Comprehensive Environmental and Social Sustainability

Assessment of Bio-CNG as a Vehicular Fuel in India

THE ENERGY AND RESOURCES INSTITUTE
Creating Innovative Solutions for a Sustainable Future

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Acknowledgement

It's our pleasure to present the report 'Comprehensive Environmental and Social Sustainability Assessment of Bio-CNG as Vehicular Fuel in India' which quantitatively attempts to assess the environmental and social sustainability benefits of using Bio-CNG as a vehicular fuel in India. The Energy and Resources Institute (TERI) is extremely grateful to all automotive industry partners and experts for their incredible support throughout this project.

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From the **DG's desk**

Surge in demand for mobility and the consequent consumption of fossil fuels for powering transport vehicles is massive and is increasing rapidly with time. However, with geopolitical tensions, shrinking crude oil reserves, and negative impacts of vehicular emissions on global and local pollution has influenced scientific community to explore alternative and sustainable fuels for the transport sector.

India is at the cusp of mobility revolution. At a time when India's automotive industry is undergoing substantial transformation, a diverse mobility solution is required, which still lags in terms of access to transportation facilities, and introduction of e-mobility is a challenge in immediate future.

Bio-CNG has emerged as a potential solution to this sustainable mobility challenge in rural areas. The transition can be accomplished by leveraging nation's significant availability of animal wastes for using Bio-CNG as a cost-effective sustainable alternative for the transport sector.

The main environmental advantage of biogas as a vehicle fuel is that it can substantially reduce greenhouse gas (GHG) emissions in the transport sector. Further when liquid residues from biogas production are used as organic fertiliser it can avoid methane (CH_4) emissions from landfilling or manure storage, resulting in additional GHG savings.

Additionally, it will also have a secondary impact on providing easy and affordable access to external markets. This will help in increasing the farmers' income and provide people with new economic opportunities. Therefore, by enhancing people's socio-economic conditions, affordable, clean, inclusive, and reliable mobility will assist the country in inching closer to achieving the Sustainable Development Goals.

The quantified environmental and socio-economic benefits from use of biogas for rural mobility presented in the document is a unique and first of its kind exercise undertaken by TERI. I am sure that the findings will provide valuable insights and perspectives to diverse stakeholders in strengthening biogas development and use as a sustainable and affordable fuels to supporting India's mobility revolution.

Dr. Vibha Dhawan (Ph.D)
Director General, TERI

Preface

In the pursuit of a sustainable and eco-friendly energy transition for India, the TERI team is pleased to present this document titled "Comprehensive Environmental and Social Sustainability Assessment of Bio-CNG as a Vehicular Fuel in India." Our motivation stems from a deep-seated belief in the transformative potential of Bio-CNG and its pivotal role in steering India towards a greener future.

This document presents a meticulous quantitative analysis of the environmental benefits associated with Bio-CNG, emphasizing upstream greenhouse gas (GHG) savings in both production and usage. By examining five distinct feedstocks—Cattle dung, paddy straw, bagasse, MSW, and press mud—we provide a nuanced understanding of their potential impact on carbon footprints. Additionally, we navigate the intricacies of compliance benefits within policies such as Corporate Average Fuel Economy (CAFE) norms. The comparative Well-to-Wheel life cycle analysis, which contrasts GHG emissions of Internal Combustion Engine (ICE) vehicles and Electric Vehicles (EVs) against Bio-CNG options, is presented to assist industry partners, particularly automotive manufacturers, in strategically aligning with evolving regulations.

In the realm of social sustainability, we venture into the grassroots impact of Bio-CNG production, examining the positive ripple effect at the local (rural) level. Our perception analysis unearths not only the economic advantages for users but also the holistic improvement in the quality of life through cost savings.

At its core, this document is a testament to the immense potential of Bio-CNG as a sustainable energy source for India. Bio-CNG stands as a beacon, that will not only help India in meeting its international targets but also has promising socio-economic benefits at the village level, utilizing locally available raw materials.

Through our journey, we have encountered challenges associated with scaling Bio-CNG—a crucial learning that positions this document as a comprehensive guide for industry stakeholders, policymakers, and end-users. We invite you to explore the insights within, recognizing Bio-CNG not just as a fuel but as a catalyst for a greener, economically vibrant, and socially inclusive India.

With optimism and dedication to a sustainable future,

TERI team

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1. Introduction

Bio-CNG is deliberated as a potential green energy alternative amidst India experiencing a mobility revolution driven by the objective of decarbonizing the transport sector in progressing towards accomplishing the country's overall climate goals. It has emerged as a viable fuel source for providing reliable and affordable transportation services to rural areas particularly in developing countries such as India. The production and use of Bio-CNG from animal and agricultural wastes through anaerobic digestion is a potential way to reduce methane emissions. Globally, methane (CH_4) is the second largest source of greenhouse gas (GHG) emissions after carbon dioxide (CO_2), accounting for 19% of the total anthropogenic GHG emissions. In 2021, methane emissions in India reached 897 million metric tonnes of carbon dioxide equivalent ($MtCO_2e$) increasing more than 30% since 1990 with India reporting second-largest emissions worldwide. Bio-CNG as vehicular fuel not only has the potential to mitigate methane emissions, but will also aid India in providing cheap, reliable, and environment-friendly transportation, especially to rural areas. This will lead to improved living standards for the rural population by integrating these remote areas to nearby cities providing easy access to external markets, raising agricultural productivity and income, and creating new economic opportunities.

The useable component of biogas is methane (45%–55%) that can be used for generating energy suitable across sectors. Biogas can be further upgraded to 95%–99% methane content enabling its injection into gas grid or its usage for mobility. Researchers have pointed to the dual contribution of bioenergy from waste and agriculture sector—first, elimination of methane emissions from organic sources and second, substituting fossil fuel resources. Methane, as against carbon dioxide, decays automatically after remaining in the atmosphere for about a decade. Thus, targeting methane emissions can effectively reduce its concentration in the atmosphere in medium run (Chugh, 2021). This aside, biogas when used in conjunction can help to stabilize energy supply from intermittent renewable technologies such as solar and wind energy. India will be able to accomplish several targets under the Sustainable Development Goals (SDGs) with the support of accessible, clean, and inclusive mobility through local employment generation, afforestation, and access to clean and low-cost energy, health benefits, and enhanced energy security.

In this setting, the report presents a comprehensive understanding of the environmental and social benefits arising from using Bio-CNG as a sustainable vehicular fuel, especially for providing affordable mobility in rural areas.

The report begins with the environmental impact assessment of Bio-CNG in Section 2, presenting the key enablers. It also attempts to suggest an action plan for usage of Bio-CNG for transportation in India. Section 3 presents a well-to-wheel analysis of fuels and powertrain components of EVs and ICEVs (petrol, diesel, CNG, Bio-CNG). Section 4 is a peek into the various existing national policies as well as successful international policies in the field. The social benefit assessment of Bio-CNG undertaken in Section 5 aims to gauge information about the social perception of rural population towards Bio-CNG and estimating the fuel-related monetary savings from switching to Bio-CNG for sustainable and affordable mobility. Section 6 maps the implications of affordable and sustainable mobility for indices under the SDGs. Section 7 summarizes the findings of the analysis carried out in this paper.

2. Environmental Impact Assessment of Using Bio-CNG In Automotive Sector

2.1 Introduction

The environmental impact assessment focuses on quantification of upstream methane avoided upon using different bio-based feedstocks for production of Bio-CNG for vehicular usage. Quantification of carbon saved will enable making a strong case for promotion of Bio-CNG-based vehicles from a policy perspective since India has multiplicity of obligations which requires a crucial balance among meeting its international climate commitments, improving the natural environment as well as meeting the socio-economic aspirations of its population; which is directly correlated with high energy demand. During the COP26, the Hon'ble Prime Minister of India committed to the nation reaching net zero by 2070. At the same event, the Global Methane Pledge (GMP) was launched which called for countries to take voluntary actions for methane reduction by at least 30% by 2030 from their 2020 levels. More than 100 countries are on board with the GMP; however, India is not a party to the same. Targeting methane which is 28 times more potent than CO_2 in causing global warming seems to be the most effective alternative for India to achieve its climate goals. Since methane is a combustible gas and India is a large producer of both animal and agricultural waste, production and utilization of Bio-CNG mobility solutions can help the country in meeting the dual target of reducing methane emissions and at the same time decarbonizing the transport sector.

The potential of the Bio-CNG sector to make agriculture sustainable is indisputable and can be a game changer in promoting sustainable farming in India. Putting Bio-CNG plants on sustainable farms helps the farmers, the environment, and the community in many ways. Bio-CNG plants help with waste management, reduce energy costs, and improve soil fertility. Cash crops which are not used as food and are not costly can be used as substrates for Bio-CNG plants. This improves crop rotation and enhances biodiversity. Bio-CNG plants can also incentivize growing cover crops. Cover crops, which are generally mulched into the ground can also be harvested and used as feedstock for biogas digesters.

2.2 Approach

The approach taken for conducting the environmental impact assessment is to determine most suitable bio-based feedstocks for Bio-CNG production in terms of their methane avoidance potential for helping potential Bio-CNG generators to make informed decisions. As mentioned earlier, this Policy Paper goes on to identify major enablers and an action plan for usage and uptake of Bio-CNG in vehicular transportation in India. Bio-CNG as vehicular fuel has the potential to reduce emissions via many different pathways, such as reduced tailpipe emissions by replacing fossil fuels, avoided methane slips from manure dumping and open burning as well as methane emissions from straw incorporation and burning of other feedstock, and green fertilizer production as by-product which can replace carbon-intensive chemical fertilizers.

2.3 Methodology

The methodology followed for the Environmental Impact Assessment is described in the following steps:

» Desk-based literature review to identify calorific value of different feedstock, feedstock-to-gas conversion ratio and upstream methane release potential of different end of life (EOL) stream of respective feedstock.

» Desk-based literature review to identify approximate equivalent Bio-CNG plant-based slurry to chemical fertilizer ratio in terms of nutrient content.

» Calculation of baseline upstream methane avoidance from two different routes (usage of biomass as feedstock for Bio-CNG production and usage of Bio-CNG plant slurry for replacement of chemical fertilizer) (Note: CNG emissions are used as a proxy for Bio-CNG).

» Calculation of emissions saved per km for benefit in CAFE[1] policy.

» Calculation of plant requirement, feedstock requirement, and savings per plant for complete transition of current CNG fleet to Bio-CNG.

» Based on all information from literature search and calculations, a proposal for an action plan involving a scheme for seeking CAFE credits, scheme for slurry management, and recommended policy solutions is developed.

2.4 Key Enablers

2.4.1 Feedstock

The sustainability benefits of using Bio-CNG as a fuel has been captured based on estimation of upstream avoided GHG emissions of Bio-CNG feedstock. Channelling this vast amount of feedstock into Bio-CNG production will prevent huge amounts of GHG slipping into the environment, particularly methane. It will have additional benefits of solid and liquid waste management in rural India. Four types of feedstocks, relevant for India, are considered which includes cattle dung, paddy straw, bagasse, and municipal solid waste to establish the best route to maximize GHG savings through Bio-CNG production. Additionally, some other feedstock like press mud has also been briefly explored for future potential.

Feedstock type 1: Animal waste (Cattle dung)

Animal waste is the most used feedstock for Bio-CNG production in India. It is the first category of feedstock considered for calculation of GHG savings from Bio-CNG production and usage. IPCC Guidelines for National Greenhouse Gas Inventory, 2006, gives a robust methodology for calculation of livestock emissions from

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[1] CAFE (Corporate Average Fuel Efficiency/Economy) norms aim at lowering fuel consumption (or improving fuel efficiency) of vehicles. CAFE regulations in India came into force from April 1, 2017. Under this, average corporate CO_2 emission must be less than 130 gm per km till 2022 and below 113 gm per km thereafter.
In other words, it requires cars to be 10% or more fuel efficient between 2017 and 2021, and 30% or more fuel efficient from 2022, in terms of CO_2 emission.

different manure management systems. The IPCC gives three levels of calculations to estimate the emission factor by livestock category and manure management system. Tier 1 calculations are the most basic where emission factors are presented based on the country's average annual temperature.

The Tier 2 calculations of the IPCC allows for more robust and representative country-specific calculations. It allows usage of India-specific values for greenhouse gases such as methane, nitrous oxide in different manure management system. Also, the methodology allows the choice of specific livestock category from which manure is obtained. For the livestock derived manure, dung from Indian dairy cows in liquid slurry manure management system has been considered as the baseline in this study. However, the emissions associated with Indian buffalos are also done as a sensitivity case. Along with upstream methane avoidance, the savings of GHG emissions through usage of Bio-CNG plant-based slurry to replace chemical fertilizer is also considered.

Using IPCC's Tier 2 method of calculation it was found that total upstream GHG emission savings from 1-tonne Bio-CNG production is 26,223 kg CO_2 eq. and the savings per km run of Bio-CNG usage is 0.982 kg CO_2 eq./km. Cattle manure's abundant availability and well-established supply chain renders it the most viable feedstock when contrasted with others that have a more fragmented supply chain.

The calculations along with other details like Bio-CNG requirement for total replacement of current CNG fleet, plant and feedstock requirement, and slurry production is demonstrated in *Annexure 1*.

Feedstock type 2: Agricultural feedstock (Paddy straw)

A significant proportion of feedstock for Bio-CNG production in India also comes from agricultural waste like paddy straw. Paddy straw undergoes several straw management practices like complete and partial incorporation of straw into the fields as well as open burning. Complete and partial incorporation of straw with soil eventually causes higher GHG emissions than burning, because the next round of paddy cultivation involves flooding of fields. This leads to anaerobic decomposition of straw under water leading to large amount of methane emissions. Burning of paddy straw involves more CO_2 emissions along with air pollutants such as SO_x, NO_x, and other particulates but methane emissions are not as much as straw incorporation process. We have considered complete incorporation of paddy straw as a baseline management practice to calculate upstream avoided emissions.

The feedstock-to-gas conversion ratio for paddy straw is relatively higher than animal manure at 100:29.4 (Chandra R. et. al, 2017). Accordingly, the amount of slurry generated as a by-product is also less in the case of paddy straw. However, as less amount of feedstock is required, the upstream avoided savings on using paddy straw is much less at 2,530 kg CO_2 eq. for 1 tonne Bio-CNG production and the per km savings is at 0.19 kg CO_2 eq. /km.

The calculations along with other details like Bio-CNG requirement for total replacement of current CNG fleet, plant and feedstock requirement, and slurry production is demonstrated in *Annexure 2*.

Feedstock type 3: Industrial feedstock (Bagasse)

Bagasse is also one of the important feedstocks for Bio-CNG production in India but its high lignin content makes its application limited (Vats N. et. al, 2019). Also, from the perspective of this study, upstream avoided emissions from bagasse are not as significant as animal or agricultural waste. Untreated waste bagasse is mostly disposed of in landfills in India and that does not have significant emissions associated with it.

Various applications of bagasse thus include direct usage as fuel or burning to make sugar cane bagasse ash (SCBA) which is used as a cement substitute to reduce CO_2 emissions from cement. In this study, we have not considered burning bagasse for SCBA production because it serves as a raw material for processes with intention to save GHG emissions. Therefore, direct usage of bagasse as a fuel is considered as the baseline bagasse management process in this study. Bagasse has a very high calorific value equivalent to 598 litres of diesel (Sari K E et. al., 2019); accordingly, most processes use small amounts of bagasse to substitute large energy needs. Bagasse burning is mostly associated with large emissions of particulates and air pollutants and very small amount of GHGs.

Due to the high calorific value of bagasse, the gas-to-feedstock conversion ratio is positive in this case at 100:320. As a result, the amount of bagasse needed is low which makes slurry management relatively more feasible. However, the total upstream emission savings are also extremely low at 6.3 kg CO_2 eq. per tonne of Bio-CNG produced which does not give any significant emission reduction on per km run. The combined effect of positive gas-to-feedstock conversion ratio along with small quantities of GHG emissions on bagasse burning gives very small amount of upstream GHG avoidance in case of bagasse while at the same time making it a good feedstock for Bio-CNG production.

The calculations along with other details such as Bio-CNG requirement for total replacement of current CNG fleet, plant and feedstock requirement, and slurry production is demonstrated in *Annexure 3.*

Feedstock type 4: Municipal Solid Waste (MSW)

MSW has high nitrogen and phosphorus content which is great for cell growth production needed for anaerobic digestion during Bio-CNG production. India has huge production of MSW owing to its rapidly increasing urban population and consumerist lifestyle. According to Singh P. et al. (2022), MSW, if harnessed correctly to produce bio-methane can replace 4,053 tonnes of conventional fuel consumption per day.

In this study, the upstream methane avoidance for Bio-CNG production is calculated considering the methane leakage from 1-tonne MSW dumped in landfills in India. India's MSW has a relatively low volatile solid constituent of 41.3% (Singhal A. et al., 2021) and accordingly has a poor feedstock-to-gas conversion ratio of 100:2.3. The MSW feedstock is considered to contain a mix of waste including food, fruit, yard waste, and paper waste. The difference between Bio-CNG and methane yield is low for some constituents such as paper and yard waste while high for food and fruit waste. An average of 55% methane yield is considered for the mixed waste.

Using a similar methodology, it was found that total upstream GHG emission savings from 1 tonne Bio-CNG plant is 40,926 kg CO_2 eq. and the savings per km run of Bio-CNG usage is 1.46 kg CO_2 eq./km. This also includes benefits of GHG savings on replacement of NPK fertilizer with slurry generated from the Bio-CNG plant.

The calculations along with other details like Bio-CNG requirement for total replacement of current CNG fleet, plant and feedstock requirement, and slurry production is demonstrated in *Annexure 4*.

Feedstock type 5: Press mud

Press mud is mostly used as soil conditioner, soil fertilizer, and for wax production. Other industrial applications are reported (cement and paint manufacturing, foaming agent, composting aid for bagasse, etc.) and it has been used as human food by resource-poor families. In animal production, it has been used as a feed ingredient, notably for ruminants, because of its sugar and mineral content, and as a compacting agent for ensiling.

There is lack of data to calculate the upstream emissions of Press mud, therefore, the calculations focus on only production of Bio-CNG from press mud as feedstock. These are given in *Annexure 5*.

Table 1 presents the formulae used to calculate the avoided emissions of different feedstock. The detailed calculations are given in *Annexures 1 to 5* as already mentioned above.

Table 1: Formulae used to calculate the avoided emissions of different feedstock
1. Methane avoidance during Bio-CNG production (Aa) = EF per tonne of feedstock treatment* amount of feedstock
(The EF factor for per tonne of feedstock is determined using different methods or through literature review which is detailed out in Annexure)
2. Methane avoidance from replacement of chemical fertilizer (Ab) = [x* (a/b)]-[y*(a/b)]
a: Slurry produced from 1 tonne Bio-CNG plant b: Amount of slurry considered equivalent to NPK fertilizer x: Emissions from 1 kg NPK fertilizer y: Emissions from 1 kg slurry
3. Total methane avoidance (At) = Aa + Ab
4. Emissions saved per km for CAFE norms (Ec)= (At/30000) + 0.108
At/30000= Emission reduction due to usage of 1 tonne Bio-CNG where 30000 is mileage of 1 tonne Bio-CNG *0.108= Current EF of CNG in kg CO_2 eq./km*
5. Total emissions avoided on replacing entire fleet of CNG to Bio-CNG for per km run= 3000000*Ec
3000000= Total CNG vehicles on road
6. Total gas required by entire fleet to run per year (G) =12000/30*3000000
12000= km travelled by 1 vehicle per year *30 km = Mileage of CNG* *30000000= Total CNG vehicles on road*
7. Number of 1TPD plants required for transition of entire fleet of CNG to Bio-CNG for 1 year (P) = G/365000
365000= Total gas produced from 1 TPD plant for 1 year
8. Amount of feedstock required for transition of entire fleet of CNG to Bio-CNG for 1 year = P* CR tonnes
CR= Feedstock-to-gas conversion ratio of individual feedstocks
9. Amount of slurry generated for transition of entire fleet of CNG to Bio-CNG for 1 year = P* S tonnes
S= Slurry generated from 1 TPD per day (different for different feedstocks)
10. Emission avoided from 1TPD Bio-CNG plant every year= At*365
365= Number of days in a year

While the calculations involve estimating GHG savings on usage of different feedstocks, plants may not always use 100% of a single feedstock. Accordingly, based on relevant calculations (*given in Annexures*), a few scenarios of combination feedstocks are mentioned below and corresponding GHG savings associated with the same are given in Table 2.

Table 2: GHG savings from different feedstock scenarios

Scenario of combination feedstocks	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
Composition	50% cow dung + 50% buffalo dung	33.3% cow dung + 33.3% buffalo dung + 33.3% paddy straw (total incorporation)	33.3% cow dung + 33.3% buffalo dung + 33.3% paddy straw (burning)	25% cow dung + 25% buffalo dung + 25% paddy straw (TI) + 25% bagasse	25% cow dung +25% buffalo dung +50% MSW	25% cow dung +25% buffalo dung +25% paddy straw (TI) + 25% MSW
GHG savings per tonne of Bio-CNG produced (kg CO_2 eq./ tonne)	24823	17374.6	17181	13045.6	32874.5	23275.5
GHG savings per km (g CO_2 eq./ km)	827	579	573	435	1096	776

2.4.2 CAFE Credit Scheme

Incorporation of benefits of Bio-CNG into CAFE compliance can be a game-changer, as it will encourage vehicle manufacturers to promote more Bio-CNG-based vehicles while contributing towards accelerated decarbonization of the economy. Going a step ahead, the manufacturers who can overachieve their CAFE targets should have the opportunity to generate credits for better performance at compliance. There is no scheme for claiming CAFE credits in India currently. However, there are examples from across the world; where CAFE credits can be transferred across fleets, automobile manufacturers, and even industries. Developing a similar scheme for India would further improve compliance with the law. The increased demand will further streamline production. Accordingly, we propose the following steps for formulation of a CAFE credit scheme:

» Step 1: Registration of Bio-CNG plants (new Bio-CNG plants set up for providing Bio-CNG for transportation)

- Type of feedstock
- Source of feedstock
- Capacity
- Usage of by-products

Based on these details, each Bio-CNG plant needs to have a carbon emission rating associated to its product. This carbon emission rating needs to include carbon reduction and removal, which is already the norm in carbon registries.

» Step 2: Validation and issuance of compliance certification from an established carbon registry that the plant is good to provide Bio-CNG to automobile manufacturers.

» Step 3: Auto manufacturers who do capital investment into Bio-CNG plants, from such registered plants, can replace their current fleet emissions for CAFE compliance with avoided emissions from the Bio-CNG plant.

» Step 4: Manufacturers can earn credits for over-compliance above their targets through reduction and removal of GHG emissions. Manufacturers should be able to carry credits for over-compliance up to 5 years in future (within the same CAFE term) and make up for shortages up to 3 years in the past (if it was in the same CAFE term), transfer them between fleets or trade them with other manufacturers to resolve shortages. In case a manufacturer has very high number of credits earned through carbon removal, then manufacturer must also be able to sell the credits to other industries through voluntary carbon markets.

2.4.3 Bio-CNG Plant Slurry

Bio-CNG slurry is a secondary product produced by anaerobic fermentation of bio-materials. Bio-CNG slurry is not only an environment-friendly organic fertilizer but also an efficiently utilized waste material. Bio-CNG slurry has two main uses for plant production—it is a bio- fertilizer with significant levels of Nitrogen (N), Phosphorus (P) and Potassium (K) along with other trace minerals and it is also a bio-pesticide with high levels of amino acids, growth hormones, and antibiotics (You L. et al., 2019).

The use of bio-slurry as a fertilizer has an advantage over using manure as fertilizer as the digestion process converts the nutrients, specially nitrogen, to a readily available form for plants to utilize, even though the content enrichment of P and K is not very high. In comparison with chemical fertilizers, the nutrient content is significantly lower than equivalent amount of Bio-CNG-based slurry but the latter do not contain toxic heavy metals like the former. Several literatures suggest that improved agriculture in terms of better crop yield and soil fertility can be achieved through a combination of chemical and organic fertilizers. While chemical fertilizer improves crop yield drastically over a short period of time, the long-term crop productivity decreases. On the other hand substituting some proportion of chemical fertilizer with slurry can help to sustain long-term agricultural production with good yield.

Considering environmental impacts and cost of chemical fertilizer, the best usage of slurry (as emerged from discussion with stakeholders) is application of 10–15 tonnes/ha, 21 to 28 days before planting. Solely based on nutrient content, it is assumed that 1 kg of chemical fertilizer can be replaced by more than 40–250 kg of untreated slurry based on feedstock (Malav L et al., 2015). However, it is neither feasible nor desirable to completely replace chemical fertilizer by slurry, hence only 20% substitution of chemical fertilizer by slurry is recommended per hectare for long-term agricultural productivity of wheat which is also applicable to most other dryland crops in India.

While Bio-CNG slurry has potential of becoming one of the major financial enablers for Bio-CNG production, it has been highlighted from the field visits in Halol and Chhota Udaipur Bio-CNG plants, that slurry management remains the single biggest challenge for Bio-CNG producers for upscaling production as well as for the nonoptimum usage of plant capacity. A 2-TPD Bio-CNG plant using animal manure as feedstock, running at full capacity produces one lakh litres of slurry per day. Without an established processing unit for slurry enrichment and most importantly without a market for slurry or even enriched organic fertilizer, it is very difficult for producers to manage such huge quantities. In such circumstance, the easiest option for producers is to run the plant at 10%–20% of its capacity to reduce slurry production.

2.5 Action Plan

2.5.1 CAFE Credit Scheme

As per latest reports from May 2023, the Government of India plans to develop the Indian Carbon Market (ICM) where a national framework will be established with an objective to decarbonize the Indian economy by pricing the GHG emission through trading of Carbon Credit Certificates. The Bureau of Energy Efficiency (BEE), under the Ministry of Power (MoP) along with the Ministry of Environment, Forest, and Climate Change (MoEFCC) has developed draft Carbon Credit Trading Scheme for this purpose. The primary target sectors are energy for which GHG emission intensity benchmark and targets will be developed. Also, a voluntary mechanism will concurrently exist for non-obligatory sector.

The ICM will create a competitive market that provides incentives to climate actors and Independent Project Proponents (IPP) to adopt low-cost options by attracting technology and finance towards sustainable projects that generate carbon credits. The ICM will mobilize new mitigation opportunities through demand for credits by private and public entities. It will also provide scope to develop new methodology for estimation of carbon emission reduction and removals from various registered projects, followed by their validation, registration, verification and issuance process to operationalize the scheme. Monitoring, Reporting and Verification (MRV) guidelines for emission scheme will also be developed after consultation. A comprehensive institutional and governance structure will be set up for the same including carbon registries as an issuing authority.

About the carbon registry

The Network for Certification and Conservation of Forests (NCCF) is a registered society established in 2015 that is involved in developing India-specific and globally benchmarked sustainability standards, as its core working area. The NCCF is a member of PEFC (Programme for Endorsement of Forest Certification) Alliance from India, a member of the International Union for Conservation of Nature (IUCN) and has observer status with the United Nations Convention to Combat Desertification (UNCCD). The NCCF started India's first ever scheme for forest certification, giving it global recognition. This scheme is used by many states currently.

Subsequently, it also started Outside Forest Certification Scheme which is currently under the process for PEFC endorsement. The NCCF is also simultaneously developing standards for non-wood forest products, ecotourism, biomass and biofuels, and land degradation among other areas. The NCCF has also set up India's first Carbon Registry (CR-I), which is an endeavour to provide a carbon trading and tracking platform for verified net GHG emissions reduction and removal.

Implementation scheme by CR-I

CR-I also gives standards for design, development, inclusion of projects, new methodologies, and tools along with rules and requirements for operation and monitoring of registered projects and other related activities. The registry lays special emphasis on all round sustainable development from projects and accordingly, registering newly developed Bio-CNG plants solely for the purpose of vehicle transportation can have an edge considering the socio-economic benefits that come with usage of Bio-CNG-based vehicles. The registry also allows savings from carbon dioxide, methane and nitrous oxide which makes our project suitable as an entry for their verification.

The Independent Project Proponent (IPP) will seek CR-I to validate the methodology (as per GHG accounting principles) and subsequently register and issue verification and certification with subsequent issuance of GHG emission reduction or removal units to the newly established Bio-CNG plants. Auto manufacturers, who are using Bio-CNG from such certified plants, must be able to use them for CAFE compliance.

CR-I appoints third party Validation and Verification Body (VVB) who are usually entities with adequate sectoral competency and human resource to effectively observe, evaluate and report on activities carried out by the IPP.

Once verified, the IPP must adhere to additional requirements such as certification renewal, and periodic audits for continuation of registration under the scheme.

2.5.2 Scheme for Slurry Management

National Policy on Organic Farming (NPOF)

- A quantitative target should be set for production of indigenous organic fertilizer in the country.
- Fertilizer manufacturers must have mandatory targets for procurement of slurry from Bio-CNG plants. Such procurement must be incentivized through subsidy given to these plants. Bio-CNG plants must thus become an important part of the fertilizer supply chain.
- Bio-CNG plants registered under carbon registry must also be encouraged to develop their own fertilizer processing units to take benefits of avoided carbon from usage of chemical fertilizer into their operation. This can be achieved through easy loan access, more know-how on organic fertilizer by activating Agricultural Extension Services (AES) in villages and through agricultural universities.
- Existing schemes on organic farming must be expanded or new schemes must be formulated with a target of converting one district in every state into an organic district.
- Farmers must be encouraged to substitute 10%–20% of their fertilizer use with organic fertilizer through fertilizer loans or other financial assistance programmes. This can be pilot tested in states such as Punjab, Uttar Pradesh, and Madhya Pradesh where there is a brewing demand for unique soil additives owing to decreasing productivity.
- Inter-state organic fertilizer trade must be allowed to meet this target within a given period of 4–5 years.

It is anticipated that, promotion of production of organic fertilizer primarily from Bio-CNG plant-based slurry can solve multiple issues at one go. Demand creation for slurry can enable Bio-CNG producers to run their plants at optimum capacity. At the same time, Bio-CNG producers themselves will have the incentive to produce enriched organic fertilizers if farmers seek such products. This will give them additional benefit of avoided carbon associated to their plant thereby encouraging auto manufacturers to buy gas from them. Benefits of such avoided carbon to CAFE will ensure that their primary product, i.e., Bio-CNG also has a sustained demand among automakers.

3. Well-to-Wheel Analysis of Fuels and Powertrain Components of EVs And ICEVs (PETROL, DIESEL, CNG, and Bio-CNG)

For the purpose of presenting a comprehensive sustainability assessment of passenger vehicles across various fuel types, it is important to understand emissions linked to upstream production of fuels (well-to-tank) and as well as the emissions during the use phase (tank-to-wheel). Accordingly, a comparative well-to-wheel Global Warming Potential (GWP) analysis of fuels and powertrain components of EVs and ICEVs (petrol, diesel, CNG and Bio-CNG) was undertaken and the key insights are presented below.

GWP is the most used parameter to assess the climate change potential of emissions. The GWP refers to the amount of energy that 1 tonne of gas will absorb over a given period, relative to 1 tonne carbon dioxide (CO_2). Most common greenhouse gases (GHGs) responsible for climate change are carbon dioxide, methane, and nitrous oxide. All these gases are considered in this study but are not marked individually and are represented as CO_2 equivalent.

Data from 4-wheeler vehicles, which has all the variants of diesel, petrol, CNG and EV is used for calculations. The GWP impact is presented for the entire lifetime of the vehicles which is taken as 160,000 km. From the results of the 4-wheeler category, it is found that Bio-CNG vehicles are best performing when it comes to global warming impact with an emission intensity of -1141 g CO_2 eq./km followed by EVs which has an emission intensity of 151 g CO_2 eq./km. Diesel, petrol and CNG vehicles have an emission intensity of 170 g CO_2 eq./km, 190 g CO_2 eq./km and 143 g CO_2 eq./km respectively. These figures are represented in Table 3 and Figure 1.

Table 3: Well-to-Wheel (WTW) emission intensity of vehicle technologies running on different fuel types

Fuel types	Emission intensity of Well-to-Wheel analysis (g CO_2 eq./km)
ICE Petrol	190
ICE Diesel	170
ICE CNG	143
EV	151
ICE Bio-CNG	-1141

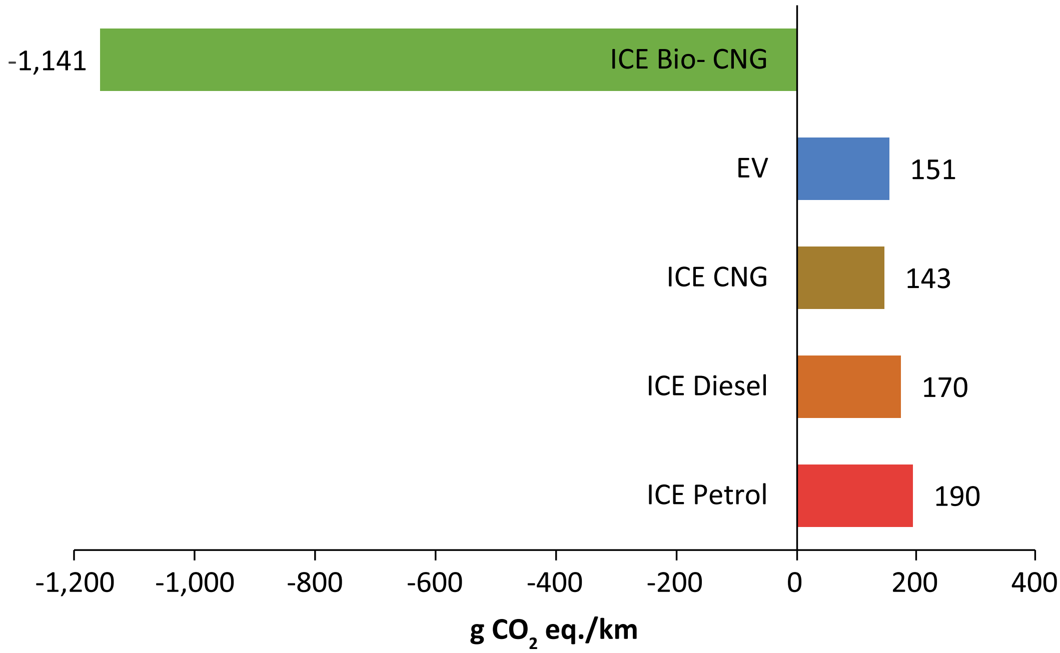

Figure 1: Well-to-Wheel emission intensity of vehicle technologies running on different fuel types

The GWP impacts of vehicles running on different category of fuel segregated into 3 stages are presented in Figure 2.

The GWP impact in the upstream phase is influenced by the weight of powertrain components (engine, battery, and motor). The diesel engine is 170 kg while the petrol, CNG and Bio-CNG engines are 87 kg. Composition of all materials considered, makes up to 80%–85% of this weight. The upstream GWP impacts associated with the petrol, diesel, CNG and Bio-CNG vehicles are 6170 kg CO_2 eq., 4443 kg CO_2 eq., 4433 kg CO_2 eq. and -182,412 kg CO_2 eq. respectively for entire lifetime of the vehicles. This includes impacts associated with engine manufacturing and Well-to-Tank (WTT) emissions of the fuel. Significant methane savings in the Bio-CNG production process has contributed to high negative WTT emissions of Bio-CNG.

The EV has an upstream GWP impact of 22,384 kg CO_2 eq. which is largely contributed by emissions associated with electricity generation which has an emission intensity of 0.79 kg CO_2 eq. /kWh. The EV battery has a heavy weight of 210 kg which is significantly composed of large amounts of aluminium and a variety of steel types like chromium and electrical steels, while the EV motor has a weight of 32 kg, which is the lowest among powertrain components.

Figure 3 breaks down the emission associated with different upstream components of the chosen vehicle types. Along with the heavy weight, the cathode materials used in batteries are extracted and processed through energy and emission intensive procedures which makes the battery the highest contributor to upstream emissions among powertrain components at 849 kg CO_2 eq. However, major contributor to upstream emissions of EV is coal intensive Indian grid at 21,425 kg CO_2 eq.

The use phase emissions of EVs are associated with electricity losses incurred during charging which amounts to 2,360 kg CO_2 eq. While for ICE, the use phase emissions are 24272 kg CO_2 eq., 23110 kg CO_2 eq., 18754 kg

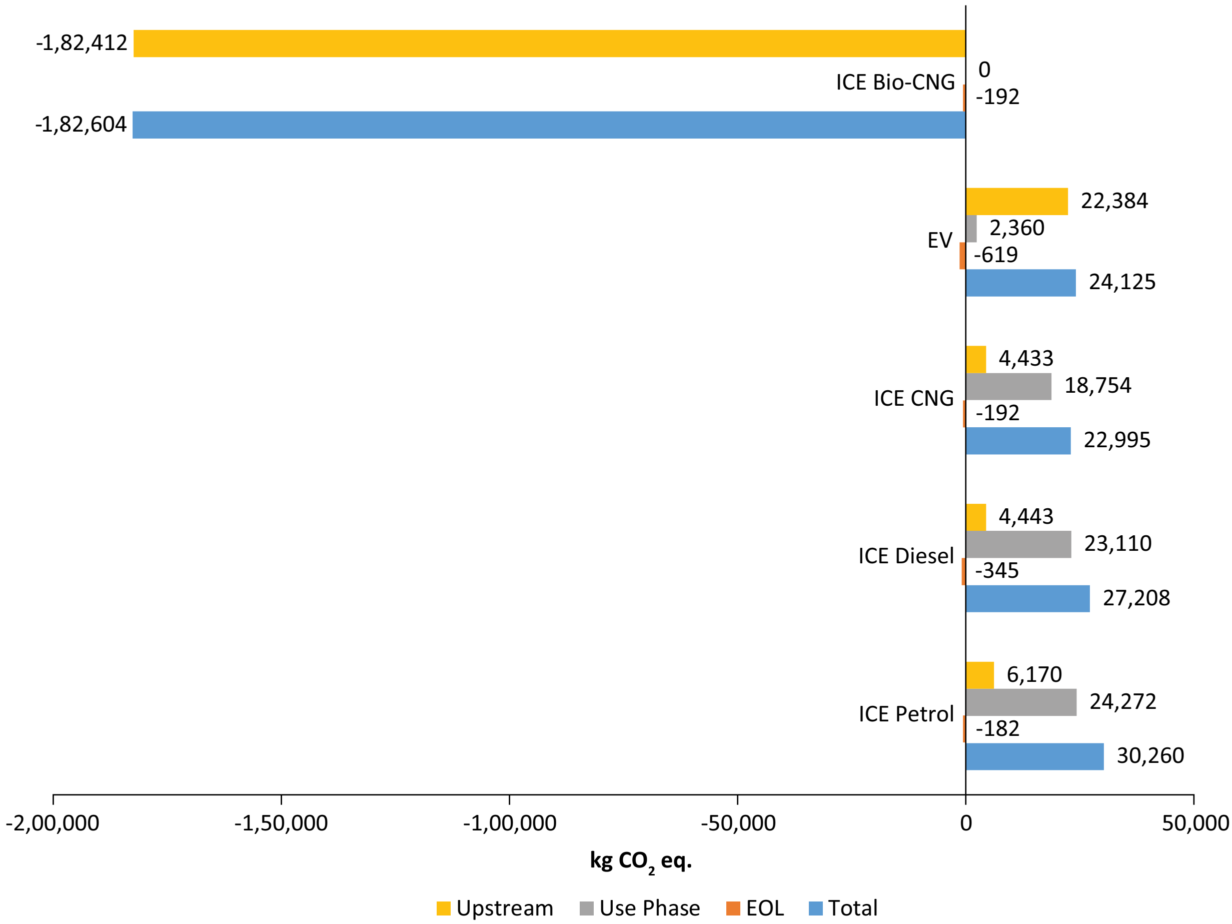

Figure 2: GWP impact (kg CO_2 eq.) of 4-wheeler ICE (diesel, petrol, CNG, and Bio-CNG) and EV segregated into 3 life cycle stages

CO_2 eq. and 0 kg CO_2 eq. for petrol, diesel, CNG, and Bio-CNG, respectively. We have considered the tailpipe emissions of Bio-CNG vehicle to be zero because these CO_2 emissions released on combustion of Bio-CNG produced from cow dung are not considered to contribute to climate change because they are part of the short-term carbon cycle (i.e., the CO_2 emitted on combustion was absorbed in the system from the current atmosphere). The emission intensity considered for rest of the ICE vehicles is at 2.667 kg CO_2 eq./litre of diesel, 2.311 kg CO_2 eq./litre of petrol, and 2.69 kg CO_2 eq./kg of CNG. Increased fuel efficiency of the diesel engine gives higher mileage and total amount of diesel required for the vehicle lifetime is 8,665.1 litres while it is higher for petrol at 10,502.9 litres causing higher use phase impact for petrol despite lower emission intensity. A total of 6972 kg of CNG and Bio-CNG is required to run a total of 160,000 km assuming a mileage of 22.95km/kg of gas for both CNG and Bio-CNG.

The Well to Tank (WTT) emissions of ICE Petrol, Diesel, CNG and Bio-CNG are 5834 kg CO_2 eq., 4013 kg CO_2 eq., 4097 kg CO_2 eq. and –182076 kg CO_2 eq. respectively. Petrol production involves a more intensive refining process leading to higher emissions while it is extremely negative for Bio-CNG due to large amount of upstream methane avoidance during Bio-CNG production from cow dung.

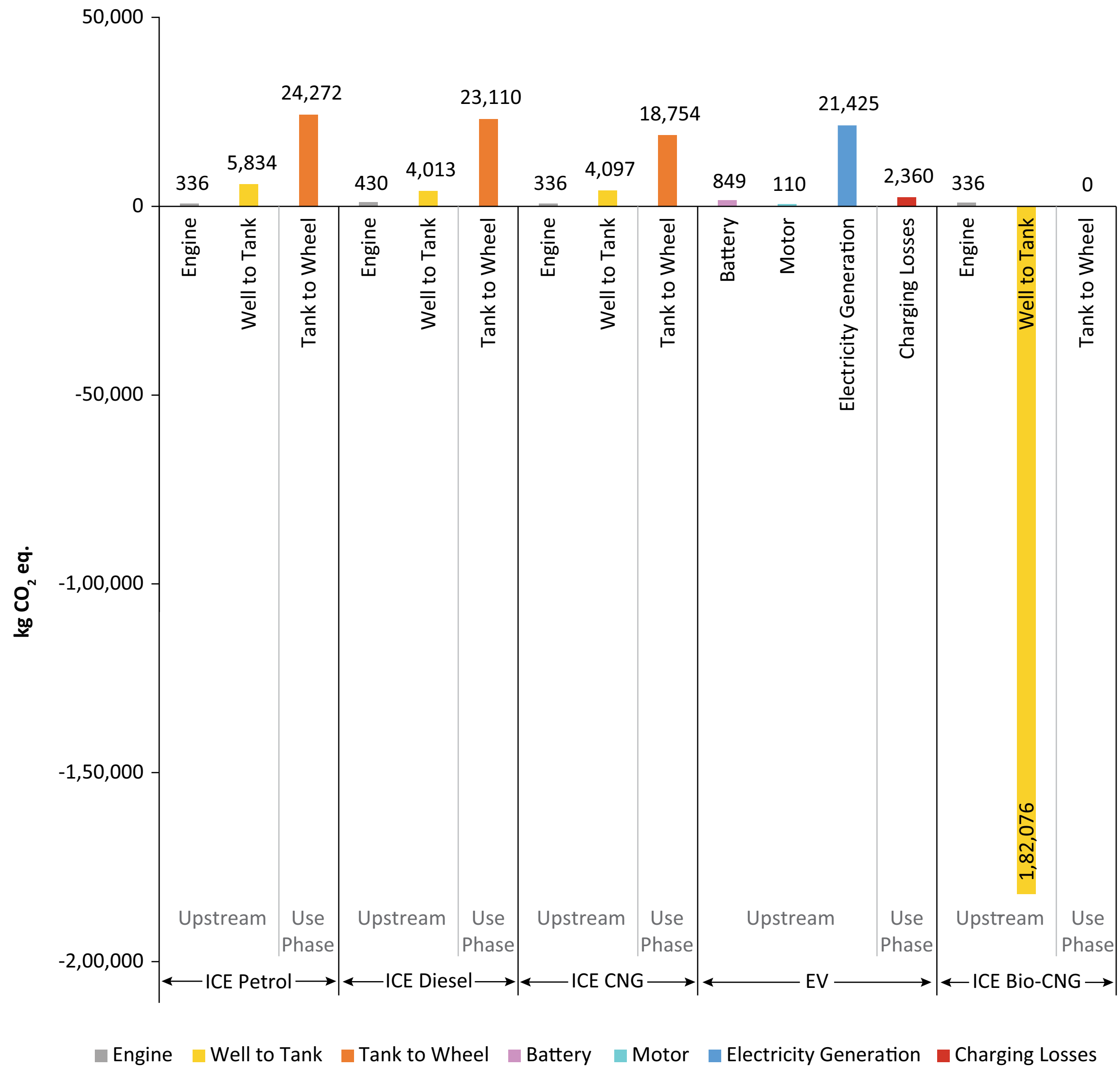

Figure 3: Breakdown of GWP impact (kg CO_2 eq.) of upstream and use phase of 4-wheeler EVs and ICE vehicles (Petrol, Diesel, CNG, and Bio-CNG)

The End-of-life emissions (EOL) has given higher benefits to EV than ICE vehicles. Virgin materials that go into making EV components have higher resource and energy intensity and hence replacing them with recycled materials is likely to benefit the environment more.

For ICE vehicles, the amount of output materials from recycling process which also serve as virgin materials avoided is multiplication of total amount of material recycled with the recycling yield of each material which is assumed to be 95% for all for the sake of simplicity. The recycling yield of most metals like aluminium, steel, cast iron, copper and manganese ranges between 90%-100% in standard recycling processes.

Avoided materials = Recycled amount* Recycling yield

From the above analysis it is evident that usage of Bio-CNG as an alternative vehicular fuel can be a game changer in mitigating GHG emissions from the transportation sector.

4. Policies and Initiatives

Policies play a key role in steering the change in a certain direction, nudging all the stakeholders to act towards a desired outcome. Sometimes policies facilitate such outcome while at other times, they may also become a hindrance. Considering the objective of mainstreaming Bio-CNG-based transportation in India, it is important to understand the existing policies around this in India as well as in other countries who are pioneering in adoption of Bio-CNG for mobility. National and international policies around Bio-CNG generation and use along with organic farming are stated below:

4.1 National Policies

In view of the potential environmental benefits, the Government of India had announced a number of policies to promote Bio-CNG that can replace fossil-based fuels. Some of the national policies are presented below.

» **National Bio-CNG Manure Management Programme (NBMMP)-** Under this programme, financial assistance is provided for setting up family type plants. The NBMMP has been implemented by State Nodal Agencies and Departments in 1981-1982 with the primary objective of providing clean cooking fuel with the aim of ensuring social security and reducing female drudgery, reducing the dependence on conventional fuels like LPG, as well as to reduce the use of chemical fertilizers by supplying organic manure in rural India.

» **GOBARDhan-** Department of Drinking Water and Sanitation (DDWS) launched Galvanizing Organic Bio-Agro Resources Dhan (GOBARDhan) scheme in 2018, as an integral part of the Swachh Bharat Mission Grameen (SBM-G). Under Phase-II of the scheme, financial assistance up to Rs 50 lakh is to be provided per district for the period of 2020-21 to 2024-25 for setting up of cluster/community level biogas plants.

» **SATAT Scheme (Sustainable Alternative Towards Affordable Transportation)** – Bio-CNG entrepreneurs and producers are encouraged under the scheme to set up new plants or enhance capacity of existing plants for Bio-CNG production, which is to be sold to Oil Marketing Companies (OMCs) to be used as vehicular or industrial fuel. SATAT also has additional objectives of producing fermented organic manure (FOM) from Bio-CNG plants. Viable projects under SATAT are eligible for loans up to 75% of the project cost. Over the course of last 5 years, 46 plants have been commissioned and over 16,000 tons of BIO-CNG has been sold.

» **Paramparagat Krishi Vikas Yojana (PKVY)-** PKVY strives to encourage organic farming, thereby leading to enhancements in soil health. Under PKVY, a subsidy of Rs. 50,000 per hectare for 3 years is provided to the farmers for major inputs required for establishing bio-fertilizer units, vermicomposting, botanical extracts etc. for the production, procurement, and post-harvest management of crops.

» **National Project on Organic Farming (NPOF) -** The scheme focuses on the assembly, promotion & market development of organic farming within the country through the National Centre of Organic Farming. The project includes financial assistance for setting up bio-fertilizer production units such as from fruits and vegetable market waste compost, bio-fertilizers, and bio-pesticides and vermiculture hatcheries. The scheme encourages the human resource development, awareness creation and market development for quality control of organic inputs.

- **Market Development Assistance (MDA) Scheme-**The MDA scheme has been launched with a robust budget of Rs.1451.82 Crores spanning three years (FY 2023-24 to FY 2025-26) with an emphasis on the "waste-to-wealth" approach. The initiative aims to promote production and take-up of organic fertilizers generated from GOBARdhan plants to promote sustainable and organic agricultural practices. The national government has also issued directives for MDA, offering Rs.1500 per metric ton for fermented organic manure or from compressed biogas (CBG) facilities, marking a significant step in sustainable agriculture.
- **Waste to Energy (WTE) Programme-**The Ministry of New and Renewable Energy is implementing Waste to Energy (WTE) Programme under the umbrella of National Bioenergy Programme. The WTE Programme has a budget outlay of Rs 600 crore for the period FY 2021-22 to FY 2025-26. This programme supports setting up of plants for generation of Bio-CNG from urban, industrial, and agricultural waste by providing central financial assistance (CFA).
- **Green Credits Programme-** In 2023, the Ministry of Environment, Forest, and Climate Change has launched the Green Credits Programme to boost the 'Lifestyle for Environment' Mission announced by the Indian Prime Minister at COP26. ICFRE has been appointed as the nodal authority for administering and monitoring the programme. The Green Credits Programme aims at encouraging environmentally conscious actions by the stakeholders through introduction of a market-based mechanism for incentivizing these climate conscious practices, thus moving towards a circular economy. Tree plantation, water conservation, sustainable agriculture, waste management, air pollution reduction, mangrove conservation and restoration, sustainable building and infrastructure, etc. are the categories included for claiming green credits under the programme.

It is evident that barring the SATAT scheme, there is no current policy that encourages large scale Bio-CNG production for vehicular usage. Even after 5 years from the roll out of SATAT, the production of Bio-CNG has not happened at the expected scale owing to several challenges and gaps. The foremost among them is lack of competitive pricing and an assured market for Bio-CNG and other by-products of Bio-CNG plants. As already mentioned, slurry management is a limitation for producer but there is a lack of initiative to streamline the slurry into the value chain of the Bio-CNG business itself. There are isolated schemes in India that promote organic farming at a village or cluster level; however, the effort is limited to only providing minimal subsidy and mostly to provisioning of post-harvest certification through schemes like National Programme on Organic Production (NPOP) and Participatory Guarantee Scheme (PGS) for marketing of produce. The newly launched Green Credit Programme has the potential of incentivizing the production of Bio-CNG for mobility by the inclusion of Bio-CNG as a sub category for claiming Green Credits. There is a need to have a dedicated policy/scheme that solves the issues at each stage of the Bio-CNG value chain, right from its feedstock procurement to marketing of the gas and the byproducts.

4.2 International Policies

Several efficacious international strategies for enhancing the production and adoption of Bio-CNG and mitigating emissions could serve as instructive paradigms for India. Few such initiatives are mentioned below.

- **Alternative Fuels Infrastructure Regulation** (**AFIR**): In July 2021, the European Commission presented the updated Alternative Fuels Infrastructure Regulation (AFIR). Its major aim is to address the growing emissions in road transportation to support the transition to a nearly zero-emission car fleet by 2050.

» **Sweden**: Sweden was among the first countries, as early as 1996, to use Bio-CNG generation for mobility. All the country's city buses have been powered by the fuel since that time. Additionally, it is also the first country in the world to have Bio-CNG-powered train. Sweden has offered financial incentives to encourage the use of Bio-CNG in transportation, including exemptions from energy taxes, cash premiums and tax exemptions that benefit the consumers, and a 2006 law that focused on the infrastructure for renewable transport fuels. Because the cost of distribution infrastructure was far lower in Sweden, the number of ethanol filling stations increased quickly. Additionally, the Swedish government has put in place investment initiatives like Klimp to promote the production, distribution, and use of renewable transportation fuels.

» **Germany**: Germany's Bio-CNG sector expanded in 2000 because of the Renewable Energy Sources Act. To promote the use of conventional agricultural wastes in Bio-CNG digesters, new categories of subsidies and incentives were also established, such as slurry bonus. Berlin, Germany collects its organic waste separately to produce Bio-CNG. This Bio-CNG is used as fuel by the trucks that collect waste. The digestate from the Bio-CNG production is purchased by farmers and applied as organic fertilizer.

» **Brazil**: Brazil launched the "RenovaBio" National Biofuel Policy on December 27, 2017, with the following goals in mind: (i) upholding the obligations under the Paris Agreement; (ii) increasing the share of biofuels in country's total energy mix (iii) fostering a proper relationship between energy efficiency and greenhouse gas emission reduction, and (iv) bringing the element of competition to biofuel market.

5. Assessing Social Benefits from the use of Bio-CNG in India's Rural Mobility

5.1 Introduction

Easy transportation of people and goods across places is crucial for economic development. With unreliable public transportation, people are switching to private vehicles. However, India is already struggling to manage the emissions of existing transportation system in the country, hence, introduction of more vehicles will add to this standing problem. In this regard, Bio-CNG emerges as a sustainable alternative.

Urban areas have witnessed a rapid advancement in the mobility revolution because of government initiatives nudging stakeholders to swiftly switch over to electronic vehicles. However, for developing countries like India where urbanisation is still underway, majority of the population resides in rural area. While the government aims at rapidly increasing the share of electronic vehicles, a diverse mobility solution is required, especially for rural India which still lags in terms of access to transportation facilities and introduction of e-mobility is a challenge in immediate future. It is important to focus on renewable vehicular fuel as well to bridge the rural-urban gap. This can be accomplished by leveraging the nation's significant potential for using Bio-CNG as a cost-effective sustainable alternative for the transport sector, given India's abundance of organic waste. This will aid the country in meeting its obligations under the international agreements to combat climate change, reducing its growing reliance on energy imports, and meeting the expanding domestic energy demand. It will also have a direct impact on improving the quality of life in rural areas by reducing the time and money spent on transportation. Additionally, it will also have a secondary impact on providing easy and affordable access to external markets. This will help in increasing the farmers' income and provide people with new economic opportunities. Therefore, by enhancing people's socio-economic conditions, affordable, clean, inclusive, and reliable mobility will assist the country in inching closer to achieving the Sustainable Development Goals.

5.2 Approach

Rural households manoeuvre around their complex commuting decisions daily with most of them not having permanent workplaces and thus no fixed trip pattern (TERI; SDS, 2017). The lack of efficient and connected public transport systems add to their woes. Thus, sustainable and shared mobility solution needs to be explored which can make commuting easier for the rural population alongside mitigating GHG emissions. Bio-CNG is a potential solution for solving the dual problem of transportation as well as vehicular emissions. However, Bio-CNG market is not fully developed yet. In the absence of Bio-CNG for large scale adoption as a potential replacement for petrol/ diesel, this section looks at CNG as a transition fuel where the attitude of rural population towards adoption of the transition fuel would mimic the perceptions that an individual will have towards Bio-CNG. This hypothesis holds under the condition that Bio-CNG is priced equal to or lesser than CNG.

The introduction and implementation of a new technology needs to take into consideration the perceptions of the people who are impacted by the technology to understand the readiness of the targeted population to adopt the technology when made available. The approach towards the proposed analysis in purview of this paper has been to capture only the fuel related monetary savings resulting from the adoption of CNG mobility in rural areas instead of Petrol run vehicles. The total monetary savings will be result of two scenarios- first, fuel related monetary savings from existing owners of Petrol vehicles transitioning to CNG vehicles, and second, savings from introduction of CNG vehicles for people with no personal vehicles. In this section, only the first scenario is explored under the ideal hypothetical condition of all existing Petrol vehicles transitioning to CNG along with close availability of CNG fuelling stations, which maximises the savings. However, the actual savings from introduction of CNG transportation for people with no modes of personal conveyance will be over and above the fuel related monetary savings with a component of time and toil cost being saved, which is outside the scope of this paper. The benefits of transition to CNG vehicles in rural areas will also have several direct and indirect impacts on key indicators of SDGs which is mapped in Section 6.

5.3 Methodology

The methodology adopted for studying the social benefits of affordable mobility in rural areas relies on both qualitative and quantitative research. CNG has been taken as transition fuel which is used as a proxy to capture the benefits of Bio-CNG since the market for latter has not been fully established. The views of rural population on CNG is assumed to reflect their inclination towards adopting Bio-CNG when made available, given the assumption that Bio-CNG is set at a price equal to or less than CNG. The analysis is done for rural areas in Gujarat due to its lucrative car sales and favourable market conditions with large inflow of first time buyers of 4-wheelers from rural areas. Gujarat is also one of the leading states to show interest in Bio-CNG. The objectives and corresponding study methods have been summarized in Table 4.

Table 4: Study Methodology of Social Benefit Assessment of Bio-CNG

S. No.	Objectives	Methodology	Assumptions
1.	Understanding Consumer's Perception	i) Field survey and one-to-one discussion in villages of Halol, Kalol, and Chota Udaipur in Gujarat. ii) Primary interview of replacement buyers of CNG vehicles in rural areas of Gujarat.	Attitude of rural population towards CNG is assumed to reflect attitude towards Bio-CNG, when available.
2.	Capturing social benefit arising from transition of existing Petrol vehicles to CNG vehicles in rural Gujarat.	Secondary data analysis Cost per kilometre comparison of Petrol versus CNG Estimation of fuel related monetary savings under the scenario of all Petrol 4-wheelers switching to CNG in rural Gujarat.	Bio-CNG is assumed to be priced equal to or less than CNG.
3.	Understanding the linkage of Affordable and Sustainable mobility with the SDGs	Mapping the findings as well as indirect impacts to key targets under SDGs.	

5.3.1 Social Perceptual Response Analysis: Field Visit

A comprehensive understanding of the correlation of affordable rural mobility and the social wellbeing of the locals can be achieved through field surveys that will enable us to first-hand experience their daily lives and complexities. Accordingly, an on-field survey was conducted in the nearby villages of the Halol, Kalol and Chhota Udaipur cites of Gujrat. One-to-one interaction with the villagers was undertaken going from household to household.

Nearly 30 households were covered in total. The interaction aimed at understanding the inclination of people towards buying CNG fuelled vehicles instead of Petrol ones. Respondents were also asked about the improvements that they have experienced because of access to transportation and the difficulties faces by them in using CNG vehicles.

5.3.2 Social Perceptual Response Analysis

To gain further insight into the perceptions of rural population regarding CNG vehicles and the difficulties faced by them, an additional primary survey was conducted consisting of in-depth telephonic interviews of replacement buyers of CNG fuelled 4-wheelers from rural areas of Gujarat, with their consent. In total, 30 customers responded to all relevant interview questions with each interview lasting not more than 5–7 minutes. The responses for each of the consumers were recorded in individual questionnaire.

The questionnaire was prepared with the primary motive of understanding to what extent cost consideration is a primary driver of shifting from Petrol to CNG. This would give an insight into the readiness of people to switch to Bio-CNG when made available and economical. The consumers were inquired about six broad questions pertaining to-

» The fuel type of the previous four-wheeler owned by them,

» The purpose for which the vehicle is used, i.e., personal or business,

» The duration of ownership of CNG vehicle,

» The reason for switching from petrol or diesel to CNG if they previously owned a vehicle powered by either of the two, or why they chose CNG powered vehicle over others if they have only owned CNG vehicle previously,

» Whether they can observe any savings from using CNG vehicle. If yes, then the purpose to which the fuel related monetary savings from adopting CNG were diverted,

» The ease of accessing CNG infrastructure in their locality and other difficulties faced, if any.

5.3.3 Secondary Data Analysis

The secondary data analysis has been done to capture the first scenario discussed earlier with respect to estimating the fuel related monetary savings that will be realized by the existing owners of Petrol vehicles from transitioning to CNG in rural Gujarat under ideal conditions and how this savings is divided across various non-conveyance expenditure heads- nutritional security, health, and education. The complete calculation along with assumptions and sources are produced in *Annexure 6 and Annexure 7*.

Fuel related monetary savings from transition to CNG is estimated as follows:

» Observer Research Foundation reports the average distance travelled by an Indian to be 5000 km/ year, i.e., approximately 14 km/day. Therefore, two scenarios of average distance travelled by a car is taken- 15 km/day and 30 km/day.

» Per kilometre cost is calculated for petrol as well as CNG powered four-wheeler at the average petrol and CNG prices prevailing in Gujarat as in September 2023 and average mileage of petrol and CNG four-wheelers.

» Yearly fuel related monetary savings from transition of one car from Petrol to CNG is calculated.

» Yearly fuel related monetary savings from transition to CNG under ideal condition of all existing Petrol 4-wheelers in rural Gujarat switching to CNG is calculated.

» The proportion of the saving going into education, healthcare and nutritional security is produced using the expenditure pattern as per the Household Consumption Expenditure Survey of NSS 68th round 2011-2012, MoSPI *(See Annexure 6)*.

5.4 Data

The data used for analysis in this paper has been obtained from the following sources:

» Data has been collected for perception study through on field interaction in the villages of Halol, Kalol, and Chota Udaipur in Gujarat, and telephonic interview of 30 replacement buyers of CNG vehicles in rural areas of Gujarat from the sales record provided by different OEMs.

» Monthly per-capita consumption expenditure of rural area on various broad food and non-food items were taken from the Household Consumption Expenditure Survey of NSS 68th round carried out by the Ministry of Statistics and Programme Implementation (MoSPI) for the period from July 2011 to June 2012.[2]

» The vehicle population data has been taken from the Commissionerate of Transportation, Government of Gujarat.[3]

» The average size of a household for rural Gujarat has been obtained from National Family Health Survey-5 of the Ministry of Health and Family Welfare.[4]

5.5 Key Findings

5.5.1 Social Perceptual Response Analysis: Field Visit

During the visit to Halol, Kalol, and Chota Udaipur villages in Gujarat, the presence of CNG fuel stations and various public transportation options such as buses, three-wheelers, two-wheelers, and few instances of four-

2 https://mospi.gov.in/sites/default/files/publication_reports/Report_no558_rou68_30june14.pdf

3 https://cot.gujarat.gov.in/vehicle-popullation.htm

4 https://ruralindiaonline.org/en/library/resource/national-family-health-survey-nfhs-5-2019-21-gujarat/

wheelers and shared mobility services were observed. The youth were seen to have the option to use personal vehicles as well as public transport for travelling to colleges and women were seen to rely on three-wheelers and other shared mobility services for travelling to markets, work, and for other household activities. Most women in these villages lack driving skills and therefore depended on the men of the household for using personal vehicle.

CNG stations have introduced the urban concept of door-to-door marketing in the villages as well from vegetable vendors and ready-made garment sellers to jewellery and other fancy items. This has positively impacted consumers' buying habits and saved time. Additionally, few women engaged in home-based craft works and cooking reported that the availability of vehicles has enabled them to sell their products in the local market, thus empowering them. There was a unanimous acceptance among the respondents that improved mobility enabled them in commuting to nearby towns/cities thereby expanding the scope of their livelihood.

Affordable mobility depends on the operating cost of the vehicle as well over the cost of ownership. CNG vehicles offer better fuel efficiency at reduced fuel cost as compared to Petrol vehicles and therefore it was found that most vehicles of the surveyed areas were run on CNG. There were respondents whose livelihood depended on vehicles like auto-rickshaw drivers and cab drivers. A trend was observed among them for owning CNG vehicles due to the reduced operating cost. The field survey primarily indicated that the affordability of CNG was the prime reason that led to its higher adoption in these villages. This was seen to be happening even though fuelling stations were considerably far away (within a 50 km radius) in comparison to petrol and diesel fuelling stations. Additionally, it was also found that aspirations to buy CNG vehicles were palpable among the current petrol and diesel vehicle owners. Also, affinity was observed to go for a cheaper fuel like Bio-CNG and willingness to even retro-fit the vehicle if a cheaper fuel is made accessible.

5.5.2 Social Perceptual Response Analysis

Of the 30 interviewees of primary survey conducted through telephonic interview, 15 reported owning CNG vehicles previously as well, while 15 switched from petrol and diesel to CNG (See Figure 4). Fuel economy emerged as the most important aspect of choosing a vehicle for the rural consumers. Twenty-five interviewees reported that CNG vehicles gave them better mileage and cost savings than petrol or diesel vehicles as they found CNG to be cheaper (See Figure 5).

Cost savings was stated as the prime reason for preferring CNG powered vehicles over petrol ones, especially by the consumers working as taxi drivers and people who were using the vehicle for business purposes. Few consumers reported the availability of CNG fuelling stations nearby as the reason for transition. While 3% of the interviewees reported ease of owning a CNG vehicle as a reason, nobody reported environmental concerns as a reason for preferring CNG vehicles over Petrol vehicles. However, it needs to be noted that although environmental concerns were not the primary driver of change for rural consumers, reduction in pollution was acknowledged when brought up. Few of the interviewees also reported the limited availability of CNG fuelling stations nearby as one of the major limitations with some reporting it to be as far as 20 km from their locality. This can also be a reason why some of the interviewees were not able to realize significant savings from CNG. Yet, even those who faced infrastructural limitations favoured CNG vehicles due to the mileage it offered.

Of the consumers surveyed, majority were not able to state with precision the amount of savings and among the interviewees who were able to approximate the monthly savings, the reporting varied. This has to do with the fact that few of them travelled less distance to be able to realize noteworthy savings while few others had fuelling stations far away. Since the saved money was not literally coming to hand in lump sum, the interviewees could not precisely state what proportion of the savings was going into what expenditure heads. Majority of them specified that the money was spent on meeting daily household expenses. Few of the people whose livelihood depended on cars said they used the money saved in their business and for paying loans.

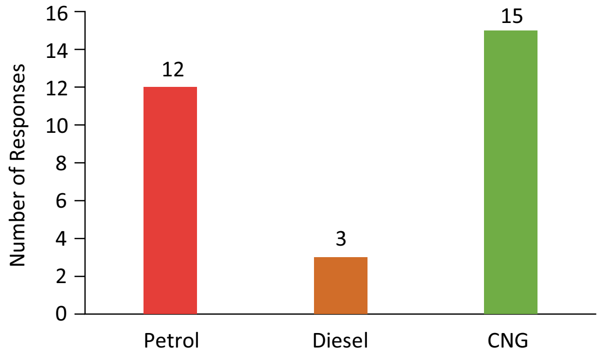

Figure 4: Fuel Type of the Previously owned vehicle

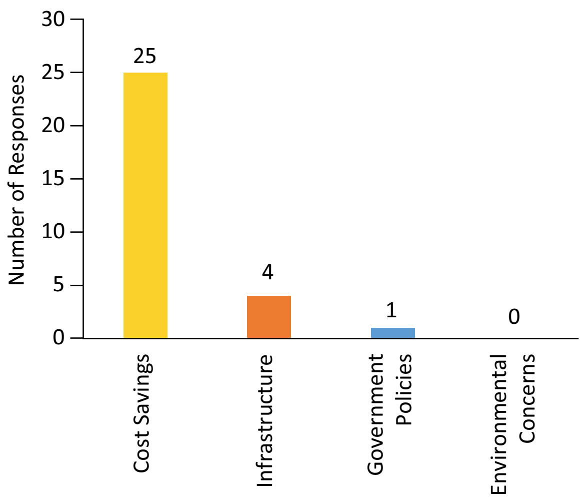

Figure 5: Reason for switching to CNG

The perception study conducted using the in-depth telephonic interview confirms cost savings experienced by the consumers by using CNG vehicles has been the primary driver of shift from Petrol to CNG, reiterating the findings form field visit. Although the reporting varied, some of the interviewees were able to overtly state the savings while the others covertly realized it in the form of improved fuel economy. Thus, majority of the consumers perceived CNG to be cost effective. However, limited infrastructural facilities of CNG stations in rural areas considerably drained the potential savings that the consumers could have realized from using CNG under perfect conditions.

5.5.3 Secondary Data Analysis

The estimation of approximate fuel related monetary savings from transition of one Petrol car to CNG shows that it reduces transportation expenditure of a household considerably, releasing money to be spent on other necessities. Full calculations with sources are produced in *Annexure 7*.

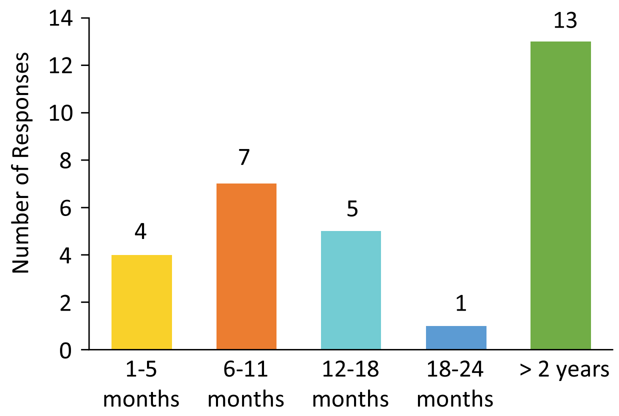

Figure 6: Duration of using CNG vehicles

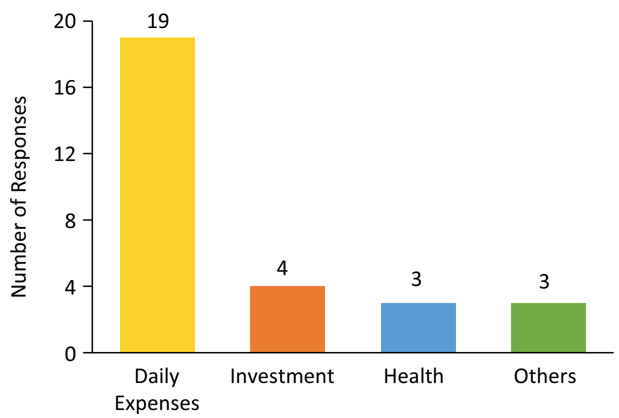

Figure 7: Allocation of fuel-related monetary savings

The yearly fuel related monetary savings from 6,56,409 registered Petrol fuelled 4-wheelers in rural Gujarat *(see Annexure 7 for estimation)* transitioning to CNG is calculated by comparing the per kilometre cost of Petrol and CNG powered four-wheelers for 2 scenarios- Case 1, where the distance covered is 15 km per day, and Case 2, where the distance covered is 30 km per day.

The per kilometre cost incurred on a Petrol-powered car at prevailing average Petrol price in Gujarat is Rs. 5.65 and that for a CNG powered car is Rs. 2.92 *(See Annexure 7)*. Thus, the per kilometre fuel related monetary savings from the transition of one 4-wheeler is Rs. 2.727. The fuel related monetary savings realized from complete transition are as follows:

CASE 1: Average daily distance covered is 15 kilometres

Hypothetically, if all the 6,56,409 4-wheelers were to transition to CNG, under ideal condition of availability of CNG stations nearby, the estimated yearly savings realized when the car is travelling 15 km a day would be Rs. 9.67 billion. This is the estimated total amount released in Gujarat's rural economy to be spent on other expenditure heads of the rural household.

Per kilometre cost of one Petrol based 4-wheeler= Rs. 5.647

Per kilometre cost of one CNG based 4-wheeler= Rs. 2.92

Per kilometre fuel related monetary savings from one Petrol 4-wheeler transitioning to CNG = Rs. 2.727

Yearly distance covered= 5,400 kilometres

Yearly fuel related monetary savings from transition of one 4-wheeler to CNG= 2.727*5400= Rs. 14,725.8

Therefore,

Yearly fuel related monetary savings from 6,56,409 4-wheelers transitioning to CNG in Case 1= Rs. 9.67 billion

CASE 2: Average daily distance covered is 30 kilometres

In the second case where the 4- wheeler is covering 30 km/ day, as the distance doubles the yearly savings in rural Gujarat from complete transition under ideal conditions would also double to Rs. 19.33 billion.

Per kilometre cost of one Petrol based 4-wheeler= Rs. 5.647

Per kilometre cost of one CNG based 4-wheeler= Rs. 2.92

Per kilometre fuel related monetary savings from one Petrol 4-wheeler transitioning to CNG = Rs. 2.727

Yearly distance covered= 10,800 kilometres

Yearly fuel related monetary savings from transition of one 4-wheeler to CNG= 2.727*10,800= Rs. 29,451.6

Therefore,

Yearly fuel related monetary savings from 6,56,409 4-wheelers transitioning to CNG in Case 2= Rs. 19.33 billion

An insight can be derived on how this savings are divided by rural households among major expenditure heads like nutrition, health, and education using the monthly per-capita consumption expenditure of rural area on various broad food and non-food items taken from the Household Consumption Expenditure Survey of NSS 68th round carried out by the Ministry of Statistics and Programme Implementation (MoSPI) for the time period from July 2011 to June 2012 given in Table 4 *(See Annexure 6 for detailed table).*

Table 5: Monthly per-capita consumption expenditure of rural area on various broad food and non-food items		
Item Group	**Rural (in Rs.)**	**Weightage of Item Groups (in %)**
cereals & cereal substitutes	154	10.76
pulses & their products*	42	2.94
milk & milk products	115	8.04
edible oil	53	3.70
egg, fish & meat	68	4.75
vegetables	95	6.64
fruits	41	2.87
sugar, salt and spices	76	5.31
beverages, refreshments, processed food	113	7.90
pan, tobacco & intoxicants	46	3.21
fuel and light	114	7.97
clothing & footwear	100	6.99
education	50	3.49
medical	95	6.64
conveyance	60	4.19
other consumer services	57	3.98
misc. goods, entertainment	76	5.31
rent	7	0.49
taxes and cesses	4	0.28
durable goods	65	4.54
All items	**1431**	**100**

Source: Household Consumption Expenditure Survey of NSS 68th round; MoSPI

The combined weightage of cereals, pulses, milk, edible oil, egg, fish and meat, vegetable, fruits, spices, and processed food in Table 4 is 52.91% of the total expenditure. The weightage of health expenditure is 6.64% and that of education is 3.49% of total expenditure for a rural household.

Thus, in Case 1 where the fuel related monetary savings from transition is Rs. 9.67 billion, assuming the expenditure pattern to remain same as given by Table 4, the proportion of estimated yearly savings that will go into ensuring nutritional security of rural Gujarat is Rs. 5.11 billion. The share of savings that will be additionally spent on health and education in rural Gujarat is Rs. 641.83 million and Rs. 337.35 million, respectively.

In case 2, the corresponding share going into ensuring nutritional security, healthcare, and education services for rural Gujarat doubles to Rs. 10.23 billion, Rs. 1.28 billion, and Rs. 674.70 million respectively as the savings double to Rs. 19.33 billion.

6. Implication of Affordable Mobility and Selected Sustainable Development Goals

Considerable share of the Indian population resides in remote rural areas which makes it crucial to provide affordable sustainable transportation facilities to integrate these regions into the mainstream. Thus, sustainable rural transport becomes a precondition for accomplishing other Sustainable Development Goals. The findings of this paper demonstrates that introduction of clean and cheap mobility in rural areas help in reducing the expenditure of households on transportation. This has numerous benefits spanning various social indices which are in tandem with the SDGs. A shift to CNG or in fact, to the even better environmentally benign option of Bio-CNG will have direct and indirect positive impact across several targets pertaining to poverty, inequality, climate change, employment, nutrition, etc. under the SDGs, given that Bio-CNG is priced equally or lesser than CNG.

The direct and indirect linkages of green and affordable mobility with Sustainable Development Goals are explored below:

***Poverty, hunger, healthcare, and education (Goals 1-4)*:** Affordable mobility is not a direct contributor to achieving SDG 1-4. However, it has indirect positive impacts on these in the long term and becomes a vital prerequisite for realising these goals. Affordable mobility that provides better connectivity to nearby cities ensures access to resources and technologies for the rural population (*target 1.4*). Reliable transportation infrastructure is essential for fostering economic growth in rural areas, which in turn helps in reducing poverty and inching closer to achieving SDG 1 pertaining to eliminating poverty. With improved access to markets, agricultural productivity rises as new technologies become easily available. It also helps in reducing spoilage of agricultural produce due to poor transport facilities (NITI Aayog; BCG, 2018) which increases the income of small food producers (*target 2.3*). This paper estimates sizable savings from switching to Bio-CNG fuelled transportation which is seen to be diverted towards consumption of pulses, milk, and other food items helping in ensuring nutritional security (*target 2.3*). Availability of transportation facilities connecting remote villages to cities also ensures improved access to healthcare including preventive, curative, maternal and childcare services thus impacting wide range of targets including reducing maternal mortality ratio, ending preventable deaths of new-borns and children under the age of 5, etc. under SDG 3 pertaining to good health and wellbeing. Transition to Bio-CNG will also help in reducing GHG emissions thus decreasing the incidents of death and illness due to air contamination (*target 3.9*). Reliable transportation also ensures easy access to quality education for the children in rural areas, positively impacting wide ranging targets under SDG 4.

Affordable and clean energy (Goal 7): Rural areas have seen an increase in the purchase of 4-wheelers with many first- time buyers entering the market. While this makes commuting easier for a section of the rural population, it also contributes to increased vehicular emissions, which is a standing problem grappling the country. Thus, a transition to Bio-CNG will keep the commuting difficulties at bay alongside reducing GHG emissions, provided that Bio-CNG is made at least as affordable as CNG. Additionally, introducing Bio-CNG shared mobility solutions in rural areas will together contribute towards increasing the share of renewable energy in the total energy mix (*target 7.2*). Green transportation solutions, thus, will have a direct impact on targets under SDG 7.

***Job opportunities, infrastructure, inequality, and sustainable communities (Goal 8-11)*:** Reliable and affordable transportation facility helps in providing better employment opportunities to the rural population, thus indirectly impacting SDG 8. It helps in reducing the share of youth who are out of employment, education, or training by connecting the remote areas to nearby cities providing easy access to education and decent employment prospects *(target 8.6)*. Transport connectivity also helps in making banking and financial services accessible *(target 8.10)*. Bio-CNG will help in providing sustainable transport infrastructure with equitable access and safe commuting which will help in increasing welfare, thus directly impacting SDG 9 and SDG 11 (target 11.2). This will in turn reduce the rural-urban inequality, helping in achieving SDG 10.

Climate action (Goal 13): Provision of affordable mobility fuelled by Bio-CNG will not only help in connecting remote villages to nearby cities but also in methane reduction due to upstream emissions caused by organic waste. Since biofuels are produced from organic waste, the mass deployment of Bio-CNG fuelled transportation will also help in management of waste which will otherwise end up in landfills. This will also help in reducing total greenhouse gas emissions per year (target 13.2).

Thus, sustainable, and cheap transportation affects wide ranging targets under the Sustainable Development Goals, directly as well as indirectly. These impacts are not independent of each other rather interconnected. Apart from the findings of the survey, there is ample empirical evidence in rural societies, where it is observed that increasing access to affordable mobility has brought in tremendous change in lives of rural people particularly vulnerable sections like women. Two inspiring case studies are mentioned below:

Project Shakti by Mahindra & Mahindra:

Project Shakti aimed to improve the mobility and livelihoods of women in rural India. Mahindra & Mahindra, a leading automobile manufacturer, provided affordable three-wheelers to women entrepreneurs in remote villages. These women became local transportation providers, offering safe and reliable transport services to their communities. As a result, not only did it create income-generating opportunities for the women, but it also improved access to education, healthcare, and other essential services for the villagers.

Kutch Mahila Vikas Sangathan (KMVS) and SEWA:

Kutch Mahila Vikas Sangathan (KMVS) and the Self-Employed Women's Association (SEWA) collaborated to establish a community-based rural transport service in the Kutch region of Gujarat. They introduced affordable shared auto-rickshaws driven by local women. This initiative empowered women economically, as they became skilled drivers and earned a livelihood. The transportation service facilitated better access to education, healthcare, and markets for the villagers, thereby improving their overall well-being.

7. Conclusion

Bio-CNG emerges as the undisputed fore-runner throughout its comparative comprehensive sustainability assessment carried out in this paper. Energy transitions are not achievable in a fortnight, given the gestation period involved in equipping the economy with the pre-requisite infrastructure to aid this transition. Even so, transition to green energy is inevitable, especially for a developing country like India where the social cost of pollution not just increases the share of medical expenses in an average Indian's expenditure basket, but makes the country pay for it with the lives of its citizen with deaths due to air pollution accounting for 17.8 percentage of the total deaths in 2019.

The environment benefit analysis of various feedstocks undertaken in this paper suggests that cow dung can serve as a good feedstock for Bio-CNG production with extremely high upstream methane release. Despite having poor feedstock-to-gas conversion ratio owing to its low calorific value, its easy availability and accessibility in rural areas makes cow dung a competitive feedstock.

Municipal Solid Waste (MSW) as a source of feedstock has similar characteristics to cow dung. It has an even lower calorific value leading to very poor feedstock-to-gas conversion ratio but a very high methane avoidance potential. However, transportation of MSW from urban to peri-urban and rural areas for Bio-CNG production needs supplementary logistics, which makes its usage relatively far-fetched in comparison to the easily available cow dung.

Table 6: Summary of all characteristics of different feedstock

Characteristic	Cow dung	MSW	Paddy straw	Bagasse
Calorific value (kJ/kg)	6000 (dung cakes which are much drier than feedstock fed into plants)	2400 (due to low volatile content of India MSW)	4000-6000	20000
Feedstock to Gas conversion ratio	Very low	Very low	Moderate	Very high
Upstream methane avoidance	Very high	Very high	Low	Very low
Remarks	Huge quantity of feedstock is required due to low calorific value however its easy availability and robust supply chain makes it a practical feedstock. Methane release per unit feedstock is high because of which upstream methane avoidance is very high.	Low calorific value has caused very low feedstock-to-gas conversion ratio due to which large amount of feedstock is required. High methane release per unit feedstock has led to high upstream methane avoidance.	Upstream methane release per unit feedstock is high but because of moderate feedstock-to-gas conversion ratio it does not require huge amount of feedstock causing relatively low methane avoidance.	High calorific value makes feedstock-to-gas conversion ratio very high due to which small amount of feedstock is required. Duality of these factors leads to very low upstream methane avoidance.

Paddy straw is also a decent contender as a feedstock with its moderate feedstock-to-gas conversion ratio. However, baseline methane avoidance of paddy straw is not high as the common practice of paddy straw burning leads to release of more air pollutants than greenhouse gases.

When it comes to bagasse, its appealing presence from the perspective of slurry management is hard to overlook. Bagasse has a very high calorific value, making it possible to generate large amount of Bio-CNG from very little feedstock. Nevertheless, since typically bagasse is burnt in India, which has been considered as the baseline case; the upstream methane avoidance is extremely low leading to practically no benefits in per-kilometre terms. Also, the low feedstock requirement in this case, only adds to a small value of methane avoidance.

The table 6 gives a summary of all the characteristics of different feedstocks. Irrespective of the type of feedstock, in the Well-to-Wheel analysis of various fuels and powertrains conducted in this paper, Bio-CNG emerges as a carbon-negative fuel with an emission intensity of -1141 g CO2 eq./km. Its exemplary performance while considering the Global Warming Potential affirms that usage of Bio-CNG as a vehicular fuel can significantly help in reducing the GHG emissions into the atmosphere.

The social benefit assessment of Bio-CNG highlights a rewarding picture under the assumption that Bio-CNG is at least as affordable as CNG. In both, the on-field interaction undertaken in Halol, Kalol, and Chota Nagpur in Gujarat, as well as the in-dept telephonic interview of replacement buyers of CNG from rural Gujarat, cost concerns emerged as the prime driver of people switching to CNG. Better fuel efficiency that CNG provided conditioned people to perceive CNG to be economical, despite CNG fuelling stations being far away. While the proximity of CNG fuelling stations did not pull down its demand amongst the target population, it negatively impacted their potential to overtly realise any savings from the transition. Respondents who did not have CNG pumps nearby were unable to visibly experience any cost savings, as compared to the respondents who were located closer to the fuelling stations, since the distance fed on the margins.

The calculation of savings from switching over to CNG in best case scenario under the stated hypothesis and assumptions of the paper shows an impressive amount being released into the rural Gujarat's economy to be spent on other vital expenditure heads of a rural household, ensuring nutritional security, and access to quality education and healthcare. Cost concerns emerging as the primary driver of transitioning to CNG also indicates the readiness of the rural population to adopt Bio-CNG when made available, provided Bio-CNG is at least as affordable as CNG.

Thus, Bio-CNG, being carbon-negative, has the potential of becoming the pivotal turning point that India needs today to anchor its transition to green energy, especially in the automotive sector. Given its commendable performance when it comes to Global warming Potential and its economic viability, Bio-CNG will serve the dual purpose of making the transport sector environmentally sustainable while simultaneously aiding in India's climate change mitigation efforts. Over and above the monetary savings experienced by the rural households, affordable and sustainable transportation is seen to positively impact majority of the targets under the Sustainable Development Goals. Cheap and reliable transportation is seen to have direct impact on connecting remote villages to major cities and other modes of transportation, enabling movement of goods and people across the country, thus stimulating economic growth. Clean mobility solutions using Bio-CNG also increases the share of renewable energy in the nation's total energy mix. It also indirectly improves agricultural productivity and farmers' income, makes access to resources, economic opportunities, education, and healthcare easier for the rural population, thus bringing overall progress for a sustainable posterity.

8. References

- Bhattacharjya S, et. al. 2023. *Comparative Analysis of Electric Vehicles and Internal Combustion Engine Vehicles from Resource Efficiency Perspective*. The Energy and Resources Institute.
- Chandra, Ram; Trivedi, Abhinav; Jha, Bhaskar; Ranjan, Amit, and Vijay, Virendra Kumar. (2017). *Energy Generation from Paddy Straw An Analysis of Bioenergy Models*. Resource Efficiency Perspective Akshay Urja. 10. 22-27.
- Chugh, Gurpreet. 2021. *The 'Green Fossil.'* The Next Stop- Natural Gas and India;s Journey to a Clean Energy Future. HarperCollins Publishers India
- Commissionerate of Transport, Government of Gujarat https://cot.gujarat.gov.in/vehicle-popullation.htm
- IRENA (2018), *Biogas for road vehicles: Technology brief*, International Renewable Energy Agency, Abu Dhabi
- Malav, Lalchand; Malav, Mahesh; Khan, Shakeel & Kumar, Sandeep. (2015). *Biogas Slurry: Source of Nutrients for Eco-friendly Agriculture*. International Journal of Extensive Research. 2. 42-46.
- Mathur, Ajay; Bhattacharjya, Souvik; Mangotra, Karan; Bajpai, Nitin. 2021. Decarbonization: Models for Sharpening the trajectory. The Next Stop-Natural Gas and India's journey to a clean energy future. Harper Collins Publishers India
- Ministry of Health and family Welfare. 2020. National Family Health Survey (NFHS-5) https://ruralindiaonline.org/en/library/resource/national-family-health-survey-nfhs-5-2019-21-gujarat/
- Ministry of Statistics and Programme Implementation. 2012. Household Consumption Expenditure Survey of NSS 68th round.
- Ministry of Petroleum and Natural Gas. 2019-2020. *Energizing India's Progress*.
- NITI Aayog & the Boston Consulting Group. 2018. *Transforming India's Mobility: A perspective.*
- NITI Aayog and Rocky Mountain Institute (RMI). 2019. *India's Electric Mobility Transformation: Progress to date and future opportunities.*
- Reserve Bank of India. https://dbie.rbi.org.in/BOE/OpenDocument/1608101727/OpenDocument/opendoc/openDocument.faces?logonSuccessful=true&shareId=1
- Sari, Kartika & Meidiana, Christia. (2019). *The use of sugar-cane waste (Bagasse) energy as substitution of fossil-fuel energy in Krebet Sugar Factory, East Java, Indonesia.* IOP Conference Series: Earth and Environmental Science. 314. 012028. 10.1088/1755-1315/314/1/012028
- Singh, Prakash & Kalamdhad, Ajay. (2022). *Biomethane plants based on municipal solid waste and wastewater and its impact on vehicle sector in India – An Environmental-economic-resource assessment*. Environmental Technology & Innovation. 26. 102330. 10.1016/j.eti.2022.102330.
- The Energy and Resource Institute and Society for Development Studies. 2019. *Faster adoption of electric vehicles in India: Perspective of consumers and industry*
- Times of India newspaper reports

- https://timesofindia.indiatimes.com/city/ahmedabad/rural-gujarat-revs-past-cities-in-car-sales/articleshow/96467748.cms
- https://timesofindia.indiatimes.com/india/dependency-on-imports-for-energy-needs-sees-a-rise/articleshow/99279917.cms
- https://timesofindia.indiatimes.com/city/ahmedabad/31-jump-in-vehicle-density-24-in-vehicle-numbers-in-5-years/articleshow/81499911.cms
- The Print news report
- https://theprint.in/economy/cng-set-to-be-2nd-most-popular-fuel-for-passenger-vehicles-in-india-by-2027-says-icra-report/1523565/
- United Nations; Economic and Social Commission for Asia and The Pacific. 2017. United Nations Publications. *Transport and Sustainable Development Goals*
- Vats, Neelam & Khan, Abid & Ahmad, Kafeel. (2019). *Effect of substrate ratio on biogas yield for anaerobic co-digestion of fruit vegetable waste & sugarcane bagasse.* Environmental Technology & Innovation. 13. 10.1016/j.eti.2019.01.003.
- You L, Yu S, Liu H, Wang C, Zhou Z, Zhang L, et al. (2019) Effects of biogas slurry fertilization on fruit economic traits and soil nutrients of *Camellia oleifera Abel.* PLoS ONE 14(5): e0208289. https://doi.org/10.1371/journal.pone.0208289

9. ANNEXURES

9.1. Annexure 1: Calculations of GHG savings due to Bio-CNG production from animal manure as feedstock

Total livestock-based emissions= (EF*N)

Where, EF=Emission factor

N= No. of animals in a particular livestock category

However, we need the emissions to account for savings associated with usage of the feedstock for biogas production instead of annual emissions of the country from total livestock category population.

1. Calculation of livestock emission factor using IPCC methodology

EF= (VS*365)*(Bo*0.67*(MCF*MS)

Where,

VS= Volatile solids (2.6) (kg/animal/day)

365= No. of days per year

Bo= Maximum methane production capacity for manure produced by livestock category (0.13) m^3 CH_4/kg VS

0.67= Conversion factor of m^3 CH_4 to kg CH_4 (kg/m^3)

MCF=Methane Conversion Factor of Liquid slurry (0.8)

MS= Fraction of manure handled in a particular manure management system (1)

EF= (2.6*365)*(0.13*0.67)*0.8*1

= 66.13 kg CH_4/animal/year

= 0.18 kg CH_4/animal/day

Let us say, one animal produces 10 kg of manure per day

Then, CH_4 emissions per 10 kg manure is =0.18 kg CH_4/10 kg manure

Therefore, methane emissions per kg of manure = 0.018 kg CH_4/kg of manure

= 18 g CH_4/kg of manure

Considering a feedstock-to-gas conversion ratio of 100:3, a 1ton biogas plant requires 33.3 tons of manure.

Therefore, methane emissions associated with 1 ton Bio-CNG plant = (0.018*33333) kg of CH_4

= 599.994 g CH_4

= (599.994*28) kg CO_2 eq.

= 16799.8 kg CO_2 eq.

Methane emissions associated with 1 ton of Bio-CNG produced from a biogas plant using cow dung as feedstock = 25199.7 kg CO_2 eq.

(Assumption is that 1-ton Bio-CNG with 90% methane concentration can be achieved from methane content of 1.5-ton biogas)

Sensitivity 1a: Livestock category: Indian Buffalos

Now, considering Indian buffalos as a livestock category, we get a value of 60.65 kg CH_4/animal/year using IPCC Tier 2 calculations.

Going forward with similar calculations, 16 g CH_4 is emitted per kg of manure.

Therefore, methane emissions associated with 1 ton biogas plant = (0.016*33333) kg CH_4

= 533.328 kg CH_4

= (533.328*28) kg CO_2 eq

= 14933.2 kg CCO_2 eq

Methane emissions associated with 1 ton of Bio-CNG produced from a biogas plant using buffalo dung as feedstock = 22400 kg CO_2 eq.

(Assumption is that 1-ton Bio-CNG with 90% methane concentration can be achieved from methane content of 1.5-ton biogas)

2. Calculation of avoided emissions from replacement of chemical fertilizer

Now, upstream methane avoidance is also considered from replacement of chemical fertilizer using biogas plant-based slurry:

Amount of slurry produced from a 1-ton biogas plant = 50000 liters

Amount of slurry for production of 1.5-ton biogas = 750000 liters

Amount of slurry that can be considered equivalent to 1 kg of NPK fertilizer as per the nutritional composition = 75.7 liters

Therefore, amount of NPK fertilizer that can be replaced using slurry for 1 ton plant =990.7 kg

Emissions from 1 kg slurry= 0.024 kg CO_2 eq.

Emissions from 1 kg NPK fertilizer = 2.85 kg CO_2 eq.

Emissions saved by replacing NPK fertilizer with slurry = (2.85*990.7) - (0.024*75000)

= 2823.5-1800

= 1023.5 kg CO_2 eq.

Total emissions saved from 1 ton biogas plant using Indian dairy cow manure

= (25199.7+1023.5) kg CO_2 eq.

= 26223 kg CO_2 eq.

3. Calculation of total emission saved per km for CAFE

Now, mileage of CNG vehicle = 30km/kg

Therefore, km run per 1 ton of gas =30000 kms

Now, emission factor of Bio-CNG = -26223/30000

= - 0.874 kg CO_2 eq/km

Now, emission factor of CNG = 0.108 kg CO_2/km

Also, upstream emissions of CNG = 0.02559 kg/km

Total life cycle emissions of CNG = 0.130 kg CO_2 eq./km

=130 g CO_2 eq./km

But the current emission associated on running a CNG vehicle =108 g CO_2/km (We have considered only tailpipe emissions based on current CAFE norms)

On replacing the CNG fleet with Bio-CNG, the emission will be = -874 g CO_2/km

That is on running 1 km using Bio-CNG, the GHG avoidance is 874 g CO_2/km while the reduction is GHG emitted from current emission is (108+874) g CO_2 eq/km= 982 g CO_2/km

Sensitivity 3a: Switching from petrol to Bio-CNG

The current emission associated on running a petrol vehicle = 112 g CO_2/km

On replacing the petrol fleet with Bio-CNG, the emission avoided will be = -874 g CO_2/km

That is on running 1 km using Bio-CNG, the GHG avoidance is 874 g CO_2/km while reduction is GHG emitted on replacement of the petrol fleet = (112+874) g CO_2 eq/km = 986 g CO_2/km

4. Calculation of plants requirement for complete transition of current CNG fleet to Bio-CNG for 1 year

Total CNG vehicles on road= 3000000 vehicles

For per km run per vehicle

Total km run by entire CNG fleet per year= 3000000

Total emissions of the fleet per km run per vehicle = (3000000*0.108) kg CO_2 eq.

=324000 kg CO_2 eq./km

On replacing the entire fleet by Bio-CNG through independent dispensing stations, emissions that can be avoided per km = 3000000*0.982 kg CO_2 eq./km = 2946000 kg CO_2 eq./km

Now, to replace the entire fleet by Bio-CNG and run the fleet for 1 year:

Let us say km travel by one vehicle per year =12000 km

Total gas required by one vehicle per year = 12000/30

=400 kg of Bio-CNG

Total gas required by the entire fleet to run per year =400*3000000

= 1200000000 kg of Bio-CNG

Capacity of 1TPD plant per year = 365000 kg of Bio-CNG

No. of 1TPD plants required to run the current CNG fleet for entire year with Bio-CNG
=1200000000/365000

= 3290 plants

5. Calculation of feedstock requirement for complete transition of current CNG fleet to Bio-CNG for 1 year

Amount of feedstock needed per day to run 3290 1TPD plants = 3290*33.3 tons

= 109557 tons of cow dung/day

Amount of slurry that will be produced while running 3290 1TPD plants

= 3290*50000 liter/day

= 164500000 liters/day

Amount of slurry that will be produced for production 1-ton Bio-CNG through production of 1.5-ton biogas = 3290*75000 liter/day

= 246750000 liter/day

6. Calculations of savings from setting up 1TPD Bio-CNG plant

Now, it has already been calculated that the savings associated with 1-ton Bio-CNG production

=25199.7 kg CO_2 eq

Therefore, savings associated with production of 1.5 tons of biogas (1-ton Bio-CNG)

= (25199.7*365) kg CO_2 eq.

= 9197890.5 kg CO_2 eq.

Therefore, production of 1 Bio-CNG using biogas plants can bring savings of 9197890.5 kg CO_2 eq. to Bio-CNG producer.

9.2 Annexure II: Calculations of GHG savings due to biogas production from agricultural manure as feedstock (paddy straw)

Yield of rice in India = 2.8 tons/ha

Rice: Straw ratio (per hectare) =1:2

Straw produced per season =5.6 tons/ha (kharif)

1. Calculations of GHG avoidance from straw management system

GHG emissions of different straw management systems:

Straw management system	Wet season (kg CO_2 eq/ha)	Dry season (kg CO_2 eq/ha)
Complete straw incorporation	4132	3086
Partial straw incorporation	2641	1890
Open burning	3891	1827

Now, the dry season emissions are only 75% of the wet season emissions of Complete Straw incorporation management system.

Therefore, we consider the total straw produced in the wet season to be 5.6 tons while we assume the amount of straw produced in the dry season to be 4.2 tons.

Emissions per ton of straw in wet season = 4132/5.6 kg CO_2 eq/ton =737.85 kg CO_2 eq. /ton

Emissions per ton of straw in dry season = 3086/4.2 kg CO_2 eq/ton= 734.76 kg CO_2 eq. /ton

Average emissions per ton annually= 736.3 kg CO_2 eq. /ton

Now, for 1 ton total solid as input biogas yield is = 400 m^3

= (400*0.67) kg of biogas

= 294.8 kg biogas

- Therefore, to produce 1 ton biogas amount of paddy straw required =3.39 tons

Therefore, amount of GHG emissions avoided = (3.39*736.3) kg CO_2 eq.

= 2496.1 kg CO_2 eq.

2. Calculation of avoided emission from replacement of chemical fertilizer by slurry

Also, 70-75% of feedstock comes out as slurry

Therefore, we assume that amount of slurry produced on producing 1-ton Bio-CNG from paddy straw

= (0.725*3.39) tons of slurry

= 2.5 tons of slurry

Now, NPK fertilizer to slurry replacement ratio is 75.7: 1

Therefore, amount of NPK fertilizer that can be replaced = 2500/75.7= 33 kg of NPK fertilizer

Emission saved from such replacement = (2.85*33) - (0.024*2500)

= 34.05 kg CO_2 eq.

Therefore, emissions saved on production of 1-ton Bio-CNG from paddy straw

= (2496.1+34) kg CO_2 eq.

=2530.1 kg CO_2 eq.

3. Calculation of total emission saved per km for CAFE

Therefore, emission saved per km on using paddy straw as feedstock

= (-2530.1/30000) kg CO_2 eq.

= -0.084 kg CO_2 eq. /km

Total emission reduction per km from current emissions = (84+108) g CO_2 eq./km

= 192 g CO_2 eq. /km

=0.192 kg CO_2 eq./km

4. Calculation of plant requirement for complete transition of current CNG fleet to Bio-CNG for 1 year

Total CNG vehicles on road= 3000000 vehicles

For per km run per vehicle,

Total km run by entire CNG fleet per year= 3000000

Total emissions of the fleet per km run per vehicle = (3000000*0.108) kg CO_2 eq.

=324000 kg CO_2 eq./km

On replacing the entire fleet by Bio-CNG through independent dispensing stations, emissions that can be avoided per km = 3000000*0.192 kg CO_2 eq./km = 576000 kg CO_2 eq./km

Now, to replace the entire fleet by Bio-CNG and run the fleet for 1 year:

Let us say km travel by one vehicle per year =12000 km

Total gas required by one vehicle per year= 12000/30

=400 kg of Bio-CNG

Total gas required by the entire fleet to run per year =400*3000000

= 1200000000 kg of Bio-CNG

Capacity of 1TPD plant per year = 365000 kg of Bio-CNG

No. of 1TPD plants required to run the current CNG fleet for entire year with Bio-CNG=1200000000/365000 = 3290 plants

5 Calculation of feedstock requirement for complete transition of current CNG fleet to Bio-CNG for 1 year

Amount of feedstock needed per day to run 3290 1TPD plants = 3290*3.39 tons

= 11153 tons of paddy straw/day

Amount of slurry that will be produced while running 3290 1TPD plants = 3290*2.5 tons/day

= 8225 tons/day

9.3 Annexure III: Calculations of GHG savings due to biogas production from industrial feedstock (bagasse)

1. Calculation of upstream GHG avoidance

Methane emission per kg of bagasse burning =0.3 g

Nitrous oxide emission per kg of bagasse burning = 0.04 g

Total GHG per kg of bagasse burning = 20.32 g CO_2 eq.

Bagasse being a cellulosic material has high volatile solids content of 96%.

Max biogas yield =4.98 m^3/kg VS =3.33 kg/kg VS =3.33 kg/ 1.04 kg of bagasse

Therefore, for 1 ton biogas production, amount of bagasse required =312.3 kg

Therefore, emissions avoided for production of 1 ton biogas = (312.3*20.32) g CO_2 eq.

= 6345.9 g CO_2 eq

=6.3 kg CO_2 eq.

2. Calculation of total emission saved per km for CAFE

Emission saved per km on using bagasse as feedstock = (-6.3/30000) kg CO_2 eq.

= -0.00021 kg CO_2 eq. /km

Total emission reduction per km from current emissions = (0.21+108) g CO_2 eq./km

= 108.21 g CO_2 eq. /km

3. Calculation of plant requirement for complete transition of current CNG fleet to Bio-CNG for 1 year

Total CNG vehicles on road= 3000000 vehicles

For per km run per vehicle

Total km run by entire CNG fleet per year= 3000000

Total emissions of the fleet per km run per vehicle = (3000000*0.108) kg CO_2 eq.

=324000 kg CO_2 eq./km

On replacing the entire fleet by Bio-CNG through independent dispensing stations, emissions that can be avoided per km = 3000000*0.00021 kg CO_2 eq./km

= 630 kg CO_2 eq./km

Now, to replace the entire fleet by Bio-CNG and run the fleet for 1 year:

Let us say km travel by one vehicle per year =12000 km

Total gas required by one vehicle per year = 12000/30 = 400 kg of Bio-CNG

Total gas required by the entire fleet to run per year =400*3000000

= 1200000000 kg of Bio-CNG

Capacity of 1TPD plant per year = 365000 kg of Bio-CNG

No. of 1TPD plants required to run the current CNG fleet for entire year with Bio-CNG

= 1200000000/365000

= 3290 plants

4. Calculation of feedstock requirement for complete transition of current CNG fleet to Bio-CNG for 1 year

Amount of feedstock needed per day to run 3290 1TPD plants= 3290*0.312 tons

= 1026 tons of bagasse/day

9.4 Annexure IV: Calculations of GHG savings due to biogas production from Municipal Solid Waste

1. Calculation of upstream GHG avoidance

Methane emission per ton of MSW in dump yard =50 m^3 CH_4 /yr

= 33.5 kg CH_4 /yr

= 938 kg CO_2 eq. /yr

Amount of biogas yield from MSW in tropical climate =0.08 m^3 CH_4/kg of VS

Total VS of MSW = 41.3%

Therefore, total VS in 1-ton MSW= (0.413*1000) kg of VS

= 413 kg of VS

Total biogas yield from 1-ton MSW = (0.08*413) m^3/ton of MSW

= 34.1 m3 CH_4/ ton of MSW

= 22.8 kg CH_4/ ton of MSW

Therefore, 23 kg of biogas can be produced from 1-ton MSW

Therefore, to produce 1 ton of biogas, amount of MSW needed = 43.4 tons of MSW

Therefore, emissions avoided for production of 1 ton biogas = (43.3*938) kg CO_2 eq.

= 40782.6 kg CO_2 eq.

2. Calculation of avoided emission from replacement of chemical fertilizer by slurry

1m^3 of biogas production produces = 7.1 kg of slurry

Therefore 1000 kg (1492 m^3) of biogas produces = (1492*7.1) kg of slurry

= 10593 kg of slurry

Now, NPK fertilizer to slurry replacement ratio is 75.7: 1

Therefore, amount of NPK fertilizer that can be replaced = 10593/75.7

= 139.9 kg of NPK fertilizer

Emission saved from such replacement = (2.85*140) - (0.024*10593)

= 144.8 kg CO_2 eq.

Therefore, emissions saved on production of 1 ton Bio-CNG from MSW

= (40782.6+144.8) kg CO_2 eq.

= 40926.8 kg CO_2 eq.

3. Calculation of total emission saved per km for CAFE

Emission saved per km on using bagasse as feedstock = (-40963/30000) kg CO_2 eq.

= -1.36 kg CO_2 eq. /km

Total emission reduction per km from current emissions = (1360+108) g CO_2 eq./km

= 1468 g CO_2 eq. /km

4. Calculation of plant requirement for complete transition of current CNG fleet to Bio-CNG for 1 year

Total CNG vehicles on road= 3000000 vehicles

For per km run per vehicle,

Total km run by entire CNG fleet per year= 3000000

Total emissions of the fleet per km run per vehicle = (3000000*0.108) kg CO_2 eq.

=324000 kg CO_2 eq./km

On replacing the entire fleet to Bio-CNG through independent dispensing stations, emissions that can be avoided per km = 3000000*1.4 kg CO_2 eq./km

= 42000000 kg CO_2 eq./km

Now, to replace the entire fleet by Bio-CNG and run the fleet for 1 year:

Let us say km travel by one vehicle per year =12000 km

Total gas required by one vehicle per year = 12000/30

=400 kg of Bio-CNG

Total gas required by the entire fleet to run per year =400*3000000

= 1200000000 kg of Bio-CNG

Capacity of 1TPD plant per year = 365000 kg of Bio-CNG

No. of 1TPD plants required to run the current CNG fleet for entire year with Bio-CNG

=1200000000/365000

= 3290 plants

5. Calculation of feedstock requirement for complete transition of current CNG fleet to Bio-CNG for 1 year

Amount of feedstock needed per day to run 3290 1TPD plants= 3290*43.4

= 142786 tons of MSW/day

Amount of slurry that will be produced while running 3290 1TPD plants

= 3290*10.5 tons/day

= 34545 tons/day

9.5 Annexure V: Calculations of GHG savings due to biogas production from Press Mud

1. Calculation of plant requirement for complete transition of current CNG fleet to Bio-CNG for 1 year

Total CNG vehicles on road= 3000000 vehicles

For per km run per vehicle,

Total km run by entire CNG fleet per year= 3000000

Total emissions of the fleet per km run per vehicle = (3000000*0.108) kg CO_2 eq.

=324000 kg CO_2 eq./km

On replacing the entire fleet by Bio-CNG through independent dispensing stations, emissions that can be avoided per km = 3000000*1.4 kg CO_2 eq./km

= 42000000 kg CO_2 eq./km

Now, to replace the entire fleet by Bio-CNG and run the fleet for 1 year:

Let us say km travel by one vehicle per year =12000 km

Total gas required by one vehicle per year = 12000/30= 400 kg of Bio-CNG

Total gas required by the entire fleet to run per year =400*3000000 = 1200000000 kg of Bio-CNG

Capacity of 1TPD plant per year = 365000 kg of Bio-CNG

No. of 1TPD plants required to run the current CNG fleet for entire year with Bio-CNG

=1200000000/365000

= 3290 plants

2. Calculation of feedstock requirement for complete transition of current CNG fleet to Bio-CNG for 1 year

Amount of feedstock needed per day to run 3290 1TPD plants= 3290*21.9 tons of press mud

=72051 tons of press mud per day

Amount of slurry that will be produced while running 3290 1TPD plants

= 3290*5.85 tons/day

= 19247 tons/day

9.6 Annexure VI: Table Break-up of MPCE by 20 broad item groups: all-India, 2011-12

Table A1: Monthly per-capita consumption expenditure on various broad food and non-food items.

2011-2012 (NSSO)		
Item Group	**Rural (in Rs)**	**Urban (in Rs)**
Cereals & cereal substitutes	154	175
Pulses & their products*	42	54
Milk & milk products	115	184
Edible oil	53	70
Egg, fish & meat	68	96
Vegetables	95	122
fruits	41	90
sugar, salt and spices	76	94
beverages, refreshments, processed food	113	236
pan, tobacco & intoxicants	46	42
fuel and light	114	176
clothing & footwear$	100	167
education	50	182
medical	95	146
conveyance	60	171
Other consumer services	57	147
misc. goods, entertainment	76	152
rent	7	164
Taxes and cesses	4	22
Durable goods	65	139
All items	1430	2630

Source: Household Consumption Expenditure survey of NSS 68th round Ministry of Statistics and Programme Implementation

9.7 Annexure VII: Estimation of fuel related monetary savings from complete transition of petrol 4-wheelers to CNG in rural Gujarat and the proportion of savings going into ensuring nutritional security, wellbeing and quality education

1. Estimation of fuel related monetary savings from complete transition of petrol 4-wheelers to CNG in rural Gujarat

Average price of petrol in Gujarat= Rs. 96/litre

Average price of CNG in Gujarat= Rs. 73/kg

Approximate mileage of a car fuelled by petrol= 17 km/litre

Approximate mileage of a car fuelled by CNG= 25 km/kg

(Source: Tata Capital, Tata Group)

Savings are calculated for 2 cases-

A car travelling 15km/day and a car travelling 30 km/day.

Case 1: Savings from transition of a car travelling 15 km/day

Monthly distance travelled by a car= 450 km

Per kilometre cost incurred on petrol powered car= Rs. 96/17= Rs. 5.647

Per kilometre cost incurred on CNG powered car= Rs. 73/25= Rs. 2.92

Therefore, per kilometre savings from switching to CNG= Rs. 5.647- Rs. 2.92= Rs. 2.727

Monthly savings from switching to CNG= Rs. 2.727*450

= Rs. 1,227.15

Yearly savings from one car transitioning to CNG= Rs. 2.727*450*12

= Rs.14,725.8

Total registered 4-wheelers in Gujarat= 32,06,687

(Source: Commissionerate of Transportation, Government of Gujarat)

As per NSS 68th round; 2011-2012,

Household reporting ownership of car per 1000 population in rural Gujarat= 20

Household reporting ownership of car per 1000 population in urban Gujarat= 69

If the ownership pattern remains same, taking this as a proxy for rural- urban share of total registered 4-wheelers; approximately 23% of total 4 wheelers in Gujarat can be registered in rural Gujarat.

Therefore, rural share of total registered 4-wheelers= 23% of 32, 06,687= 7, 37, 538

CNG powertrain penetration in India= 11%.

(Source: ICRA, Business Standard)

Taking this as a proxy for share of CNG 4-wheelers in rural Gujarat,

Share of 4-wheelers fuelled by Petrol= 7, 37, 538- 11% of 7, 37, 538= 6, 56,409

Yearly savings from 6,56,409 Petrol 4-wheelers transitioning to CNG

= 6, 56,409 * 14, 725.8= Rs. 9,66,61,47,652.2

Case 2: Savings from transition of a car travelling 30 km/day

Monthly distance travelled by a car= 900 km

Per kilometre cost incurred on petrol powered car= Rs. 96/17= Rs. 5.647

Per kilometre cost incurred on CNG powered car= Rs. 73/25= Rs. 2.92

Therefore, per kilometre savings from switching to CNG= Rs. 2.727

Monthly savings from switching to CNG= Rs. 2.727*900

= Rs. 2454.3

Yearly savings from one car transitioning to CNG= Rs. 2.727*900*12

= Rs.29,451.6

Yearly savings from 6,56,409 Petrol 4-wheelers transitioning to CNG

= 6, 56,409 * 29,451.6= Rs. 19,33,22,95,304.4

2. Estimation of increase in spending on nutrition, health, and education because of savings realized from transition to CNG

According to the Household Consumption Expenditure Survey of NSS 68th round 2011-2012, combined weightage of cereals, pulses, milk, edible oil, egg, fish and meat, vegetable, fruits, spices, and processed food is 52.91% of the total expenditure. The weightage of health expenditure is 6.64% and that of education is 3.49% of total expenditure for a rural household. Assuming the expenditure pattern to remain same;

Case 1: Yearly savings from transitioning to CNG= Rs. 9,66,61,47,652.2

The proportion of estimated yearly savings going into-

Food expenditure= Rs. 5,11,43,58,722.77

Health expenditure= Rs. 64,18,32,204.1

Education expenditure= Rs. 33,73,48,553

Case 2: Yearly savings from transitioning to CNG is Rs. 19,33,22,95,304.4

- The proportion of estimated yearly savings going into-

Food expenditure= Rs. 10,22,87,17,445.56

Health expenditure= Rs. 1,28,36,64,408.21

Education expenditure= Rs. 67,46,97,106.12