Evaluating Biofuel Energy Policies for Sustainable Transportation Sector: A System Dynamics Approach

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Abstract
Energy is vital for techno-socio-economic development of global transportation sector. A country's energy policy will aim to provide an appropriate mix of resources to meet its energy demand. Biofuels have emerged as an alternative to meet the energy requirements. The contribution of this study is the evaluation of sustainable biofuel energy policies to increase the usage of biofuels in the transport sector without affecting the country's food security and to achieve social, economic and environmental benefits. The successful implementation of complex relationship between the factors influencing the production and use of biofuels is also addressed. In the present work, a system dynamics model has been developed to evaluate biofuel production focusing food security and to assess its impact on the economy and the environment. Simulation results have shown that the maximum biodiesel blending between 3.03% to 11.01% is possible without impacting the food security. It has been noted that 20% or less of biodiesel blends can be used as direct replacements for diesel fuel in all heavy-duty diesel vehicles without any alteration or modification of their engines. It has been demonstrated that biofuel blending strategies have a positive impact on the reduction of CO_2 emission in the Indian transport sector.

Keywords- Transport sector, Biofuel, Energy policy, System dynamics, Food security, Biodiesel.

1. Introduction
India is one of the fastest growing developing countries facing acute problems of energy demand, pollution and population. In the recent years, India's energy consumption has risen at a faster pace. Fossil fuels (coal,

oil and gas) currently play a major role in global energy systems. India is projected to be the second largest contributor to the increase in global energy demand, accounting for 16% of the growth by 2035. Energy consumption is more than doubling due to rapid population growth and economical development (IEA, 2011). India has imported 80% of its domestic demand for crude oil that is roughly 159.26 million tons of crude oil, accounting for 31% of the country's total imports in 2009-10 (Kumar and Mohan, 2012).

Petroleum and liquid fuels are a major source of energy for the global transport sector. In 2012, the transport sector depended on petroleum fuels for 96% of its energy requirements (IEO, 2016). India's energy security would remain vulnerable until alternatives to fossil fuels are not available. The country has a ray of hope for energy security when biofuels are used. Any fuel derived from biological sources known biofuels that can be categorized into two types: bioethanol, a petrol supplement and biodiesel, a diesel supplement (Shailesh, 2009). Biofuels are categorized as first generation- if the feedstock is edible by nature, second generation- if the feedstock is non-edible, and third generation- if the source of oil is micro-organisms as algae (Agarwal, 2007). Biofuels are derived from renewable biomass resources and are therefore considered to be environmentally friendly fuels. Biofuels have the capacity to provide strategic advantages, to support sustainable development, and to complement conventional energy sources.

The purpose of this research is to investigate two aspects of the transportation system: first, to assess viable biofuel energy policies, and second, to assess the effect of optimal transport energy strategies without compromising food security on greenhouse gas emissions from the transportation sector. This analysis aids in determining research criteria and recommending a feasible research methodology. The potential use of system dynamics (SD) methodology, Forrester (1968) has been proposed in this work to examine the viability of producing biodiesel from Jatropha Curcas without affecting food grain cultivation. The proposed model demonstrated a relationship between supply-side and demand-side measures for biofuel use. Biodiesel production and use strategies include: 1. supply-side measures such as food security and land use; and 2. demand-side measures such as population, vehicle production, demand, and fossil fuel prices, as well as environmental benefits. The model has implemented some demand side policies to reduce fossil fuel consumption or carbon emissions as a means of replacing fossil fuels or protecting the environment without compromising food security (Rajagopal and Zilberman, 2007).

Some specific research questions are as follows:

- Could of biofuels usage fulfill energy needs in the transport sector in an environment friendly and cost-effective way?
- How do they provide a higher degree of national energy security without impacting food security?

The remainder of the manuscript is organized as follows: a summary of literature related to the technical, social, economic and environmental aspects of biofuel production and use of biofuel have presented in Section 2. Section 3 describes a system dynamics model with its validation for production of biofuels. Alternative scenarios for reaching the maximum possible percentage of blending for bio diesel are discussed in Section 4. Section 5 analyses the effect of biodiesel used to determine reduction in emission inventories of various pollutants in the Indian transportation sector. Finally, Section 6 gives conclusion and scope of future work.

2. Review of Literature

Biofuels production has increased rapidly across the globe during the last decade. High oil prices, global climate change, energy security and unreliable oil supplies have resulted in increased demand for biofuels production (Francis and Andrew, 2008; Banse et al., 2008). It is therefore wise to assess the feasibility of biodiesel production and its usage in the transport sector. Biofuel plays a crucial role in the sustainability and energy efficiency of the transport industry as a promising renewable energy source. Potential negative impacts caused by change in land use and intensification of agriculture. This can be mitigated by agro-ecological zoning, the use of eco-hydrology and bio-diversity-friendly theories in field, watershed and landscape scales (Souza et al., 2017). The feasibility of biofuel uses can be measured in terms of: biodiesel production, its use, energy security, food security, economic benefits, job creation and rural development (Sethi, 2009).

The transport sector plays an important role in the economy and its rapid growth has contributed significantly to the country's socio-economic growth (Mustapa and Bekhet, 2016). The technical, social, economic and environmental aspects of the production and use of biodiesel in the transport sector have been identified as key issues in the literature. Technical aspects relate to the performance characteristics of biodiesel uses on internal combustion engines in terms of power, torque and specific fuel consumption (Agarwal, 2007; Ajav et al., 1999; Arcoumanis et al., 2008; Bhattacharyya and Reddy, 1994; Carraretto et al., 2004; Graboski and McCormick, 1998; Karthikeyan and Mahalakshmi, 2007; Kumar et al., 2010; Ramadhas, 2004; Sinha and Agarwal, 2005; Pramanik, 2003). A few studies have been focused on use of biofuel in the fleet, such as a proportional blend with the main fuel or a pure biofuel (Barisa et al., 2015; Menezes et al., 2017; Sanches-Pereira and Gómez, 2015). Standard compression-ignition (CI) engines designed to operate on petroleum-based diesel fuel have also been suitable for biodiesel as well. Biodiesel can be conveniently used in its pure form in existing diesel engines or can be blended in any proportion with diesel fuels. When biodiesel is used in diesel engines without any modifications acceptable performance has been achieved. A blend of 20% biodiesel fuel in diesel has no major adverse effect on the measured performance (Agarwal, 2007; Murugesan et al., 2009). A 20% or less biodiesel blends can be used as a direct replacement for diesel fuel in all heavy-duty diesel vehicles without any engine or fuel system modifications (Agarwal et al., 2008; Rakopoulos et al., 2008).

Social aspects of biofuel production and use concentrate on the job's creation and social growth. Growth in population and growing social needs affect the land requirements for food grain and biodiesel production (ADB, 2011; Clayton, 2009; Deal and Schunk, 2004; Grosshans et al., 2007; Kalantari et al., 2008; Mitchel, 2008). The economic criteria for the use of biofuels are based on benefits of replacing fossil fuels and earnings from carbon credits. Economic factors such as capital investment cost, manufacturing cost, tax rate, biodiesel break-even price etc. are related to the production of biodiesel (ADB, 2011; APEC, 2010; Bhaduri et al., 2008; Fischer et al., 2009; Rajagopal and Zilberman, 2007; Searchinger, 2008; Searchinger and Heimlich, 2008; Shafiei et al., 2016). Environmental aspects of use of biofuels address the impact of biodiesel use on the reduction of greenhouse gases and emissions of different pollutants from diesel vehicles. The use of biodiesel in engines brings with it some environmental benefits, such as a reduction in the emission of carbon dioxide (CO_2), carbon monoxide (CO), particulate matter (PM), hydrocarbons (HC), sulphur dioxide (SO_2), methane (CH_4) and smoke density except nitrogen oxides (NOx), which are important elements in the greenhouse gas effect (ADB, 2011; Agarwal, 2007; Benvenutti et al., 2019; Carraretto et al., 2004; Krahl et al., 2010; Makareviciene and Janulis, 2003; Rajagopal and Zilberman, 2007; Ramadhas et al., 2004; Rakopoulos et al., 2008; Reddy and Ramesh, 2006; Searchinger et al., 2008; Yang et al., 2009).

In the near future, the transportation sector will be a potential contributor to environmental and energy related issues.CO_2 emissions have emerged as the most serious environmental issue in recent decades. Mustapa and Salleh (2019) have focused on minimizing CO_2 emissions from the transport sector. A linear programming modelling and sensitivity analysis is used to investigate the effects of mitigation scenarios such as low carbon fuels, fuel efficiency improvement, travel demand management, and integrated mitigation strategies on the CO_2 emissions. In this analysis, linear programming modeling does not consider the effects of time and uncertainty. The parameters found in the model are considered to be constant and the real-life parameters cannot be taken into account. Dong et al. (2019) have used the Logarithmic Mean Divisi an Index (LMDI) decomposition method to evaluate the driving forces of changes in CO_2 emissions, taking into account different levels of income. After decomposing the changes to emissions, a scenario analysis of the potential to reduce emissions has been carried out to identify feasible mitigation pathways. Although the LMDI approach provides complete decomposition and is time-reversal invariant, its zero-value strategy is not inherently robust. To address this issue, Wood and Lenzen (2006) have proposed the use of LMDI analytical limits in cases of zero values. These limits can be replaced by complete computational loops, such that, in addition to providing the right decomposition result, this improved method often greatly reduces computation times.

Biofuels are being marketed as a low-carbon alternative to fossil fuels because they have the potential to reduce greenhouse gas (GHG) emissions and the associated climate change effect from transportation (Jeswani et al., 2020). Countries leading in biofuel production, particularly biodiesel and bioethanol having the most influence on the transportation sector due to their low production costs and impact on marginal emerging economies. The strategy entails using a biodiesel blend mix that is greater than the current norm (B10: 10% biodiesel and 90% diesel), eventually reaching a 20% mix (B20). Sánchez Anchiraico et al. (2022) demonstrated the advantages and potential opportunities for replication of the strategy across the country while demonstrating evidence of a large decrease in greenhouse gas (GHG) emissions. They examined the expected social, economic, and environmental consequences of this strategy. Fontoura and Ribeiro (2021) conducted a comprehensive literature study to evaluate the usage of Systems Dynamics (SD) in the development and implementation of urban transportation policy. Among the applications of SD in the transportation sector, the use of this method in the development and implementation of sustainable transport policies stands out. Ghaderi et al. (2020) used system dynamics to investigate and analyse interactions among variables in the bioethanol and biodiesel supply chains in order to build scenarios to evaluate relevant policy alternatives and their potential future implications on bioethanol and biodiesel market share. Ghisolfi et al. (2022) examined 50 papers that met our search criteria and were classified by decarbonization strategies, external factors required to support them, and simulated policy instruments. The authors summarized their analysis by making recommendations for the future use of the system dynamic method in the transportation sector.

All aforementioned issues are complex, dynamic and interdependent. System Dynamics (SD) allows the assessment of different dynamic aspects (issues) and policies (strategies). It is well suited for exploration over a number of years (Benvenutti et al., 2019; Bisen et al., 2014). Since 1994, Shepherd (2014) has reviewed 50 peer-reviewed journal papers to identify the use of system dynamics for the logical, systematic and detailed representation of complex large-scale systems. Abbas and Bell (1994) evaluated the strengths of the system dynamics approach to complex system modeling through dynamic, causal feedback interactions between both the structural components of the model as well as through empirical formulations.SD has certain features that make it attractive as a tool for evaluating social, economic and environmental impacts. Some of these features of SD are:

- The ability to dynamically model, a large number of variables in complex, nonlinear relationships. This helps one to consider several related aspects of the problem that leads to a holistic approach.
- An explicit simulation of qualitative variables.
- The ability to experiment with alternative policy options.
- The capacity to create alternative scenarios.
- The ability to incorporate features of both exploratory and normative impact analysis approaches (Bisen, 2016; Mohapatra et al., 1994).

It has been summarized that disaggregated studies of issues related to biofuels production and its use in the transport sector have the drawback that an aggregate system-wide effect cannot be measured. The present work therefore suggested an integrated modeling framework. A Some SD models are aggregated models showing policy impacts in terms of approximate magnitudes and directions of change. However, the proposed SD model has been further refined to explain the system in a more detailed manner, thus providing a numerically accurate output.SD approach has been used to analyse the viability of biofuel (biodiesel) production from Jatropha Curcas without affecting food grain production. Alternative scenarios projections have been presented over the next 20 years from the year 2010 to 2040. These scenarios have been assessed in terms of crop land requirements and availability, demand and supply of food grain and production of biodiesel for displacement of fossil fuels. The impact of biodiesel produced has been shown to be reduced in terms of the quantity of pollutants, i.e., Carbon Dioxide (CO_2), Carbon Monoxide (CO), Hydrocarbons (HC), Nitrous Oxide (NOx), Sulphur Dioxide (SO_2), Methane (CH_4) and Particulate Matter (PM).

3. Research Methodology

The research methodology is based on system dynamics (SD) modeling framework. The current model has incorporated the dynamic response of land use change for food grain production, social development and biodiesel production within the framework of the structure. The dynamics has been created by integrating the food grain supplies per unit of land (food grain yield), demand of food grain, availability of wasteland, forest land and agricultural land in the modeling framework. The model has implemented a for policy deliberations mechanism, where policymakers can perform policy exercise simulation in a hypothetical environment. The model has been envisioned as an effective long term policy planning tool that is capable of analyzing the biofuels production without affecting food security and other associated impacts of their use. In the modeling framework presented, The SD model has interfaced with spread sheets for handling and manipulating large data. SD modelling methods have been used to model the supply-demand side measures of biofuel used and other causal relationships in such a way as to explain the feedback mechanisms and dynamic of land use relationship among different purposes.

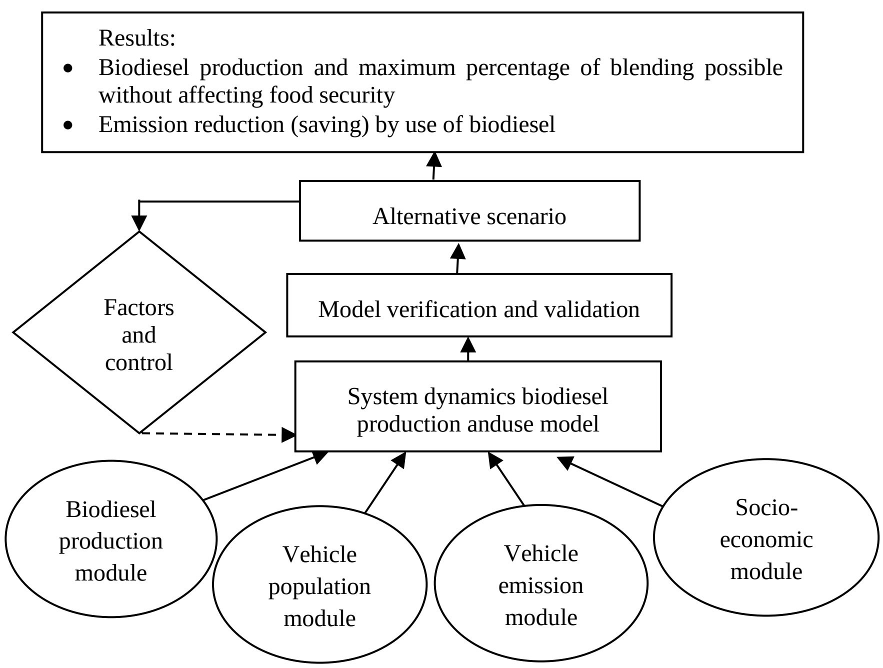


Figure 1. Schematic illustration of the framework of proposed system dynamics model.

3.1 Model Development

The proposed SD model for the production and use of biodiesel is divided in to four modules namely biodiesel production, vehicle population, vehicle emission and socio-economic (Figure 1). A complex nonlinear feedback mechanism of closed loops has been implemented in each of these modules consist of various factors such as technological, socioeconomic, environmental, etc. All four modules are linked together to generate alternative scenarios with defined population assumptions, changes in land use pattern, food grain yields, biodiesel feedstock, technological changes and control measures adopted. These alternative scenarios help to analyse the potential biodiesel production and impacts of its use as well as develop strategies to be adopted against undesirable food scarcity consequences.

3.1.1 Biodiesel Production Module

Production of biodiesel in millions of tons per year has been estimated using a stock and flow diagram (Figure 2). Production of biodiesel requires land for the cultivation of biodiesel crops. Biodiesel Production is determined by the land available, crop yield of biodiesel and conversion ratio for feedstock to biodiesel. Hong Yangand his peers have developed analytical equations for biodiesel production based on land availability including biodiesel density (Yang et al., 2009), that are as follows:

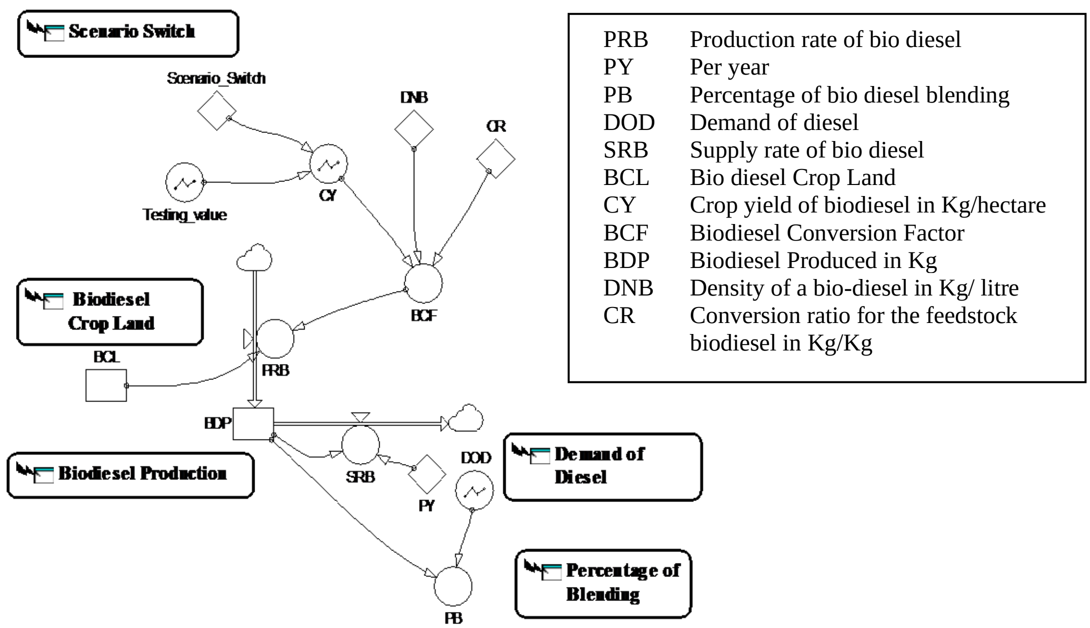


Figure 2. A system dynamics model for biodiesel production.

$$BDP = LAB * BCF \quad (1)$$

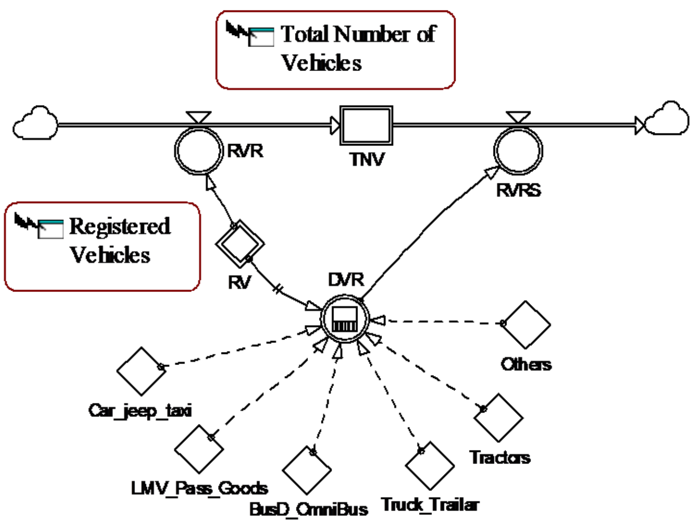
where, LAB = Land available for biofuel in hectare
BDP = Biodiesel produced in Kg
BCF = Biodiesel conversion factor

$$BCF = (CY/ CR*DNB) \quad (2)$$

where CR = Conversion ratio for the feedstock biodiesel in Kg/Kg
DNB = Density of a biodiesel in Kg/ litre
CY = Crop yield of biodiesel in Kg/hectare
Each of the components of Eq-1 and Eq-2 affects biodiesel production.

3.1.2 Vehicle Population Module

Stock-and-flow diagram of the vehicle population module is shown in Figure 3. All diesel vehicles in their respective types, age and technology distribution are considered for a full description of the transportation system. Estimation of a total number of vehicles from its annual registration records including their age and distribution of technology is carried out using this module. The replacement of old vehicles with new ones depends on the process of technology substitution and vehicle retirement after the end of their useful service life. Future projections of vehicle numbers have been made using the growth rates, vehicle retirement age and Central Pollution Control Board guidelines (CPCB, 2010).



TNV	Total number of vehicles
RVR	Rate of Vehicle Registration
RVRS	Rate of Vehicle removal after their service life
RV	Registered vehicles
Car_jeep_taxi	Car, Jeep and taxi
LMV Pass Goods	Light Motor Vehicles, Passenger and Goods vehicles
BusD_omnibus	Bus Diesel and Omni bus
Truck _trailer	Truck and trailer
DVR	Rate of vehicle removal after service life and Delay
Tractors	Tractors
Others	Other miscellaneous vehicles for which categorywise break up is not reported

Figure 3. A system dynamics model forvehicle population.

3.1.3 Vehicle Emission Module

Pollution inventories of different pollutants (CO_2, CO, HC, PM, NOx, SO_2, and CH_4) using diesel and its biodiesel blends have been estimated using this module (Figure 4). The reduction of emissions using biodiesel blends has also been assessed. Emission inventories of pollutants have been estimated using emission factors (in g/km) and traffic activity data (vehicle kilometres) for different types of vehicles. The pollution inventories indicate changes in air quality. The accuracy of emission inventory estimates depends upon the availability of reliable local data such as the number of on-road vehicles, emission factor and vehicle utilization. Emissions from the transport sector depends primarily on type of transport and fuel other than from type of combustion engine, emission mitigation techniques, maintenance procedures and vehicle age (Ramachandra and Shwetmala, 2009). Emissions in the model have been quantified on the basis of number of vehicles and distance travelled in a particular year. A simple analytical expression is formulated (Eq.3) to estimate the emissions of pollutants.

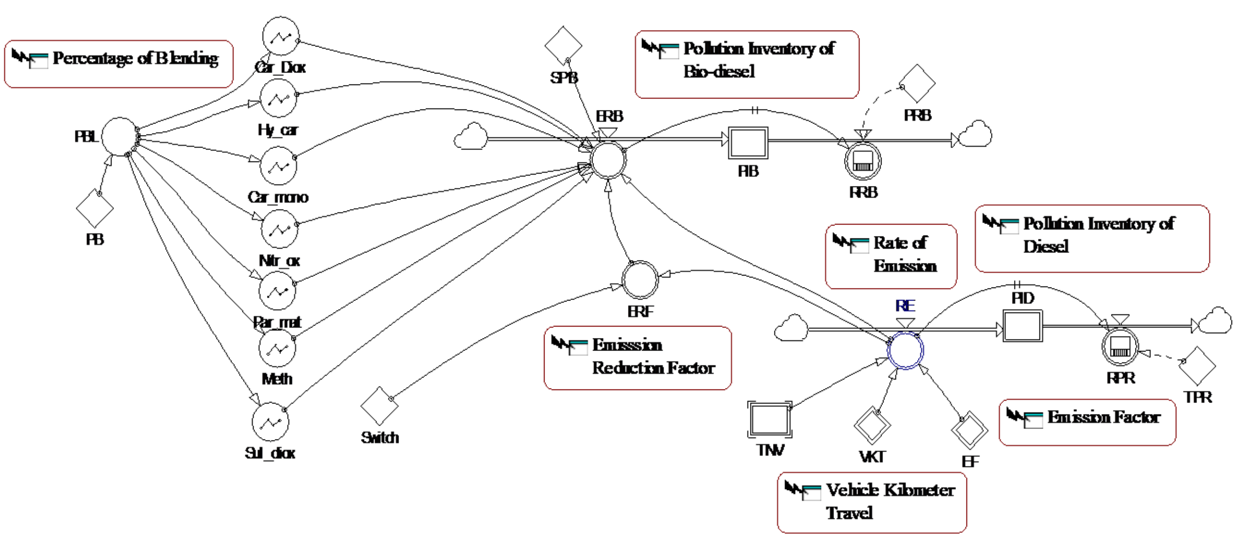
$$Ei = \sum(V_j \times D_j) \times E_{i,j,km} \quad (3)$$

where, E_i = emission of compound (i);
V_j= number of registered vehicles per type (j);
D_j = distance travelled in a year by a vehicle type (j);
$E_{i,j,km}$= emission factor of compound (i) from vehicle type (j) per driven kilometre.

Different blending percentages of biodiesel may lead to different levels of emission reductions. Emission data for CO_2, HC, CH_4, CO, NO_X, SO_2 and PM are taken from literature (EPA, 2002; Francis et al., 2005) that have checked biodiesel blend emissions for different blending percentages. Emissions from biodiesel fuels are calculated by using Eq. 4 for a particular blending percentage:

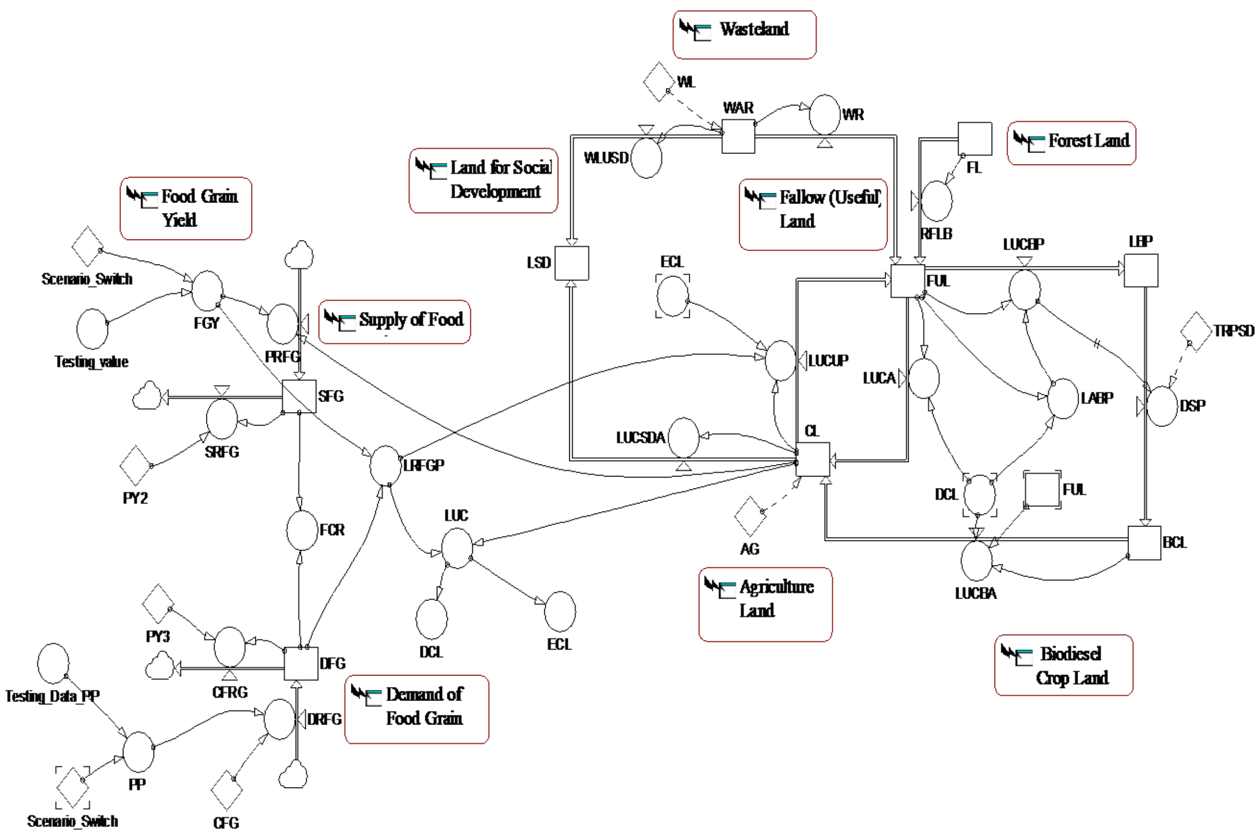
$$EIB = \sum (V_j \times D_j) \times E_{i,j,km} \times ERF \quad (4)$$

EIB = Emission inventory for biodiesel
ERF = Emission reduction factor



PID	Pollution inventory of diesel	TPR	Time required for pollution removal
PIB	Pollution inventory of Bio diesel	ERB	Emission rate of bio-diesel
RE	Rate of emission	RRB	rate of pollution removal for bio-diesel
RPR	Rate of pollution removal	ERF	emission reduction factor
VKT	Vehicle kilometer travel	SPB	Switch Policy for bio diesel
EF	Emission factor	PRB	Pollution removal for biodiesel
TNV	Total number of vehicles	PB	Percentage of bio diesel blending

Figure 4. System dynamics model for vehicle emissions.



FGY	Food Grain Yield in tons/ha	LUC	Land Use Change	LBP	Land for biodiesel plantation
SRFG	Food Grain Use per Year	DCL	Demand of Crop Land	DSP	Delay in seed production (Gestation period)
PRFG	Prodiction Rate of Food Grain	ECL	Excess Crop Land	TRPSD	Time require to producing seed from plant
SFG	Supply of Food grain	LSD	Land for other purpose	BCL	land available for Biodiesel Plantation
FCR	Food Consumption Ratio	WLUSD	waste land use for social development	LUCBA	Land use change from biodiesel production to agricultural
LRFGP	Land Requirement for Food Grain Production	WAR	Waste Land available for reclamation	LABP	Land available for biodiesel plantation
DFG	Demand of Food Grain	WR	wasteland reclamation Rate	LUCA	Land Use Change for Agricultural
CFRG	Consumption Rate of Food Grain per Year	FL	Forest Land	CL	Crop Land for food grain production
DRFG	Demand Rate of Food Grain	RFLB	Rate of forest land for biodiesel production	AG	Agricultural Land
PP	Population	FUL	Fallow Land	WL	Waste land
CFG	Consumptin rate per person per year	LUCBP	Land use change for biodiesel	LUCUP	Land use change for any useful

Figure 5. Socioeconomic stock and flow diagram.

3.1.4 Socio-Economic Module

In this module, land available for biodiesel production, land requirements for food grain production, demand and supply of the food grain and cost benefits of biodiesel use have been estimated. Specific parameters have been estimated by considering the dynamics of various feedback processes affecting food security (Figure 5). An empirical approach has been used to assess the land use requirements for food grain production (supply) on the basis of population driven demand for food grain and biodiesel production. This is a data-driven approach that uses land use patterns and yields of food grain and biodiesel feedstock. Land for production of biodiesel and land for social needs will lead to reduced land area for food grain production. As a result, crop commodities /food grain prices will increase. Availability of land for biodiesel production shall be assessed on the basis of the following criterion:

(i) Food grain demand for population,
(ii) Land requirements for food grain production (supply) on the basis of food grain demand,
(iii) Average area of cropland used for food grain production that included food grain buffer stock land as safety stock,
(iv) Land for production of biodiesel available from agricultural land without affecting food security,
(v) The price of biodiesel linked to the price of diesel based on energy content for economic viability of biodiesel production.

These conditions have been incorporated into the policy measures to support the production of biodiesel without affecting food security. Changes in land use due to the production of biodiesel would not have occurred in a region that does not meet conditions 1-4. The condition 5 set out the price of biodiesel by means of a correlation between the diesel and biodiesel. One assumption is that biodiesel crops only use wastelands or fallow lands, and there is no displacement of food crops. On the other hand, if the food grain production exceeds demand, future crop yields are projected by growth projection from historical trends (MOA, 2012). Energy security objectives of nation and the use of wasteland without affecting food security can be achieved by biodiesel production using waste land. It is therefore in line with the national development policy (Francis et al., 2005).

3.2 Model Verification and Validation

The proposed system dynamics model for biodiesel production has provided a visual representation of interrelationship and interdependence between variables of a real-world system. The developed model should reasonably replicate the real world in order to predict the behaviour of the system. Estimates predicted by an incomplete model cannot represent the actual behavior of the system. Therefore, there is a need to verify the model with the observations of the real world. System dynamics model validation is needed to build confidence in the model (Sahay et al., 1996). Senge and Forrester (1980) have defined validation as the process of establishing trust in the soundness and usefulness of a model. Drew (1996) has stated that the validity or significance of a model depends on its suitability for a particular purpose, its scope and its ability to predict its macro-behaviour. It has been emphasized that the model should be capable to defending the specifics of the model structure. The variable interactions, validity and consistency of the sources of contents are paramount. System dynamics model validation is a multi-step process that requires sufficient confidence in the model (Sterman, 2000). Its overall objective is to analyze the underlying trends of the system and to assess the impact of different policies on the system.

In order to validate proposed system dynamics model two scenarios have been modeled, first for estimating land requirements for food grain production where the variables influencing the food grain requirements such as population, food grain productivity, wasteland conversion, etc. are changing with the current trend (Table 1). The other scenario for estimating of emission inventories for the current trend in diesel vehicles that depends on growth in vehicle population, advancement in vehicle engine technology, changes in vehicle use, etc.

Estimates show an increasing trend of land used for food grains until 2015 that is almost constant and then declining after the year 2030 (Figure 6). Land use for food grain depends not only on productivity of land (food grain yield) but also on the demand of food grain measured in terms of population requirements in kg per person per year (Amarasinghe et al., 2007). Food grain yield shave been improved as a result of increased and productivity, resulting in a decrease in land requirements due to population driven food grain demand.

Table 1. Land requirement for food grain in baseline run of the model.

Land use for food grain production			
Year	Land in million hectares	Year	Land in million hectares
2005	120.70	2025	124.41
2010	123.11	2030	124.22
2015	124.32	2035	122.96
2020	124.01	2040	121.33

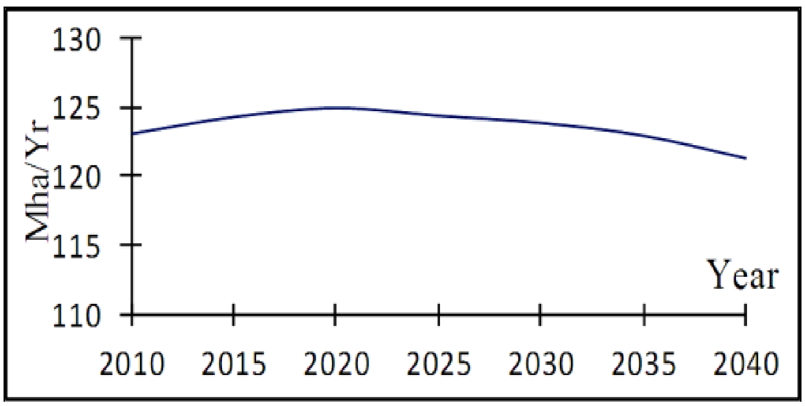


Figure 6. Trend of land use for food grain production.

Table 2 and Figure 7 reflect the emission inventories from the of diesel vehicles pollutants. There has been an increasing trend in the emission of CO2 from diesel vehicles. The emission of CO_2 depends on the total fuel consumption that in turn depends on net effect of improving in engine efficiency and increasing the number of vehicles. CO emissions are shown in Figure 8. This initially shows an increase in emissions by the year 2015, then a decrease in by the year 2020 and again an increase after the year 2020. The emission of CO and other pollutants such SO_2, HC, PM, NOx etc. depends not only on the number of vehicles but also on the efficiency of vehicles measured in terms of pollutant emissions in gms per km of vehicle travel. Due to strict emission norms, engine efficiency is improving over the years, resulting in less emission per kilometer of travel by vehicle. Improving engine efficiency also offsets the rise in emissions due to an increase vehicle numbers.

Table 2. Total emissions in MT/year of different pollutants of diesel vehicles for baseline.

Year	CO2	CO	HC	Nox	PM	SO_2	CH
2010	177.22	6.63	0.43	1.33	0.11	0.19	0.04
2015	294.30	7.70	0.90	2.96	0.15	0.51	0.10
2020	430.81	5.45	0.66	3.85	0.10	0.77	0.14
2025	540.12	6.80	0.83	4.79	0.12	0.96	0.18
2030	622.72	8.12	0.90	5.47	0.13	1.15	0.22
2035	726.96	9.48	0.96	6.36	0.15	1.34	0.26
2040	831.20	10.83	1.09	7.25	0.17	1.53	0.29

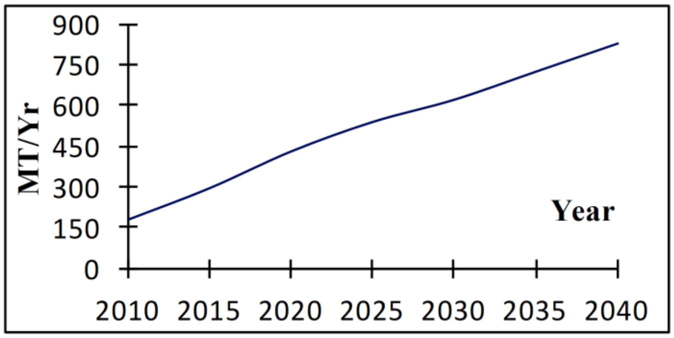


Figure 7. Trend in CO_2 emission.

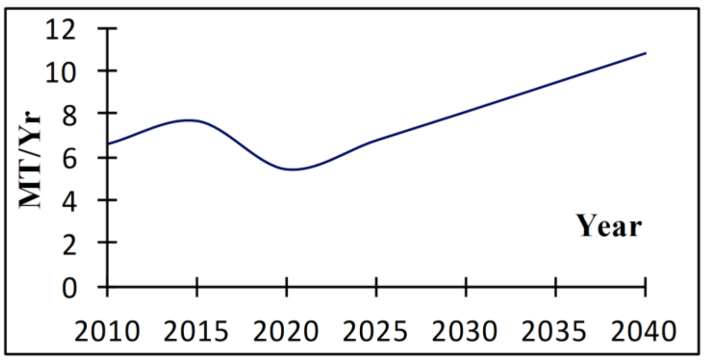


Figure 8. Trend in CO emission.

4. Policies and Scenarios

Alternative scenarios have been developed in the proposed model to find out the maximum possible percentage of blending i.e., maximum possible biodiesel production, land requirements, food grain demand, pollutants emission, earned carbon credits, employment generation and foreign exchange savings. Scenarios have been created based on a literature review (Bhaduri et al., 2008; Reinhardt et al., 2008), taking appropriate assumptions for values of key variables influencing biofuel production and use. These scenarios have covered social (e.g., food security, land use, job creation, etc.), techno-environmental (e.g., CO_2, CO, SO_2, HC, PM, NOx and CH_4 emission, etc) and economic (e.g., carbon credits, cost–benefit) aspect of biofuel production and use. Food grain and biodiesel feedstock yield, land use, population, number of vehicles, emission norms (based on engine technology), retail price of diesel, carbon credits are key variables for scenario generation. A scheme for conducting policy experiments and outcome of the results in the form of scenarios has been presented in Figure 8. These scenarios have been classified into three broad categories: a) social b) techno-environmental and c) economic. Their sub-classification has been shown in Figure 9. Scenarios have been developed for each sub-classification based on extreme and average values of factors shown in Table 3.

Table 3. Simulation scenarios for biodiesel production and its factors.

Scenario matrix				
Sr. No.	Factors considered for scenario generation	Scenario-1	Scenario-2	Scenario-3
1	Food Grain Yield in Ton/ha	Time trend	Lower rate	Higher rate
2	Population in million	Time trend	Higher rate	Lower rate
3	Average Yield of Jatropha in ton/ha	Time trend	Lower rate	Higher rate

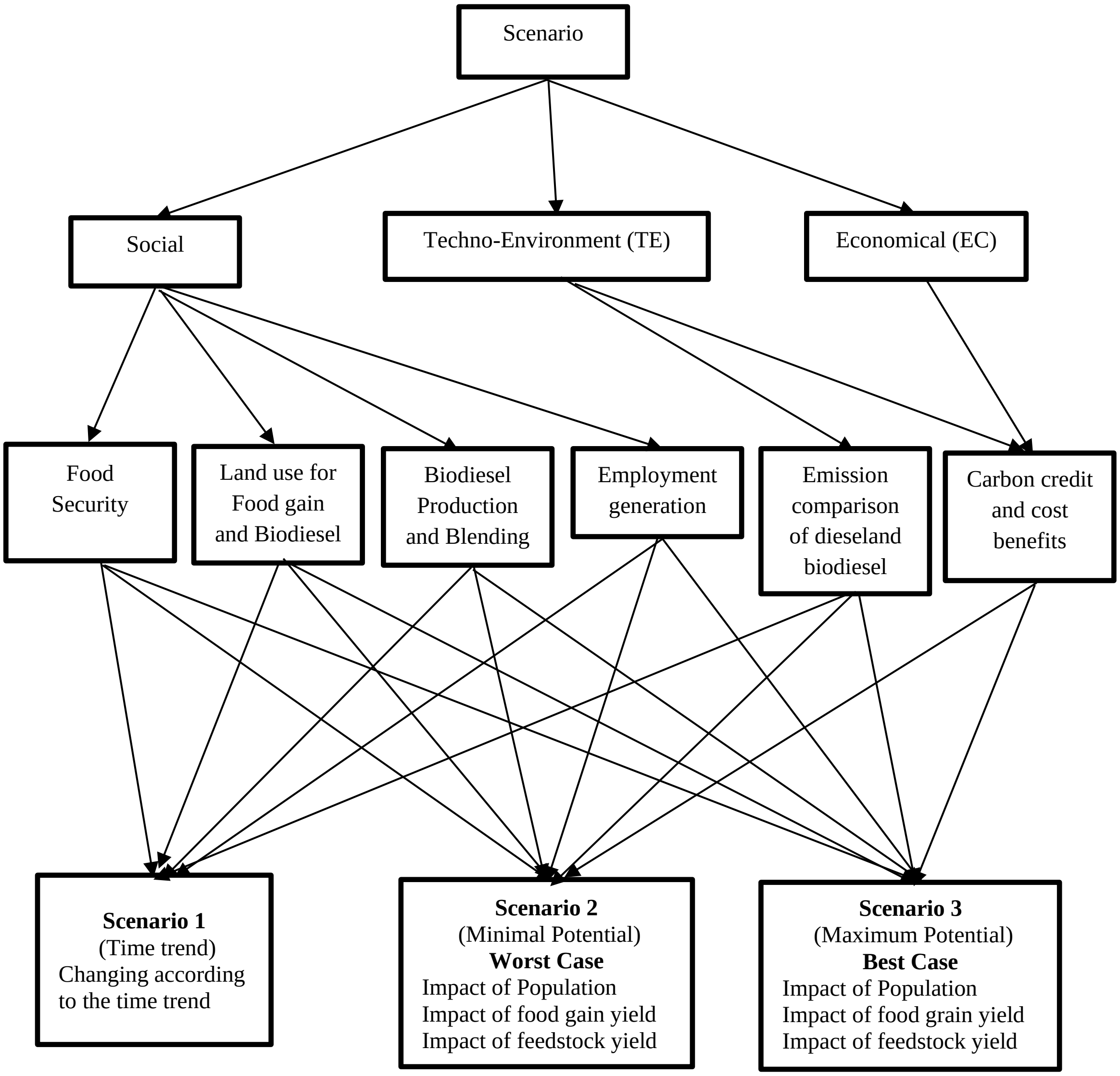


Figure 9. Alternative scenarios.

5. Results and Discussions

Impact of biodiesel production and its use has been evaluated to determine reduction of pollutants emission inventories in the Indian transport sector. Emissions from the road transport sector depend mainly on type of transport and fuel other than the type of combustion engine, emission mitigation techniques, maintenance procedures and vehicle age. The major pollutant emitted from transport are Carbon dioxide (CO_2), Methane (CH_4), Carbon monoxide (CO), Nitrogen oxides (NOx), Sulphur dioxide (SO_2), Particulate matter (PM) and Hydrocarbon (HC). Alternative scenarios have been developed and simulated using system dynamics modeling methods. The POWERSIM software modelling tool is used to model the supply-demand side measures and other causal relationships in a way that clearly describe the feedback mechanisms and dynamics relationships of land use for various purposes. Strategies of biodiesel production and its use include supply-side measures such as land use, food security, yield of food grain and biodiesel feedstock, rural development and demand side measures such as population, growth in vehicles, demand and price of fossil fuels and environmental benefits. In this study, baseline year has been taken as 2015, as biodiesel industry is still in its infancy in the region. A time period of twenty-five years has been used for analysis. Environmental benefits have been assessed in terms of the emission inventories of pollutants such as CO_2, CO, PM, SO_2, CH_4 as well as NOx and percentage reduction of pollutants relative to fossil fuel (diesel) for each scenario.

The results for the alternative scenario for the maximum production of biodiesel that would replace the demand of diesel fuel at a national level without impacting food security have been presented. The emission inventories of unblended diesel with blended diesel have been compared under alternative scenario conditions. These results have depicted the maximum production of biodiesel, its percentage blending and the emissions inventories of blended and unblended diesel fuel and reduction (savings) in blended biodiesel emissions inventories.

5.1 Maximum Biodiesel Production under Alternative Scenario without Affecting Food Security

Scenario 1 has revealed the variability of time trend variables has called "time trend scenario" (business as usual). Land in India is primarily divided in agricultural land, social useable land, forest land and wasteland (MOA, 2007). The availability of land for the production of biodiesel is through and diversion from any of the above-listed forms. The increase in agricultural yields has not only compensated the increased demand of food grains due to population growth but created the likely hood of over farmland being available for social purposes or for the production of biodiesel. Wasteland may be made available for the production of biodiesel, but its reclamation is restricted due to policy, natural and social reasons (Gunatilake et al., 2011). Its availability is growing but it is sluggish, and contingent on the government's policy steps. Minimal scenario 2 (worst case) represents the higher population growth rate a lower rate of food grain yield and biodiesel seeds growth compared to time trend while maximal potential scenario 3 (best case) represents a lower population growth rate, higher rate of food grain yield and biodiesel seeds growth as compared to the time trend.

Results for the production of biodiesel and maximum possible blending in the three scenarios are shown in the Table 4, indicating that the maximum possible blending during simulation period for scenario 2 is 0.76%-3.03%. Maximum production of biodiesel without impacting food security under time trend scenario (scenario 1) will be about 2.08 million tons in the year 2015 that will gradually increase to 22.35 million tons in the year 2040 (Figure 10). It will give maximum blending in the range of 2.52%-5.84% during the simulation period i.e. 2015- 2040while in the case of best case scenario it will be in the range of 5.24%-11.01%. The reasons behind the variation in results are the availability of land for biodiesel production that depends on the food grain demand, population, and food grain yield and biodiesel seeds.

Table 4. Maximum biodiesel production in million tons and maximum blending possible in percentage.

Year	Demand of diesel	Minimal potential scenario 2		Time trend scenario 1		Maximal potential scenario 3	
		Maximum biodiesel production	Maximum blending possible	Maximum biodiesel production	Maximum blending possible	Maximum biodiesel production	Maximum blending possible
2015	82.38	0.62	0.76%	2.08	2.52%	4.32	5.24%
2020	112.00	0.84	0.75%	2.97	2.65%	18.09	16.15%
2025	152.26	2.58	1.70%	6.34	4.16%	24.07	15.81%
2030	206.99	5.36	2.59%	10.31	4.98%	30.46	14.72%
2035	281.40	8.74	3.11%	16.16	5.74%	36.59	13.00%
2040	382.55	11.61	3.03%	22.35	5.84%	42.14	11.01%

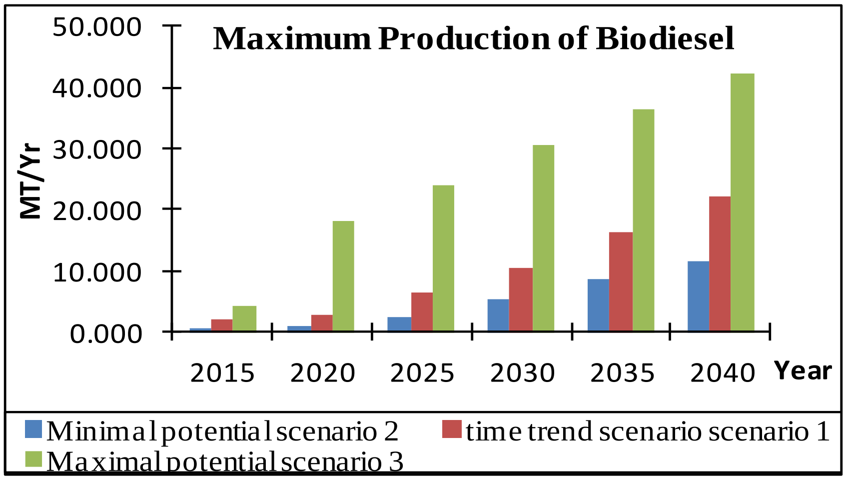


Figure 10. Maximum production of biodiesel under alternative scenarios.

5.2 Net Annual Emission Savings by Biodiesel Use

Annual emission reduction for each pollutant has been calculated on the basis of the difference between emission inventories before and after biodiesel blended fuel use. The net annual pollution reductions from the use of biodiesel use are the highest under maximal potential scenario 3 among all scenarios. Figure 11 and Table 5 show the net annual emission reduction of pollutants through the use of biodiesel in alternative scenarios.

It has been shown that the net annual CO_2 emission reduction would be 8.13million tons per year for 2.52% biodiesel blending in year 2015 and it will increase to 44.62million tons per year for 5.84% blending in year 2040 under the time trend scenario. In case of minimal potential scenario, the reduction in of CO_2emissions will be 4.06 million tons and 26.30 million tons in years 2015 and 2040, respectively. The reduction of CO_2 emissions will be 14.42 million tons and 78.34 million tons in 2015 and 2040, respectively, under maximal potential scenario.

In general, the current model is based on the use of biodiesel for road transport, as this sector consumes a large proportion of total diesel produced and is therefore a major source of environmental pollution. Developments in engine technology have been taken into account as an 'emission factor.' Around the same time, the emission factor value also has to be updated in order to meet the emission standards that the transport regulatory authorities enforce from time to time. The data input level itself has been taken care of in the current model. The consideration of other competitive uses of wasteland, such as alternative renewable energy for industrial purposes, was implicitly included in the social development section; thus, alternative renewable energy as such is not included separately. Wasteland would also be needed for social growth, such as urbanization, industrialization, infrastructure development, etc. Jatropha has to contend with other crops, including cash crops, solely on economic grounds. Small seed and yield of oil are preventing farmers to grow Jatropha. Increasing prices and the lack of availability of cheap labor would make it more difficult to produce biodiesel with Jatropha. Low yield of biodiesel feed stock (Jatropha seed) is already considered for study in a minimal potential scenario 2. It is therefore concluded that without government funding, it would not be economical for farmers to cultivate Jatropha seed for the production of biodiesel.

Table 5. Comparison of emission for diesel and biodiesel in million tons and % reduction.

Pollutants	Year	Emission from Diesel	Emission with Biodiesel blending			% Reduction compared to emission without blending		
			Minimal potential scenario 2	Time trend scenario 1	Maximal potential scenario 3	Minimal potential scenario 2	Time trend scenario 1	Maximal potential scenario 3
CO2	2015	294.30	290.24	286.17	279.88	1.38%	2.76%	4.90%
	2020	430.81	424.91	418.47	372.84	1.37%	2.86%	13.46%
	2025	540.12	528.69	518.25	468.90	2.12%	4.05%	13.19%
	2030	622.72	605.18	593.51	545.93	2.82%	4.69%	12.33%
	2035	726.96	703.54	688.52	647.10	3.22%	5.29%	10.99%
	2040	831.20	804.90	786.58	752.86	3.16%	5.37%	9.43%
CO	2015	7.70	7.66	7.58	7.45	0.45%	1.49%	3.17%
	2020	5.45	5.43	5.37	4.91	0.45%	1.54%	10.00%
	2025	6.80	6.73	6.63	6.13	1.01%	2.49%	9.79%
	2030	8.12	8.00	7.88	7.38	1.52%	3.00%	9.10%
	2035	9.48	9.31	9.15	8.72	1.77%	3.48%	8.03%
	2040	10.83	10.64	10.45	10.10	1.72%	3.54%	6.78%
HC	2015	0.90	0.89	0.88	0.86	1.18%	2.55%	4.67%
	2020	0.66	0.65	0.64	0.57	1.17%	2.65%	13.15%
	2025	0.83	0.82	0.80	0.73	1.91%	3.83%	12.89%
	2030	0.90	0.88	0.86	0.80	2.61%	4.46%	12.04%
	2035	0.96	0.93	0.91	0.86	3.01%	5.06%	10.70%
	2040	1.09	1.05	1.03	0.99	2.95%	5.14%	9.16%
Nox	2015	2.96	2.96	2.97	2.98	-0.10%	-0.26%	-0.54%
	2020	3.85	3.85	3.86	3.91	-0.10%	-0.28%	-1.68%
	2025	4.79	4.79	4.81	4.86	-0.18%	-0.43%	-1.64%
	2030	5.47	5.49	5.50	5.56	-0.27%	-0.52%	-1.53%
	2035	6.36	6.38	6.40	6.45	-0.32%	-0.60%	-1.35%
	2040	7.25	7.27	7.29	7.33	-0.32%	-0.61%	-1.14%
PM	2015	0.148	0.147	0.146	0.143	0.45%	1.36%	2.88%
	2020	0.096	0.095	0.094	0.087	0.45%	1.42%	9.01%
	2025	0.121	0.120	0.118	0.110	0.92%	2.27%	8.82%
	2030	0.132	0.130	0.128	0.121	1.39%	2.73%	8.20%
	2035	0.153	0.151	0.148	0.142	1.64%	3.15%	7.24%
	2040	0.175	0.172	0.169	0.164	1.60%	3.21%	6.12%
SO2	2015	0.51	0.51	0.50	0.48	1.00%	2.52%	5.24%
	2020	0.77	0.77	0.75	0.65	1.00%	2.65%	16.15%
	2025	0.96	0.95	0.92	0.81	1.70%	4.16%	15.81%
	2030	1.15	1.12	1.10	0.98	2.59%	4.98%	14.72%
	2035	1.34	1.30	1.27	1.17	3.11%	5.74%	13.00%
	2040	1.53	1.49	1.44	1.36	3.03%	5.84%	11.01%
CH4	2015	0.0960	0.0960	0.0960	0.0959	0.03%	0.06%	0.14%
	2020	0.1437	0.1436	0.1436	0.1431	0.03%	0.07%	0.42%
	2025	0.1809	0.1808	0.1807	0.1802	0.04%	0.11%	0.41%
	2030	0.2181	0.2179	0.2178	0.2172	0.07%	0.13%	0.38%
	2035	0.2552	0.2550	0.2549	0.2544	0.08%	0.15%	0.33%
	2040	0.2924	0.2922	0.2919	0.2916	0.08%	0.15%	0.28%

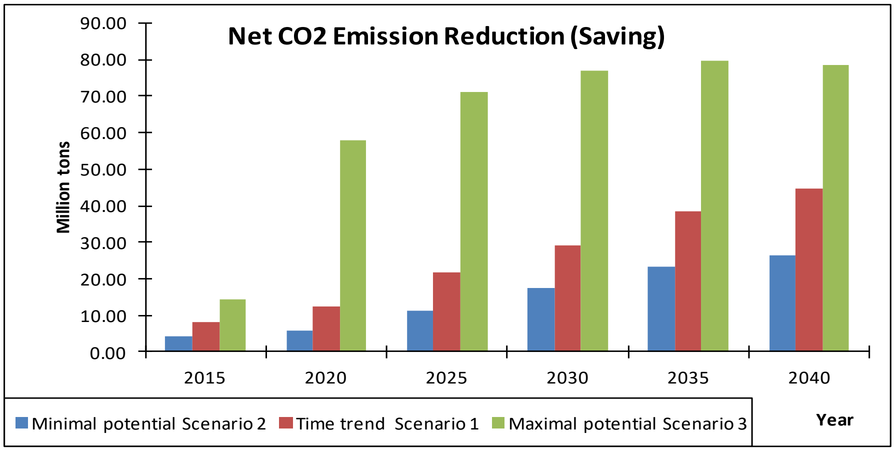


Figure 11. Net CO_2 reduction (saving) under alternative scenarios.

6. Conclusion

An effort has been made to examine the viability of biodiesel production without affecting food security. The impact of the use of biodiesel is assessed in the reduction of emission inventories. Three different scenarios have been simulated, taking into account the sensitivity of biodiesel and food grain yields, food gain demand and population over time. The results indicate that in the best-case scenario the possible blending of biodiesel is more than the business-as-usual scenario and the worst-case scenario from the year 2015 to 2040. If the blending percentage is further raised food security and social needs will be adversely affected. It has been found that no engine modification is needed for low a blending of bio diesel up to 20%. Thus, the research in engine technology for the blending percentage may not be necessary in the Indian context. In the Indian scenario, the maximum possible blending is approximately 5-11%, therefore funding needed to upgrade engine technology can be used to develop infrastructure for the production of biodiesel. Further, vehicle emissions will be lowered in all three scenarios considered for policy experimentation. CO_2 and other emissions will also be significantly reduced under the maximal potential scenario. Biodiesel blending has a considerable impact on emissions and displacement of fossil fuel. The growing energy needs and restricted domestic fossil fuel reserves, the Government of India plans to expand its renewable and biofuels program. In addition to present work, the direction for future research can be twofold:

The introduction of new tax policies, tax incentives, subsidies, farm productivity from land use change etc. may also be integrated into the future modeling framework.

Hybridization and use of various simulation approaches in the field of biofuels production can provide further insights into emissions modeling.

Conflict of Interest

The authors confirm that there is no conflict of interest to declare for this publication.

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