers is aimed at creating enabling conditions for the biofuel economy. Such a move would help the producers to limit their risk. Launch of flexi fuel vehicles would remove the demand side barriers, therefore the ethanol demand will continue to grow. Collective efforts of all the stakeholders will attract investment and boost employment, more importantly additional job opportunities in the ethanol value chain in the rural areas.

CHAPTER 3

SYNTHESIS OF LITERATURE

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SYNTHESIS OF LITERATURE

3.1 Analysis of extant literature

The extant literature on biofuels lifecycle present deep focus on energy and greenhouse gas emission ignoring other promising areas of research (Liu *et al.*, 2018). The ethanol consumption behaviour can be related to studies on electric vehicles, hybrid vehicles and broadly under the area of alternative fuel vehicles. Studying ethanol fuel for AFVs is important as it has been found to be the most used flexible fuel in vehicles many developed and emerging economies. Ethanol, also known as ethyl alcohol, is a transparent and colourless liquid capable of serving as a fuel for petrol (gasoline) vehicles. It is commonly blended with gasoline at various percentages, with commercialized options typically offering blends containing up to 85% ethanol by volume for use in gasoline vehicles (Meng, 2019; Vohra *et al.*, 2014).

Past studies focusing on flexible fuel vehicle like ethanol elaborated benefits of ethanol as a renewable fuel, reducing fuel consumption of gasoline, no mix of fuel sulfur and aromatics, knocking resistance, improved combustion, flexibility to use up to 10% of ethanol without any modification and reduction in GHG emissions on a life cycle basis (Ghadikolaei *et al.*, 2021). Further, some drawbacks have been identified which include costly, usage of edible feedstocks leading to food inflation, ignition issues in cold climates, engine modification requirement for using more than 10% of ethanol, reduction in fuel economy and limited global availability (Meng, 2019). Often ethanol as a fuel draws a considerable amount of debate due to intricacies of food-water-energy nexus. However, its multiple advantages including indigenous production, supply, easy applications, and local employment generation put it in the alternative fuel race.

In a study on South Korean consumers willing to pay for bioethanol products, researchers found that knowledge, attitudes towards the environment, gender, and income levels are key factors that have a notable impact on willingness to pay (Mamadzhanov *et al.*, 2019). A similar study focused on consumers in Brazil found that willingness to pay is significantly influenced by both knowledge about biofuels and income levels (Garcia *et al.*, 2022).

Factors such as vehicle cost, fuel expenses, infrastructure availability (including charging or refuelling stations), fuel taxes, vehicle performance, government subsidies for AFVs, environmental awareness and responsibility, public acceptance, knowledge about global air pollution and AFVs, and the types of AFVs available, among others significantly influence consumers' intentions and willingness to purchase vehicles (Bagheri *et al.*, 2021).

However, the degree of impact of each factor varies across different countries. These factors are identified from multiple literature reviews across alternative fuels including electric vehicle, biodiesel, hydrogen fuel cell and hybrid vehicle in recent past.

3.2 Literature gaps

There are plenty of literature on technical aspects of bioethanol. However, fewer studies are available on covering techno-commercial aspects of bioethanol. Further, limited studies are available on consumer adoption of bioethanol. A comprehensive study on examining the supply side and demand side is missing. This study which covers the critical aspects like stakeholder analysis and consumer intention to use bioethanol for sustainable cities offers newer scope and insights.

A comprehensive assessment through bibliometric study on biofuel (Hasan *et al.*, 2023) indicates that sustainable biofuel economy supports poverty reduction, supports agriculture development, enhances renewable energy productions, economic acceleration, climate mitigation, greenhouse gas emission reduction, technological innovations, and development. Biofuel offers sizable opportunities for farmers to boost their income through selling the agricultural wastes and byproducts. The development of the biofuel value chain substantially assists economic growth and enhances additional direct and indirect employment opportunities (Hartley *et al.*, 2019). Further, the biofuel economy facilitates efficient labour markets and effective mobility of human resource capital. Numerous other studies (Datta, 2022; Yimam, 2022) highlighted that modern biofuel value chain enhances socioeconomic well-being of farmers by ensuring a greater financial stability. Biofuel economy provides new avenues for income generation for multiple stakeholders across the value chain. However, the magnitude of benefits accruing to the stakeholders like farmers needs more scientific assessment across the regions. Broadly biofuel value chain allows farmers and their communities to take advantage of the emerging ecosystem. Further, at a macro level it opens trade opportunities and international collaborations. Even it offers potential opportunities for the less developed economies to boost their infrastructure to produce and export biofuels. In the recent years the scientist and researchers from India produces second highest numbers of scientific documents on biofuel, which is testament to researchers' interest to advance research on the subject to popularise biofuel adoption. However, most of these documents are on the technical side but research on adoption or intention to use biofuel are limited. Further, research on consumer adoption of bioethanol is scarce. **Table 3.1** presents summary of some of the important and relevant studies on biofuel.

Table 3.1: Existing relevant research on biofuel and research gaps

Title of the Research and Reference	Type of study & Findings	Research Gaps
"Fuel ethanol production from starchy grain and other crops: An overview on feedstocks, affecting factors, and technical advances"(Li *et al.*, 2022)	Review Starchy crops are the biggest contributor to bioethanol production.Ethanol production from starchy material is dependent on the starch content. By product DDGS adds to the viability of ethanol plant.	This is a review paper but doesn't cover the critical aspects like industry analysis, stakeholder analysis, and adoption intention.
"Road map for ethanol blending & prospective scope towards sustainable development in Indian scenario"(Singh Bisht *et al.*, 2023)	Ethanol can strengthen and support sustainability with social, economic, and environmental implications.	The paper left scope for examining the adoption of ethanol in the context of renewed interest in higher ethanol blending. Further, scope for understanding consumer adoption.
"Ethanol blending and its environmental impacts: A case study of India"(Azad *et al.*, 2024)	Case study Examines stoichiometry relation. E20 blending has significant environmental impact through reduced emissions.	The paper leaves an opportunity to assess the perceived impact of ethanol blended fuel on consumer purchase.
"Forecasting ethanol demand in India to meet future blending targets: A comparison of ARIMA and various regression models"(Dey *et al.*, 2023)	The paper used regression model to forecast demand. India will continue to face ethanol shortage to meet future blending targets. Suggested to take effective measures to address the shortage.	The paper didn't explore the challenges associated with the ethanol production, transport, and consumption. So, there are scope for further study to examine finer aspects linked to ethanol value chain.
"Ethanol for an agriculture-based developing economy: A computable general equilibrium assessment for Uganda"(Nakamya and Romstad, 2020)	Empirical: Static computable general equilibrium (CGE) model The paper investigates the impact of ethanol in a developing economy dependent on agriculture. Ethanol could improve trade balance. Ethanol projects are pro-poor.	The paper used computational model, which didn't account for critical parameters like stakeholders' engagement. It is important to understand the demand side through examining consumer perception and intention to use ethanol.
"The role of productivity and efficiency gains in the sugar-ethanol industry to reduce land expansion for sugarcane fields in Brazil"(Danelon *et al.*, 2023)	Sugar-ethanol mills might improve total factor productivity rising their scale of production – so merging for economies of scale.	The consumer adoption and demand side were ignored by the authors. So, there is a scope to investigate demand side.
"An assessment of sustainability metrics for waste-to-liquid fuel pathways for a low carbon circular economy"(Narayana Sarma and Vinu, 2023)	Biorefinery can reduce the wastage and improve the sustainability.	The paper advocates to examine the role of bioethanol for a low emission economy. There is scope for examining adoption of ethanol.

3.3 Theoretical framework

Theory of planned behaviour (TPB) and stimulus organism response (S-O-R) theory was used in the study. The construct of purchase intention was borrowed from TPB and acted as an organism in the SOR model. TRA and TPB have been used together to analyse ethical consumption behaviour (Yadav *et al.*, 2022).

The Theory of Reasoned Action (TRA) suggests that behaviour is determined by intentions. Initially designed for willful behaviour, it faced criticism for oversimplifying general behaviour (Liska, 1984). To address this, the TRA and TRA incorporated subjective norms and additional constructs. Subjective norms account for social influence on behaviour, complementing attitude. The mediating link, intention, is influenced by motivational factors.

The TPB extends TRA, incorporating purchase behaviour, behavioural intention, attitude, and subjective norm. TPB is extensively used to understand consumer behaviour in green contexts (Yadav *et al.*, 2024). TPB posits that attitudes reflect self-assessment, subjective norms indicate group pressures, perceived behavioural control represents ease or difficulty, intentions are internal confirmations, and behaviour is the final action, culminating in product purchase.

The SOR theory framework, rooted in environmental psychology, posits that the environment comprises stimuli (S) influencing individuals' internal or organismic states (O). These internal states then elicit approach or avoidance responses (R) from individuals (Wu *et al.*, 2021).

The SOR paradigm encompasses crucial aspects including attitudes, emotions, perceptions/feelings, judgments, beliefs, motivations, and thinking. To promote sustainable cities and enhance the purchase intention of ethanol blended fuel, this study specifically concentrates on organismic variables, namely the cost perception, risk perception, policy incentive, infrastructure, and SDG. Promoting sustainable cities was taken as final response.

3.4 Development of conceptual model

This conceptual model provides a framework for understanding the potential factors influencing consumers intention to purchase ethanol blended fuel that could lead to sustainable cities. The conceptual model presents potential relationship between the dependent and independent variables.

3.5 Hypothesis Formulation

3.5.1 Policy Incentive and purchase intention

The motivations and drivers behind environmental and ethical consumption have been a longstanding focus of consumer research (Ellen *et al.*, 1991). A variety of financial incentive measures, such as direct purchase subsidies and favourable tax policies, have been introduced to lower the cost of alternate fuels vehicles and incentivize increased adoption among consumers. Recently researchers found that favourable tax policies positively influenced the inclination for buying hydrogen fuel cell vehicles (Harichandan and Kar, 2023) . Various studies on the effects of financial incentive policies on the adoption and sales of electric vehicles have consistently demonstrated that these policies enhance consumers' willingness to embrace them (Langbroek *et al.*, 2016). Similar benefits could also be offered to ethanol fuel vehicles.

The adopting motivation is crucial for ethanol blended fuel purchase intention and sustainable cities. We have grounded this construct in the initial stage of buying process and awareness of ethanol blending. Therefore, posit the following hypothesis:

H1: Policy incentive has a significant impact on consumers its purchase intention.

3.5.2 Cost perception

Cost perception refers to an individual's subjective understanding or interpretation of the costs associated with a product or service. Studies have found that less knowledgeable consumers perceive ethanol to be costlier than conventional fuel (Broberg and Kažukauskas, 2021). Perceived value is contingent upon a passenger's subjective assessment of a price, which is influenced by the perceived quality relative to the price, rather than the absolute monetary value of the price itself (Jeong and Hyun, 2019). High-cost perception has been found to be a purchase barrier to green consumption (Niedermeier *et al.*, 2021).

Cost plays an important role in minds of consumer for any purchase decision. The role of cost in ethanol blending is yet to explored. We propose that cost perception can significantly influence the purchase intention of consumers, thereby affecting consumers' purchase intention. So, we develop the following hypothesis:

H2: High-cost perception impacts consumer's purchase intention of ethanol blended fuel.

3.5.3 Infrastructure Readiness

The higher price, engine issues, and limited infrastructure availability of alternative fuel, such as ethanol, are often cited as deterrents to consumer adoption (Ghadikolaei *et al.*, 2021). However, governments and alternative fuel manufacturers argue that the limited demand volume and relatively low consumer interest in purchasing alternative fuel vehicles contribute significantly to these challenges. While ethanol fuel offers environmental benefits and potential energy security advantages over traditional gasoline, its higher price and limited infrastructure availability present barriers to widespread adoption. If consumers show limited interest in purchasing ethanol-blended fuels, fuel suppliers may be less incentivized to invest in expanding ethanol infrastructure or increasing production capacity. This lack of demand can create a self-perpetuating cycle where limited infrastructure and higher prices deter consumers, further dampening demand. Ethanol can be used with 100% neat content if a proper infrastructure in terms of engine is provided as in Brazil (Meng, 2019).

Infrastructural readiness has been found to be an important determinant of alternative fuel purchase among consumers (Hardman *et al.*, 2018). Here infrastructure readiness mainly refers to engine and ethanol blending compatibility. It is relevant across several stages, from generating interest to the final decision-making. Infrastructure readiness is vital to purchase decisions especially for energy usage. Based on the literature review we generate the following hypothesis:

H3: Infrastructure readiness leads to consumer's purchase intention of ethanol blended fuel.

3.5.4 Motivation

Consumers' motivations, such as environmental concerns, cost savings, or government incentives, play a crucial role in shaping their attitudes and intentions towards purchasing ethanol blended fuel. An individual's desires (or needs) are shaped by their values and their influence on acceptance. Motivation represents the internal force that propels individuals toward fulfilling those needs. This impetus for fulfilment can be categorized into different dimensions, including social, environmental, or self-esteem influences. Prior research (Kang and Park, 2011) on electric vehicles (EVs) has underscored the pivotal role of motivation levels in the adoption of new technologies, particularly within the transportation domain.

Therefore, the following hypothesis is developed to check the linkage between motivation and purchase intention of ethanol blended fuel:

H4: Level of motivation impacts consumer's intention of buying ethanol blended fuel.

3.5.5 SDGs

Some studies explored conceptual linkages of biofuel economy with sustainable development goals (SDGs)(Hasan *et al.*, 2023). Linkage of SDG (Poverty alleviation) and biofuel economy was conceptually examined by multiple scholars (Costa and Oliveira, 2022). Therefore, they suggest considering the social life cycle when formulating and evaluating the overall sustainability of a national biofuels policy. It is fairly established that Water-Energy-Food- Land (WEFL) Nexus approach is essential for achieving the long-term SDGs (Machado and Abreu, 2024). The Nexus scenario (NS) looks to optimize cost, water, food, energy, and land demands in the integrated supply biofuel chain.

In the context of hydrogen adoption role of SDGs have been examined by multiple scholars. Authors have established positive linkages between adoption of hydrogen fuel cell vehicles and SDGs (Harichandan *et al.*, 2023). While research on the relationship between a hydrogen economy and the SDGs is limited, some generalizations can be drawn (Falcone *et al.*, 2021) (Falcone *et al.*, 2021). Studies (Pradhan *et al.*, 2017; Spaiser *et al.*, 2017) analysed collaborations, trade-offs, and contradictions among the 17 SDGs using time series data. Similarly, researchers (Weitz, N., Carlsen, H., Skånberg, K., Dzebo, A. and Viaud, 2019) employed a cross-impact matrix to explore these dynamics in the European Union.

SDGs may not always align directly with traditional purchasing processes, but their presence and alignment can strongly influence consumer interest and decision-making, especially for those who prioritize sustainability. It can also be a case with ethanol blending. As a result, the following hypothesis is formulated:

H5: SDGs significantly influences consumer's intention of buying ethanol blended fuel.

3.5.6 Risk Perception

Risk perception refers to consumers' perceived uncertainties about using ethanol fuel blends in their vehicles. Given that ethanol blending technology is still in its nascent stages, especially concerning engine fuel dynamics, it is relatively underdeveloped from the Indian standpoint (Kar *et al.*, 2022). Concerns about ethanol fuel potentially harming engine efficiency and longevity may weigh heavily on consumers' minds compared to other vehicle options. Consequently, a higher perception of risk is likely to lead to a reduced purchase intention (Chen *et al.*, 2012; Ma *et al.*, 2014). Past studies have demonstrated that consumers' willingness to adopt innovations is negatively influenced by their perception of risk (Itaoka *et al.*, 2017).

Risk assessment is a vital component during the evaluation and decision-making phases, particularly when contemplating the adoption of new technology. Consumers' perceptions of the risks linked to embracing new technology, such as concerns about reliability and financial risks, significantly influence their decision-making process. This impact is particularly noticeable among individuals who prioritize sustainability in their choices. Therefore, we hypothesize the following:

H6: Risk perception play a significant role on consumer's intention of purchasing ethanol blended fuel.

3.5.7 Purchase intention

The purchase intention of blended ethanol fuel may positively impact sustainable cities through emission reduction. Ethanol-blended fuels typically emit lower levels of pollutants compared to conventional gasoline, leading to improved air quality and reduced pollution in urban areas. This supports the goal of creating sustainable cities by promoting healthier living environments and mitigating environmental degradation (Escorcia Hernández *et al.*, 2023) Ethanol, derived from renewable sources such as sugarcane or corn, rice, and algae reduces reliance on finite fossil fuels and promotes the conservation of natural resources. By encouraging the adoption of ethanol-blended fuels, cities can contribute to sustainable energy practices and resource preservation (Sharifi *et al.*, 2024).

Ethanol production involves renewable feedstocks, fostering investment in renewable energy infrastructure and supporting the transition to a more sustainable energy mix. Increased purchase intention for ethanol-blended fuels drives demand for renewable energy sources, aligning with sustainability objectives (D'Adamo *et al.*, 2024). Ethanol production often involves local agricultural activities and processing facilities, stimulating economic development in rural areas. Ethanol production can boost local economy by increasing farmers income. It can certainly help local employment and entrepreneurial activities. By promoting ethanol-blended fuel consumption, cities can indirectly support local economies and contribute to balanced regional development. Ethanol fuel adoption encourages environmentally conscious consumer behaviour, fostering a culture of sustainability. This includes reducing greenhouse gas emissions, promoting energy independence, and supporting initiatives to address climate change, contributing to the long-term sustainability of cities (Escorcia Hernández *et al.*, 2023).

The following hypothesis intends to test the relationship between purchase intention and promoting sustainable cities:

H7: Consumer's purchase intention of ethanol blended fuel leads to promoting sustainable cities.

CHAPTER 4

RESEARCH METHODOLOGY

CHAPTER 4
RESEARCH METHODOLOGY

4.1 Mixed methods

This research adopted a mix method approach to better examine the problem in hand. Therefore, both qualitative and quantitative approaches were applied. A qualitative approach was used to identify certain variables useful to understand the consumers intention to purchase blended ethanol. Qualitative research integrated with qualitative methods offer a number advantages to researchers (Olaghere, 2022). Researchers combine elements of both qualitative and quantitative approaches enriching understanding of the problem and identify possible solutions. Mixed method supports better data corroboration (Johnson *et al.*, 2007); therefore it supports higher research outcome. Further, qualitative enquiry supports researchers to develop grounded theory. In fact quantitative research requires complementary support from qualitative research, these two are not diametrically opposite to each other (Olaghere, 2022).

Traditions are more complementary and connected than diametrically opposed and disconnected. Researchers call for ethics and reflexivity in mixed method to make the approach far more acceptable (Cain *et al.*, 2019). Multiple researchers established how the qualitative and quantitative methods effectively used improve research output (Bryman, 2006). Authors have shown ways to address anomaly in mixed methods (Biddle and Schafft, 2015). Mixed method helps better data triangulation along with analytical density (Fielding, 2012). Game heuristics helps interpret the qualitative material and interpret the quantitative model (Stolz and Lindemann, 2020). Mixed method adds value to management research (Molina-Azorín, 2011) and this approach used to answer research questions in management research (Heyvaert *et al.*, 2013). Qualitative experiment includes focus group study and interview for qualitative inquiry

(Robinson and Mendelson, 2012). Several scholars advocate integrating “mixed methods and grounded theory—or mixed methods–grounded theory (MM-GT)” (Guetterman *et al.*, 2019).

Authors (Zhou and Wu, 2022) examined numerous mixed method articles published in and confirmed that mixed methods users’ “experienced uncertainty during integration due to lack of guidance and confidence”. It is evident that adoption mixed methods throw multiple challenges. However, scholars (Johnson *et al.*, 2019; Uprichard and Dawney, 2019) have provided useful guidance to better application of integrating qualitative and quantitative methods to achieve research objectives.

Scholars (Fetters and Molina-Azorin, 2017) suggested to use the concept of integration trilogy as “an overarching concept that includes all dimensions where philosophers, ethicists, methodologists, applied researchers, and other academicians consider in a meaningful way mixed methods approaches at the philosophical, methodological, and methods levels to inform an all-encompassing mixed methods research approach” (p. 293). Many researchers advocated application of maximum integration of qualitative and quantitative methods throughout the research project. However, such a high level of integration is extremely challenging and tasking. Recently scholars (Zhou and Wu, 2022) recommended that the following care may be taken to achieve maximum integration:

1. “A theoretical framework could offer evidence for integration at all four research dimensions such as design, collection, mixing, and finding interpretation”.
2. “Use of multiple sources could offer evidence for integration at research design and mixing dimensions”.
3. “Use of visual tools to organize evidence for integration at research design and mixing dimensions”.

4. "Coordinating with collaborators to acquire evidence for integration at all four research dimensions"

Martens called for a greater adoption of mixed method in research across sectors (Mertens, 2014) and the call was well supported through researchers (Kong *et al.*, 2018; Linnander *et al.*, 2018; Plano Clark, 2019). Based on the recommendations of previous researchers (Fetters and Molina-Azorin, 2017; Molina-Azorín, 2011; Plano Clark, 2019) we adopted mixed method to examine consumers intention to purchase ethanol blended fuel.

The goal was to analyse the evolution of the ethanol economy in India. A preliminary set of reading material was selected to which new texts were added over time. In parallel, the main actors involved in the ethanol industry were identified.

After identifying the actors involved in the process, interviews were conducted with key officials from the major organizations involved, including the Oil Marketing Companies like Indian Oil Corporation Limited (IOCL), Bharat Petroleum Corporation Limited (BPCL), HPCL), Indian Sugar Mill Association (ISMA) and sugar mills. The choice of the key informant was based on how long the informant had worked for the company, the extent of their involvement in the ethanol industry, and their knowledge of the technical and managerial aspects of this industry. The input of the focus group and interviews were used to design/refine the questionnaire.

4.2 Structural equation modelling

Structural equation modelling (SEM) essentially a quantitative analytical method better suits to examine and confirm statistical linkages between measured (observable) and underlying (latent) variables (Brown *et al.*, 2021). SEM is a very flexible modelling approach that permits researchers to specify statistical models consisting up of equations elucidating the relationships between "constructs and their relationships with observed variables"(Henseler and Schuberth, 2020). Compared to "PROCESS ("an observed-variable modelling tool that relies on OLS regression"), SEM offers a greater flexibility, "both in terms of model specification and handling missing data, as well as its ability to account for random measurement error when estimating relevant effects involving latent variables" (Hayes *et al.*, 2017).

Recently researchers have successfully applied SEM in research ranging from healthcare to energy domain. Scholars (Sahoo *et al.*, 2022) applied SEM in the context of Electric vehicle adoption in India. Similarly, researchers (Harichandan and Kar, 2023) deployed SEM to understand consumers attitude and perception towards adoption of hydrogen fuel cell vehicles in India. In context of sustainability research SEM was effectively deployed by multiple researchers (Yadav *et al.*, 2022).

Authors (Schuberth *et al.*, 2023) have examined application SEM approach and found that a Monte Carlo simulation demonstrated that the choice of SEM the approach could have a substantial impact on the results and their validity. Further, they advised that the researchers should objectively select a SEM approach that fits their conceptual model.

4.3 Questionnaire design

A five-point Likert scale, varying from Strongly disagree (coded as 1 for analysis) to Strongly agree (coded as 5 for analysis) was used to capture the responses against the items asked in the survey. A total of 34 questions or survey items were included in the survey form (items presented in Table 4.1. The constructs composed of variables like, adopting motivation (four items) adapted from(Ma *et al.*, 2014), purchase intention (four items) adapted from (Nordlund *et al.*, 2016), promoting sustainable cities (four items), sustainable development goals (five items) adapted from (Harichandan *et al.*, 2022), policy incentives (four items) (Harichandan and Kar, 2023), risk perception (four items) (Hoang *et al.*, 2019), infrastructure (five items) (Ma *et al.*, 2014) and cost perception (four items) (Kar *et al.*, 2022). Reflective indicators, which reveal impacts on variables, were used to assess constructs.

Table 4.1: Items, factor loading and VIF values.

Variable	Item	FL	VIF
Adopting Motivation1	Neighbours' participation will motivate me to use Ethanol blended fuel.	0.769	1.689
Adopting Motivation2	Important people to me feel that I should useEthanol-20 fuel in the near future.	0.858	2.341
Adopting Motivation3	People whom I adore think Ethanol-20 fuel is desirable for me	0.877	2.620
Adopting Motivation4	If I purchase Ethanol-20 fuel, then people important to me would also buy it.	0.842	1.820
Purchase Intention1	I intend to purchase Ethanol-20 blended fuel because it is environmentally friendly.	0.891	2.898
Purchase Intention2	I intend to purchase Ethanol-20 blended fuel even though it is more expensive than a conventional fuel.	0.801	1.794
Purchase Intention3	I intend to purchase Ethanol-20 blended fuel over the conventional fuel when their product qualities are similar.	0.854	2.289
Purchase Intention4	I intend to buy Ethanol-20 blended fuel in the near future.	0.906	3.152
Promoting SC1	Ethanol will support sustainable city initiatives.	0.905	3.207
Promoting SC2	Ethanol will help sustainable transport and mobility.	0.912	3.423
Promoting SC3	Ethanol will promote sustainable consumption in cities.	0.892	3.004
Promoting SC4	Ethanol will create sustainable supply chain.	0.893	3.058
Risk Perception1	I am aware of the risk associated with Ethanol-20 fuel.	0.637	1.311
Risk Perception2	I believe that Ethanol-20 fuel is a risk-free source of transportation	0.852	2.224
Risk Perception3	I trust Ethanol-20 fuel because it can provide for my best interest in mind	0.894	2.475
Risk Perception4	I don't think I am at risk when using Ethanol-20 fuel.	0.869	2.459
Cost Perception1	Ethanol-20 blended fuel is expensive over conventional vehicles.	0.714	2.728
Cost Perception2	Ethanol-20 blended fuel has a high price as compared to conventional fuel.	0.791	3.105
Cost Perception3	Ethanol-20 blended fuel has high service charges.	0.745	2.539
Cost Perception4	Ethanol-20 blended fuel has a low maintenance cost per km travel.	0.879	1.301
Infrastructure1	Inadequate Ethanol-20 blended refuelling stations hinder the adoption of Ethanol-20 fuel.	0.707	1.716
Infrastructure2	The high cost of Ethanol-20 is a deterrent to adoption.	0.871	2.508

Infrastructure3	More Ethanol-20 blended refuelling station are required in my place	0.905	3.387
Infrastructure4	More Ethanol manufacturing facilities are desired in the country	0.899	3.314
Infrastructure5	More investment is required to build ethanol infrastructure	0.714	1.853
SDG1	Ethanol will support reliable and modern energy for all.	0.913	4.049
SDG2	Ethanol will lead to sustainable industrialization practices.	0.916	4.043
SDG3	Ethanol will support access to sustainable transport for all.	0.915	4.162
SDG4	Ethanol will promote the need for responsible consumption and production.	0.892	3.542
SDG5	Ethanol is crucial for combating climate change and its impacts.	0.908	3.787
Policy1	Funding for ethanol related research and development should be increased.	0.895	2.907
Policy2	Govt. should provide production-linked incentives to Ethanol manufacturers.	0.910	3.302
Policy3	Govt. should provide financial and tax incentives for Ethanol-20 blended fuel buyers.	0.888	2.858
Policy4	The hassle-free land allocation must be made available to set up refuelling stations at effective prices.	0.892	2.875

4.4 Sampling and Data Collection

We employed convenience sampling approach to collect survey responses as it allows flexibility in collecting responses. The questionnaire was circulated using prominent social networking platforms such as LinkedIn, WhatsApp, etc. To randomise and improve the generalisability of results we distributed the questionnaire to all regions of India divided in six zones based on geographical location. As presented in Table 4.2, the north zone which has highly populous states of India like Uttar Pradesh and Bihar contributed 39% of the survey responses while east, south, west, central, and north-east contributes 22%,17%,13%, 5% and 4% respectively. We also targeted to reach consumers with high income range and education as they are more likely to invest in new technologies and be aware of new alternative forms of fuel. Around 48% of the respondents were from the highest income category of more than Rs15 lakh annual income and 54% were postgraduate.

Table 4.2: Descriptive Statistics Respondents (N=303)

Variable	Description	Coding	Frequency	Percent (%)
Gender	Male	1	250	83%
	Female	2	52	17%
	Others	3	1	-
Education Level	Secondary	1	4	1%
	Graduate	2	125	41%
	Postgraduate	3	164	54%
	Doctorate	4	10	3%
Age Group	18 to less than 28	1	120	40%
	28 to less than 38	2	67	22%
	38 to less than 48	3	38	13%
	48 plus	4	78	26%
Occupation	Government Sector	1	154	51%
	Student	2	100	33%
	Private Sector	3	24	8%
	Self-employed	4	10	3%
	Other	5	15	5%
Annual Income	Less than 5 Lakh	1	106	35%
	5 Lakhs to Less than 10 Lakhs	2	17	6%
	10 Lakhs to Less than 15 lakhs	3	35	12%
	More than 15 Lakhs	4	145	48%
Region	North	1	118	39%
	Central	2	16	5%
	East	3	66	22%
	North-East	4	12	4%
	South	5	53	17%
	West	6	38	13%

The sample size was determined using G power software which resulted in minimum sample requirement of 153 presented in ***Figure 4.1***. To circumvent any possible issues with a small sample, we collected more than 300 responses. The final responses used for the study was 303 responses. The descriptive statistics of the respondents is presented in ***Table 4.2***.

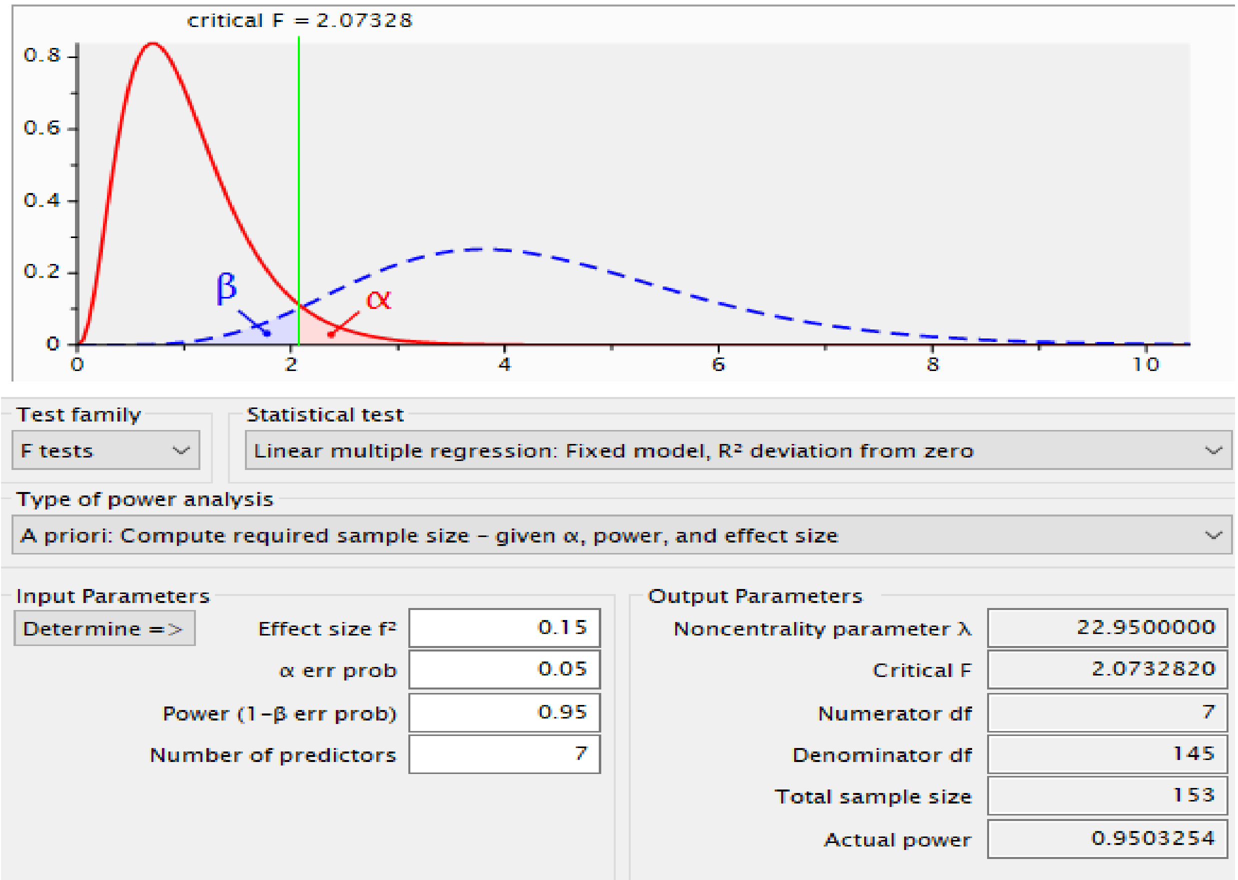

Figure 4.1: Sample determined through G-Power test.

CHAPTER 5

DATA ANALYSIS

CHAPTER 5

DATA ANALYSIS

5.1 Tool & techniques: Smart PLS

"PLS is optimal for estimating composite models while simultaneously allowing the approximation of common factor models involving effect indicators with practically no limitations"(Sarstedt *et al.*, 2016). When estimating data from common factor population PLS performs better than other methods, however the differences are marginal.

5.2 Test for coefficient of determination (R2)

Smart-PLS version 4.0 was used to estimate parameters using a PLS method. "PLS is a variance-based method for generating reliable primary data evaluations. SmartPLS-3 creates predictive validity by investigating the R^2 and path co-efficient" (Hair *et al.*, 2019b; Jr. *et al.*, 2017) in comparison to SPSS, AMOS, and CB-SEM. In addition, bootstrapping with 5000 trials was utilized to examine the causal relationship between the constructs and latent variables.

The coefficient of determinant values suggests the amount of variance explained by the endogenous constructs. In this model, there were two endogenous constructs purchase intention and promoting sustainable cities whose R^2 value were 0.443 and 0.529 respectively as shown in research model **Figure 5.1**. The values 0.75, 0.50 and 0.25 are considered substantial, moderate, and weak. Therefore, the values were satisfactory and in the moderate to substantial range.

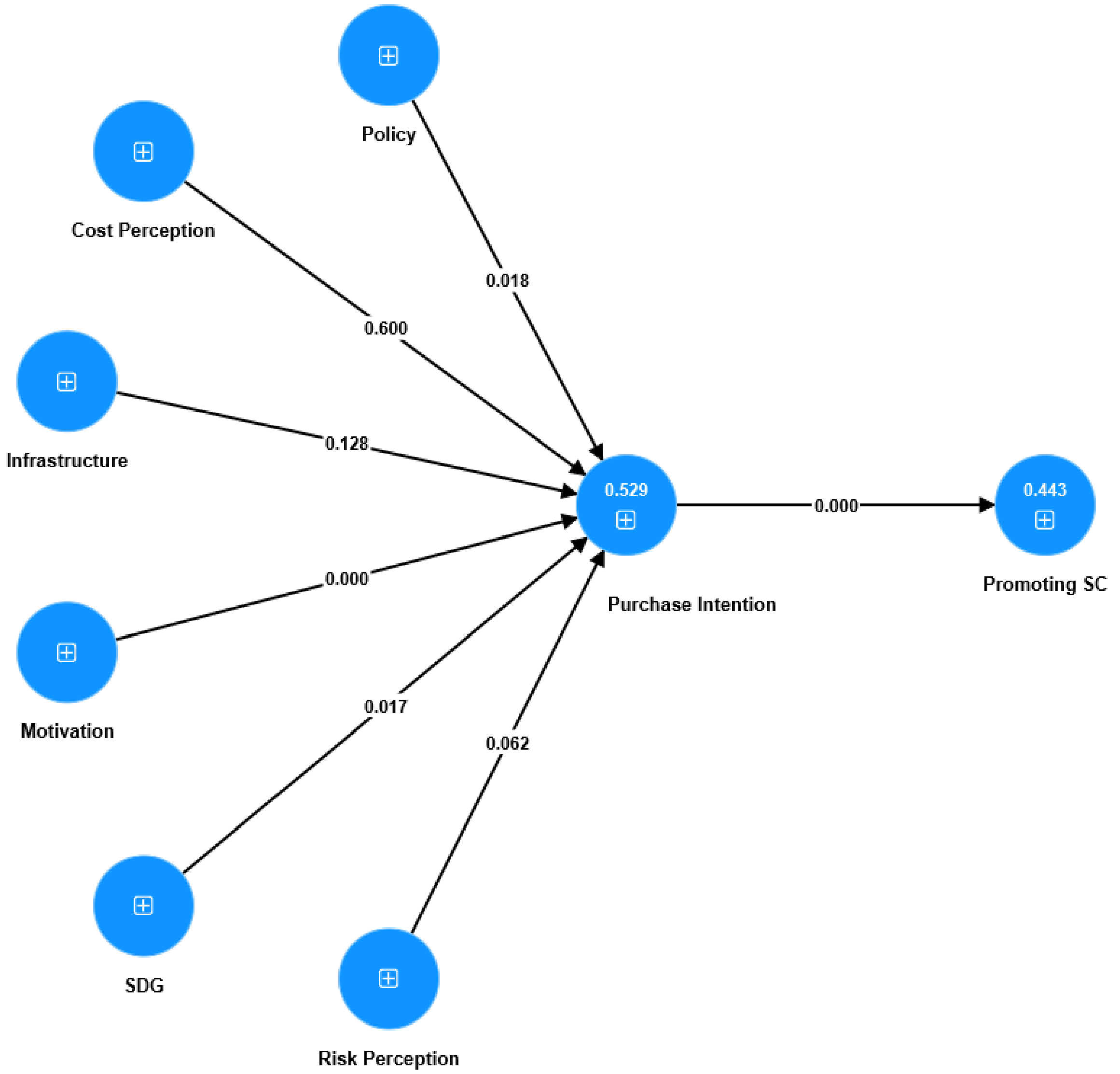

Figure 5.1: Research model

5.3 Research model validation

Next, the measures were refined to evaluate their construct reliability, convergent validity, and discriminant validity (Hair *et al.*, 2019a). To evaluate the measurement model, first the internal consistency was checked using Cronbach's alpha and Composite Reliability (. These criteria help us assess the measurement of assigned indicators. All the values of Cronbach's alpha and composite reliability were found to be above the threshold of 0.7 and therefore, internal consistency and reliability was achieved as presented in **Table 5.1**. The convergent validity was checked using outer loading and average variance extracted (AVE). All the outer loading were found to be above 0.708

excluding risk perception and infrastructure. After their removal no significant impact was observed on the reliability and validity of the constructs and therefore the items were retained (Hair *et al.*, 2019a). Finally, the discriminant validity (**Table 5.2)** was checked using HTMT and Fornell Larcker criterion (Fornell and Larcker, 1981). All the HTMT values were below the minimum threshold of 0.85 and Fornell Larcker values were also satisfactory and therefore discriminant validity was achieved.

Table 5.1: Measurement model results

	Cronbachs alpha (above 0.7)	**Composite reliability (rho_c)**	**Average variance extracted (AVE)**
Cost Perception	0.845	0.864	0.616
Infrastructure	0.871	0.911	0.722
Motivation	0.858	0.904	0.702
Policy	0.918	0.942	0.803
Promoting SC	0.922	0.945	0.811
Purchase Intention	0.886	0.921	0.746
Risk Perception	0.832	0.890	0.672
SDG	0.947	0.960	0.826

Source: Authors analysis

Table 5.2: Discriminant validity of constructs

HTMT	**Cost Perception**	**Infrastructure**	**Motivation**	**Policy**	**Promoting SC**	**Purchase Intention**	**Risk Perception**	**SDG**
Cost Perception								
Infrastructure	0.379							
Motivation	0.221	0.477						
Policy	0.207	0.599	0.556					
Promoting SC	0.168	0.546	0.654	0.711				
Purchase Intention	0.164	0.500	0.710	0.635	0.733			
Risk Perception	0.346	0.532	0.736	0.571	0.641	0.656		
SDG	0.190	0.456	0.561	0.705	0.707	0.633	0.633	
Fornell-Larcker								

Cost Perception	**0.785**							
Infrastructure	0.313	**0.850**						
Motivation	0.234	0.422	**0.838**					
Policy	0.200	0.551	0.502	**0.896**				
Promoting SC	0.189	0.503	0.588	0.655	**0.901**			
Purchase Intention	0.197	0.452	0.629	0.576	0.666	**0.864**		
Risk Perception	0.367	0.467	0.621	0.508	0.570	0.565	**0.820**	
SDG	0.197	0.428	0.510	0.658	0.660	0.584	0.568	**0.909**

5.4 Hypothesis validation

We conducted validation of hypotheses, and the details are presented in **Table 5.3.** The study examined all seven hypotheses (H1-H7) and found that five (H1, H4, H5, H6, and H7) were supported. Based on the analysis, two hypotheses (H2&H3) were rejected.

Table 5.3: Reporting of hypotheses testing results

Hypothesis	Relationship	Coefficient (β)	Standard Deviation (STDEV)	t-value	Decision	R^2
H1	Policy -> Purchase Intention	0.177	0.075	2.358	Supported*	0.529 (PI) and 0.443 (PSC)
H2	Cost Perception -> Purchase Intention	-0.028	0.052	0.524	Not Supported	
H3	Infrastructure -> Purchase Intention	0.077	0.051	1.524	Not Supported	
H4	Adopting Motivation -> Purchase Intention	0.332	0.065	5.069	Supported*	
H5	SDG -> Purchase Intention	0.195	0.082	2.384	Supported*	
H6	Risk Perception -> Purchase Intention	0.132	0.071	1.870	Supported**	
H7	Purchase Intention -> Promoting SC	0.666	0.053	12.566	Supported*	

**supported at p< 0.01; **supported at p<0.10*

Source: Authors analys

CHAPTER 6

DISCUSSIONS AND IMPLICATIONS

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6.1 Hypothesis validation

The first hypothesis (H1), concerning the influence of policy on purchase intention, is supported, in line with previous studies (Park *et al.*, 2022). This suggests that government policies promoting cleaner fuel significantly influence individuals' intentions to purchase products or services that contribute to sustainable cities. Policies such as incentives for eco-friendly fuel or regulations promoting sustainable practices may enhance consumer confidence and encourage sustainable consumption behaviours.

Sustainable cities are increasingly focusing on environmental, social, and economic sustainability. These cities aim to minimize their impact on the environment, promote a high quality of life for residents which build resiliency to climate change. Therefore, sustainable transport holds key to sustainable cities.

However, the hypotheses relating to the influence of cost perception (H2) and infrastructure (H3) on purchase intention are not supported. This indicates that perceptions of cost associated with sustainable products or services and the availability of infrastructure may not significantly impact individuals' intention to purchase. Other factors such as perceived value or environmental consciousness may exert stronger influences on consumer decision-making in this context.

The hypothesis relating to the influence of cost perception on purchase intention (H2) is not supported. This indicates that perceptions of cost associated with sustainable products or services do not significantly impact individuals' intention to purchase ethanol blended fuel and rather acts as a barrier (Niedermeier *et al.*, 2021). It is possible that other factors such as perceived value or environmental consciousness play a more dominant role in shaping purchase intentions, overshadowing concerns about cost.

Similarly, the hypotheses concerning infrastructure (H3) as predictors of purchase intention is not supported. This finding was contrary to the previous findings (Gönül *et al.*, 2021; Hardman *et al.*, 2018). This suggests that individuals may not consider the availability of infrastructure promoting sustainability as significant determinants of their purchase intentions of ethanol blended fuel. This maybe because ethanol blending fuel from consumers perspective does not require additional effort like purchasing a new compatible vehicle which is the case for electric vehicle or hydrogen fuel cell vehicles. Other factors such as personal values, convenience, or product attributes may exert stronger influences on consumer decision-making in this context.

The hypothesis regarding the relationship between adopting motivation and purchase intention (H4) was supported in line with previous studies (Kang and Park, 2011; Teimouri *et al.*, 2022). This suggests that individuals with higher levels of motivation towards adopting sustainable practices are more likely to express intention to purchase products or services that contribute to sustainable cities. This finding aligns with existing literature highlighting the importance of intrinsic motivation in driving sustainable consumption behaviours. Additionally, the hypotheses concerning the influence of SDGs (H5) and risk perception (H6) on purchase intention are supported to varying degrees. This suggests that individuals' perceptions of risk associated with sustainable products as well as their alignment with broader sustainability goals influence their intention to purchase alternative fuels (Spaiser *et al.*, 2017). However, it is essential to note that the magnitude of these effects may vary depending on individual attitudes, beliefs, and contextual factors.

On the other hand, the hypothesis regarding the relationship between Purchase Intention and promoting sustainable cities (H7) is strongly supported (D'Adamo *et al.*, 2024). This underscores the pivotal role of consumer intentions in driving initiatives aimed at promoting sustainable urban development. Consumers who express higher intentions to purchase sustainable products are likely to contribute more actively to the creation of sustainable cities through their consumption choices.

Overall, the findings highlight the complex interplay of various factors in shaping consumer behaviour towards sustainable consumption and urban development. While some factors may exert significant influences on purchase intentions, others may have relatively weaker or negligible effects. Further research is needed to explore the underlying mechanisms driving these relationships and to develop targeted strategies for promoting sustainable consumption behaviours in the context of building sustainable cities.

6.2 Implications

The transition towards sustainable urban development in India necessitates a comprehensive evaluation of consumer behaviours and preferences, particularly in the context of adopting ethanol-blended fuel. Our research delves into the intricate dynamics influencing purchase intentions and outlines the critical role of ethanol-blended fuel in fostering sustainable cities. The findings of this study, encapsulated in supported and unsupported hypotheses, provide a nuanced understanding of the factors shaping consumer decisions. To leverage these insights for actionable change, we propose four innovative policy implications (**Table 15**) aimed at amplifying the adoption of ethanol-blended fuel. These policies are inspired by global best practices and tailored to address the unique challenges and opportunities within the Indian context. By aligning government actions with consumer motivations and barriers, these policy implications endeavour to catalyse a significant shift towards cleaner, more sustainable urban environments. The forthcoming recommendations are predicated on a deep analysis of the research findings, drawing from successful international models to propose a strategic framework for India's sustainable urban development through the adoption of ethanol-blended fuel.

6.3 Recommendations

6.3.1 Flexible Fuel Vehicle (FFV) Incentive Scheme

Drawing inspiration from Brazil's successful FFV program, India could introduce a comprehensive FFV Incentive Scheme. This program would provide tax incentives, subsidies, or rebates for consumers purchasing FFVs, vehicles capable of running on any blend of ethanol and gasoline (Brito *et al.*, 2019). To encourage manufacturers, the scheme could offer tax benefits, subsidies for FFV production, or research and development grants focused on ethanol-compatible vehicles. Brazil's approach has significantly boosted FFV adoption, making ethanol a popular fuel choice due to the availability of vehicles that can efficiently use it. By implementing a similar scheme, India could address consumer purchase intentions directly, making ethanol-blended fuel an attractive option through the widespread availability and incentivized purchase of FFVs.

Like the FAME initiative's approach to electric vehicles, the FFV Incentive Scheme could include demand incentives directly provided to consumers at the point of sale to reduce the upfront cost of FFVs. Additionally, establishing a network of 'Ethanol Green Corridors' with assured FFV servicing and ethanol refuelling stations along major highways could mirror the charging infrastructure push for EVs, ensuring FFV users have consistent access to ethanol fuel across major travel routes.

6.3.2 Renewable Fuel Mandate and Certification

Like the US Renewable Fuel Standard (RFS), India should establish a Renewable Fuel Mandate that requires fuel suppliers to blend a minimum percentage of ethanol with gasoline, gradually increasing this mandate beyond 20 % to encourage higher ethanol blends (Younes *et al.*, 2022). Alongside, a certification system for sustainable biofuels could ensure that the ethanol blended into the fuel supply meets stringent environmental, social, and economic sustainability criteria. This policy would not only mandate the use of ethanol-blended fuel but also reassure consumers about the sustainability and quality of the fuel they are using, addressing concerns related to environmental impact and fuel performance.

Drawing from global best practices in biofuel certification, this scheme could introduce an 'Ethanol Star' rating system for vehicles based on their efficiency and emissions when running on ethanol-blended fuel. This rating system would help consumers make informed decisions, similar to how energy efficiency ratings are used for appliances and incentivize manufacturers to design vehicles that perform optimally on ethanol blends.

6.3.3 Ethanol Pricing and Infrastructure Development Policy

Learning from the ethanol distribution models in countries like the US, where infrastructure and pricing policies have been key to ethanol adoption, India should introduce an Ethanol Pricing and Infrastructure Development Policy. This would involve stabilizing ethanol prices through subsidies or minimum price guarantees to make ethanol competitively priced against fossil fuels. To overcome infrastructure challenges, the policy could support the development of ethanol distribution networks through public-private partnerships, offering incentives for the establishment of ethanol refuelling stations across urban and rural areas. Such a policy would address the unsupported hypotheses regarding cost perception and infrastructure challenges, making ethanol more accessible and financially attractive to consumers.

Taking cues from hydrogen mobility's focus on infrastructure, this policy could pilot 'Ethanol Energy Hubs' in urban centres. These hubs would integrate ethanol refuelling stations with renewable energy sources (like solar or wind) to produce ethanol fuel, showcasing a sustainable model of fuel production and distribution that reduces carbon footprint and aligns with the circular economy principles.

6.3.4. Urban Mobility and Public Transportation Ethanol Initiative

Taking cues from cities around the world that have integrated biofuels into their public transportation systems, India could launch an Urban Mobility and Public Transportation Ethanol Initiative. This initiative would prioritize the transition of buses, taxis, and other public service vehicles to ethanol or ethanol hybrid engines, supported by subsidies for fleet conversion and the establishment of dedicated ethanol refuelling infrastructure within urban centres. This approach would not only reduce urban pollution and greenhouse gas emissions but also serve as a high-visibility endorsement of ethanol-blended fuels, encouraging wider consumer acceptance, and adoption.

Leveraging the concept of smart cities, this initiative could integrate ethanol-fuelled public transport options into urban planning software platforms, providing real-time data on emissions savings and public transport efficiency. This integration would not only promote the use of ethanol-blended fuel in public transportation but also encourage urban residents to opt for these greener transport modes, enhancing the sustainability profile of

Indian cities. We present a mapping of hypotheses (**Table 6.1)** with relevant schemes to promote adoption of ethanol blended fuel for sustainable cities.

Table 6.1: Mapping of hypotheses with relevant schemes

Hypothesis (H)	Description	Result	Relevant Schemes
H1	Influence of policy on purchase intention	Supported	Flexible Fuel Vehicle (FFV) Incentive Scheme
H2	Influence of cost perception on purchase intention	Not Supported	Ethanol Pricing and Infrastructure Development Policy
H3	Influence of infrastructure on purchase intention	Not Supported	Ethanol Pricing and Infrastructure Development Policy
H4	Relationship between adopting motivation and purchase intention	Supported	Renewable Fuel Mandate and Certification
H5	Influence of SDGs on purchase intention	Supported	Urban Mobility and Public Transportation Ethanol Initiative
H6	Influence of risk perception on purchase intention	Supported	Renewable Fuel Mandate and Certification
H7	Relationship between Purchase Intention and promoting sustainable cities	Supported	Urban Mobility and Public Transportation Ethanol Initiative

Source: Authors analysis

CHAPTER 7

CONCLUSION, LIMITATIONS AND FUTURE DIRECTION

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7.1 Conclusion

In conclusion, the findings from the hypothesis testing shed light on the multifaceted nature of consumer behaviour in the context of linking blended ethanol fuel purchase intention promoting sustainable cities. The supported hypotheses underscore the importance of intrinsic motivation and government policies in driving individuals' intentions to purchase products or services that contribute to sustainable urban development. Specifically, the positive relationship between adopting motivation and purchase intention highlights the significance of personal values and beliefs in shaping sustainable consumption behaviours. Moreover, the support for the influence of policy on purchase intention emphasizes the pivotal role of regulatory frameworks and incentives in fostering a conducive environment for sustainable consumption. Further, risk perception also plays a role in purchase intention of ethanol blended fuel.

The strong linkage between the purchase intention of ethanol-blended fuel and promoting sustainable cities underscores the pivotal role of sustainable fuel adoption in advancing urban sustainability initiatives, particularly in high-tech cities. As urbanization accelerates and cities face increasing challenges related to pollution, congestion, and resource depletion, the transition to sustainable fuel sources emerges as a critical strategy for mitigating environmental impact and fostering sustainable urban development.

Furthermore, the strong linkage between purchase intention of ethanol-blended fuel and promoting sustainable cities reflects a broader trend towards environmentally conscious consumer behaviour and the increasing demand for sustainable products and services. As consumers become more informed about the environmental impact of their choices, they are actively seeking out sustainable alternatives, including cleaner transportation fuels.

This consumer preference drives market demand for ethanol-blended fuel and incentivizes businesses and policymakers to invest in renewable energy infrastructure and sustainable transportation solutions.

Ethanol-blended fuel offers several benefits that directly contribute to the sustainability of high-tech cities. By reducing emissions and air pollution, ethanol-blended fuel helps to improve air quality and create healthier living environments for urban residents. This is especially important in densely populated areas where air pollution levels can have significant health implications and exacerbate respiratory issues. Additionally, the use of ethanol-blended fuel supports efforts to reduce greenhouse gas emissions and combat climate change, aligning with global sustainability goals and commitments to decarbonize the transportation sector. Moreover, India having high potential for agricultural waste e.g. paddy straw, wheat straw, corn cobs, sugarcane trash, bagasse etc. to convert into ethanol using advanced technology e.g. 2nd Generation ethanol through Gasification, enzymatic hydrolysis etc. apart from traditional way of producing ethanol from sugar molasses, grains etc. higher blending of Ethanol in Petrol will boost rural economy and create huge employment opportunity simultaneously controlling mindless burning of agriculatural wastes. Considering, consumers inclination for greener fuels, India should gradually move towards E85 and E100. IOCL already started retailing E100 from 350 Retail Outlets, which should gradually made available through a greater number of outlets. Vehicle manufacturers should work hand-in hand with the fuel retailers to increase adoption of ethanol blended fuel.

However, the non-supported hypotheses regarding the influence of cost perception and infrastructure on purchase intention suggest that traditional economic factors and logistical considerations may not be the primary drivers of consumer behaviour in the context of sustainable cities. Instead, factors such as perceived value, environmental consciousness, and alignment with sustainability goals may play more significant roles in shaping individuals' intentions to purchase sustainable products or services. These findings underscore the need for holistic approaches that consider not only economic factors but also social and environmental dimensions in promoting sustainable consumption behaviours.

Overall, the findings highlight the complexity of consumer decision-making processes and the importance of understanding the underlying motivations and contextual factors influencing sustainable consumption behaviours. Moving forward, policymakers, businesses, and other stakeholders must consider these insights to develop targeted interventions and strategies aimed at promoting sustainable alternative fuel consumption and building more sustainable cities. By addressing consumer concerns, aligning with sustainability goals, and creating enabling environments, we can foster a culture of sustainability and contribute to the creation of more resilient and equitable urban environments for future generations.

7.2 Limitations and Future Direction

The study has some limitations including focus on a single geography of India. If a multi-country sample is used in future research, then findings may have higher generalisability. Further, we have used convenience sampling which may be improved further by using probabilistic sampling approach. Future studies may use other alternative fuels and examine their consumption dynamics with respect to the sustainable cities.

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