Environ Model Assess (2015) 20:609–624
DOI 10.1007/s10666-015-9448-4

Assessing the Effectiveness of Alternative Policies in Conjunction with Energy Efficiency Improvement Policy in India

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Received: 6 February 2014 / Accepted: 5 February 2015 / Published online: 19 February 2015

Abstract Energy efficiency improvement is often advocated for fuel conservation and mitigation of greenhouse gas emissions in Indian personal transport sector. However, in the long run, this policy is found to induce direct rebound effects as it leads to more car trips and hence longer travels. Attempts have been made in this paper to test the effectiveness of alternative energy policies in conjunction with energy efficiency improvements in personal transport sector of India with the help of a system dynamics model. Four alternative energy policies considered in conjunction with the energy efficiency improvement policy are carbon tax imposition, car sharing, car scrappage, and a combination of all of these. Simulation results show that while the combined policy gave the best scenario in terms of fuel consumption and greenhouse gas emissions, the car sharing policy gave the best scenario in terms of direct rebound effect values.

Keywords Energy efficiency improvement · System dynamics · Direct rebound effect · Carbon tax · Car sharing · Car scrappage

1 Introduction

Energy conservation and environmental protection are the two important issues faced and discussed all over the world. Increasing consumption of fossil fuels has resulted in fuel vulnerability and is a threat toward the future energy sustainability. Transport sector is considered as the major consumer of fossil fuel in the world. United Nations Organization estimations show that 72 % of oil consumption is from transport sector and road traffic, and the transport sector accounts for 22 % of total carbon dioxide emissions, 66 % of the total carbon monoxide emissions, 47 % of nitrogen oxide, and 39 % of hydrocarbons in the world [49].

India also faces the issues of transportation fuel vulnerability and atmospheric pollution due to greenhouse gas (GHG) emissions. India stands third among the 26 most fuel-vulnerable countries in the world [31]. The demand for transportation fuel (gasoline/diesel) has increased over the years, and presently, more than 80 % of India's oil needs are met through imports. A major share of this demand is from the transport sector of the country [27, 44]. High fuel consumption levels have resulted in high levels of emission which has been one of the reasons for the climate changes in the country [35]. As per IEA [33] report, India is one among the five largest GHG emitters in the world, and its share has been doubled between 2000 and 2010. The IEA report observes that the emission levels in India are continuously on the rise and the major contributor to this is the transport sector with a 20 % contribution.

In order to mitigate the increasing fuel consumption and GHG emissions, Indian government has adopted the policy of improving the energy efficiency (or fuel efficiency) of the vehicles [4, 51]. The need to mitigate environmental pollution from the transport sector has led to the adoption of emission control practices in 1991 through fuel efficiency regulations in the country. Steps are adopted since 1996 to improve the fuel quality in order to bring about vehicle fuel efficiency improvements in India. Recently, the maximum limit of benzene availability in petrol has been set at 5 % for the country (3 % for the metros), and the sale of leaded petrol has been discontinued throughout the country [44]. In June 2009, Indian Government announced that it would soon make fuel efficiency labeling of cars mandatory [10]. A previous study by the authors in personal transport sector in India involving passenger cars

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[44] and other existing studies in the world on the effectiveness of energy efficiency improvements showed that this policy was not successful in mitigating the increasing fuel consumption and GHG emissions in the country in the long run [2, 53]. The study also revealed that this policy has induced direct rebound effect (for details on direct rebound effects, see Greene [30]; Herring and Sorrell [32]; Roy [53]; Sorrell and Dimitropoulos [57]; Sorrell et al. [58]) in the personal transport sector in India. Direct rebound effect occurs when an increase in the energy efficiency of a particular service leads to the decrease in overall cost of that service, resulting in an increase in usage and hence an increase in energy consumption [8, 30, 44].

In this paper, we extend our previous research by studying the effectiveness of alternative energy policies in conjunction with the energy efficiency improvement policy in personal transport sector in India. Four alternative energy policies of imposing carbon tax, car sharing, car scrappage, and a combination of these three policies are considered. The aim is to seek for a policy synergy when the alternative energy policies are clubbed with the energy efficiency improvement policy toward fuel consumption and GHG emission mitigations in the context of India. The projections are made for a time horizon of 11 years starting from 2012 to 2022.

2 System Dynamics and Energy Modeling

2.1 System Dynamics Methodology

The present study is based on system dynamics (SD) methodology. SD is a method of analyzing system-related problems and involves the study of how a system can be defended against or benefited from the shocks that falls upon it from the external world [16]. SD, a methodology of system enquiry, is a theory of structure and behavior of systems that helps in analyzing and representing the interactions governing the dynamic behavior of complex socioeconomic systems [63]. It is rooted in feedback control theory and nonlinear dynamics. It can handle complex feedbacks and delays present in the system in predicting the system's behavior over time. To develop an SD model, a causal loop model (or CLD) is developed initially. Causal loop diagrams depict the causal relations that exist between the variables in a system through the use of text, arrows, and symbols. A causal relationship between two variables is positive if they move in the same direction and negative if they vary in the opposite direction. A causal loop is reinforcing if it has zero or an even number of negative causal relations that results in reinforcing the behavior of the system. A causal loop is balancing if it has odd number of negative causal relations and it stabilizes the system behavior over time. Thus, causal relations finally form feedback loops that are either reinforcing (R) or balancing (B) in nature [60]. The causal loop diagram is the input to the final quantitative model involving flow diagrams that will bring out the behavior over time of the system being studied. SD uses quantitative means to investigate the dynamic behavior of the real-world system and its responses to policy decisions. Policy experimentation can be carried out by making appropriate changes in the structure, model parameters, or in the policies of the management. Thus, SD aids in analyzing the effects of alternate policies on the system's behavior before implementing them. The dynamic behavior generated through simulation reveals the changes in the key variables over a period of time. Thus, SD helps in scenario generation and in identifying suitable policies for the problem considered.

System dynamics is widely applied in energy modeling. SD have been used to study the market penetration of alternative fuel vehicles [28], to model the urban transportation-related issues of road congestion, modal split [61], and emissions [49]. Kiani et al. [37] gave a detailed survey on the application of SD in energy system modeling. Meadows et al. [41] had utilized SD in the study of nonrenewable energy resources. SD have been utilized to study the discovery life cycle of natural gas [47] and for estimating petroleum resources [17]. Elias [21] carried out a systemic analysis of energy efficiency in New Zealand's residential sector. This vast literature shows the suitability of SD in energy system modeling. Moreover, Bhattacharyya and Timilsina [12] suggested the utilization of methods of simplicity, straightforward interpretation, and limited data requirements in contrast to the complex estimation procedures in energy system modeling. This has motivated the use of SD methodology in the present research work.

The research is mainly aimed at analyzing the influence of energy efficiency improvements on the fuel consumption and the associated GHG emissions in Indian personal transport sector in the long run. The research also aims to experiment with certain policies for its effects on mitigating the fuel consumption and emissions from the sector under the prevailing conditions. To accomplish these aims, we have selected the problem solving methodology of SD as this technique is mainly utilized for long-term forecasting and policy planning. In addition, SD can take in to consideration the feedback loops in the systems which are present in the energy efficiency—personal transport system considered in the present work. This will in turn help to find out the counter intuitive behavior (if any) of the system like a reverse in the fuel consumption for the same fuel price increase rate in the long term. Moreover, SD modeling has been used for strategic energy planning and policy analysis for more than 25 years. Thus, the SD methodology was found apt for the present modeling venture.

2.2 The Energy System Dynamics Model

The personal transportation—energy efficiency system considered by the authors in the present work—has dynamic implications arising from a number of modules. These modules are as given below:

1. Fuel efficiency improvement dynamics.
2. Fuel efficiency—four-wheeler ownership dynamics.
3. Travel behavior dynamics.
4. Social impact dynamics.

SD technique has been adopted by the author to model the system, simulate, and obtain the system behavior which is a combination of dynamic interactions of all the four modules. A complete discussion on the suitability and appropriateness of SD for transportation system involved modeling can be found in Abbas and Bell [1].

3 The Personal Transportation—Energy Efficiency Model

The SD model developed was confined to personal transport sector of India comprising only passenger cars. The model was developed to capture the influence of alternative energy policies in conjunction with the energy efficiency improvement policy on the car ownership, on the social impact of traffic congestion, on fuel consumption, and on associated GHG emissions in personal transport sector in India in the long run.

The behavior of the model is dependent on the values of India's gross domestic product and the fuel price in the country for the next 12 years. It is assumed that the gross domestic product will follow an 8 % growth rate per year. The fuel price is assumed to rise continuously and reach rupees 180 per liter at the end of 12 years. The inflation was adjusted by incorporating a time factor to the model. The SD methodology utilizes standard objects in representing the system entities. A square box represents a "level variable" like population. A circle either represents a "variable" or a "constant" or a "fraction." The turbine-shaped objects represent a "rate variable" in the system. The delays in the system are presented by two parallel lines crossing the causal links (//). Subsequent sections describe the SD model developed.

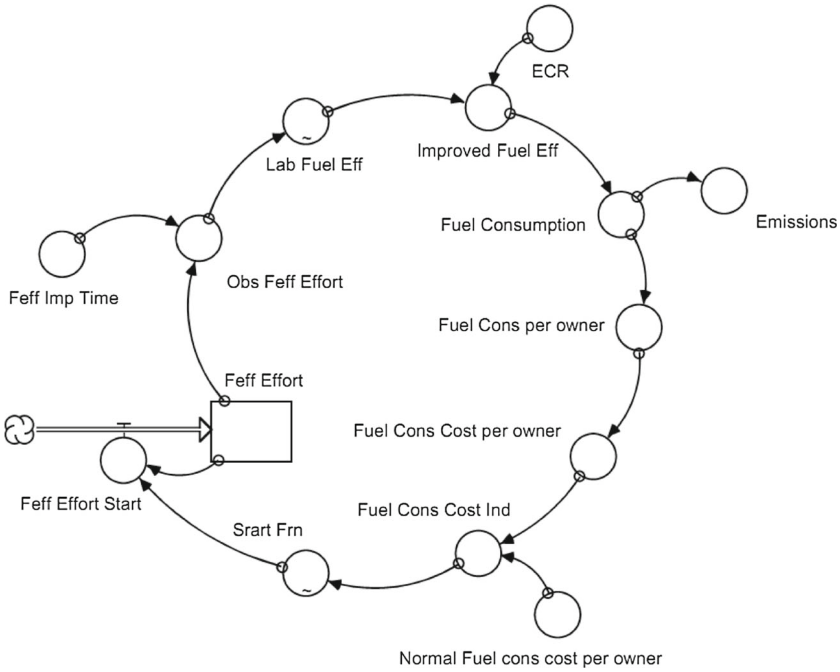
3.1 Fuel Efficiency Improvement Dynamics

The stock and flow model for the fuel efficiency improvement dynamics are shown in Fig. 1. The increase in fuel consumption which, in turn, leads to GHG emissions motivates the government and car manufacturers to improve the fuel efficiency of vehicles. The European Union (EU) fuel efficiency standard followed by India is introduced as "improved fuel efficiency" and is modeled as

Improved fuel efficiency = lab fuel efficiency * efficiency cutoff ratio

The claimed fuel efficiency by the car manufacturer cannot be attained by their vehicles on the road due to the congested road and traffic conditions in India. Thus, the "efficiency cutoff ratio" is a value that determines the on-road fuel efficiency attained by the cars on Indian roads. This ratio when multiplied

Fig. 1 Fuel efficiency improvement dynamics [44]



ECR = Efficiency Cut off Ratio
Start Frn = Efficiency Improvement Start Function

with the car manufacturers' claimed fuel efficiency gives the on-road fuel efficiency attained by the cars on Indian roads [55].

It takes time to measure and report information. It takes time to make decisions and for the decisions to affect the state of a system. This makes delays in systems important. The improvement in vehicle fuel efficiency takes place sometime after the investments are made on technology. Gradual improvement of vehicle fuel efficiency is captured by using the "fuel efficiency improvement time" (Feff Imp Time) as a delay process in the model.

3.2 Fuel Efficiency - Four-Wheeler Ownership Dynamics

The stock and flow model for the four-wheeler ownership dynamics are shown in Fig. 2. The fuel efficiency improvement policy affects the four-wheeler (car) sales in India. Owing to the increase in fuel prices, consumers are attracted toward fuel efficient four wheelers as it reduces the travel cost. In the present model, we have considered the four-wheeler sales to be determined by the four-wheeler price, disposable income (DI), and the four-wheeler marginal utility of fuel efficiency to performance. The disposable income is considered for the urban people as they are found to be the potential customers for four wheelers in the country. The four-wheeler scrappage is determined by the average age of the four wheelers which is taken to be 15 years [5, 52].

Due to inefficient transport infrastructure in India, the real improved fuel efficiency is not attained by four wheelers on Indian roads. The on-road fuel efficiency is the realized fuel efficiency for four wheelers on Indian roads. This is roughly 80 % of the real improved fuel efficiency [55]. The average on-road fuel efficiency is obtained by dividing the level of four-wheeler ownership into fuel efficiencies by the four-wheeler ownership.

3.3 Travel Behavior Dynamics

Improvements in fuel efficiency reduce the travel cost as the four wheeler consumes less amount of fuel owing to these efficiency improvements. This in turn motivates the four-wheeler user (i.e., a commuter using a four wheeler) to drive more resulting in an increase in four-wheeler distance traveled (VMT) which is captured in the consumer travel behavior dynamics shown in Fig. 3.

The fuel considered in the present study is gasoline, and the price of gasoline is taken to be the total of international fuel price at which the fuel is imported and the fuel tax imposed by the government. This is because more than 85 % of the fuel requirements in India are met through imports [27, 44]. In the present simulation, the international fuel price is considered as an exogenous variable. In travel behavior dynamics submodel in Fig. 3, the travel cost and the four-wheeler distance traveled are modeled as

$$\text{Travel cost} = (\text{fuel price}/\text{ average on road fuel efficiency})/\text{time factor}$$

$$\text{VMT} = (\text{per capita disposable income} * \text{percentage used in travel})/\text{travel cost}$$

3.4 Social Impact Dynamics

Improvements in four-wheeler fuel efficiency have indirect effects on the society. Increased vehicle travel, triggered by

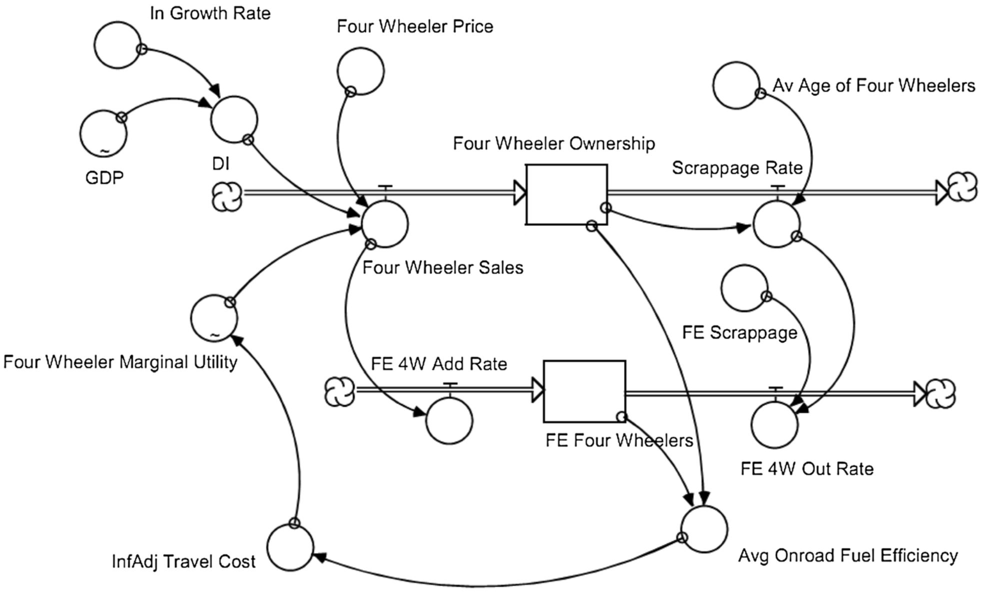


Fig. 2 Four-wheeler ownership dynamics [44]

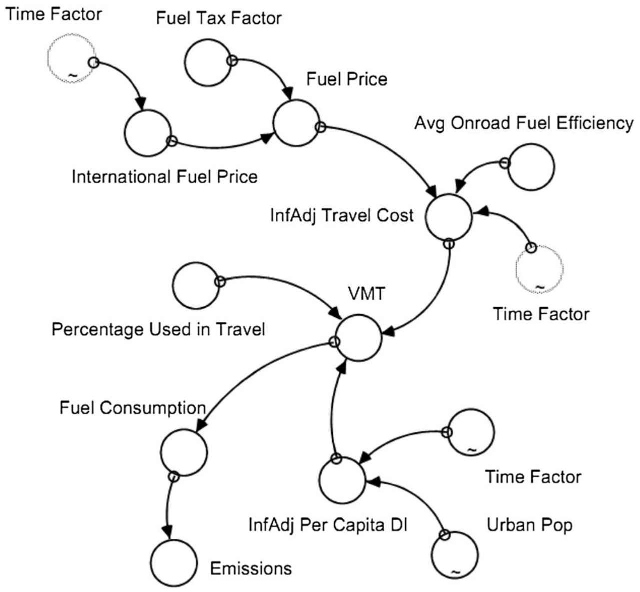
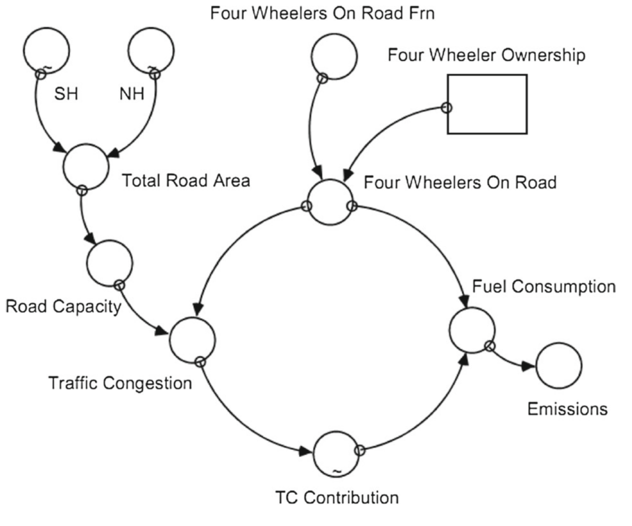


Fig. 3 Travel behavior dynamics [44]

fuel efficiency improvements, generates external costs of traffic congestion and tailpipe emissions. These social impact dynamics are depicted in the form of a stock and flow diagram in Fig. 4.

The road capacity is expressed in passenger car units (PCU) [14], and it is the total area of the national highways (NH) and state highways (SH) in India. The values for national highways (NH) and state highways (SH) are taken from India Government approved data bank [46, 48] and are introduced into the model as graph functions. Total road area is the length of road multiplied by the breadth of road. The Government data bank provided the annual increase in length of these highways in the country which are represented by "NH" and "SH" in the model. The constants multiplied with NH and SH are the breadths of these highways to obtain the total road area or the road capacity.



SH = State Highway Road Area; NH = National Highway Road Area

Fig. 4 Social impact dynamics [44]

Social impact of traffic congestion is modeled as

$$\text{Traffic congestion} = \text{four wheelers on road}/\text{road capacity}$$

The fuel consumption is modeled as a function of four wheelers on road, four-wheeler distance traveled (VMT), improved fuel efficiency, and traffic congestion (TC). Previous research works in transportation modeling have shown that the traffic congestion considerably increases the fuel consumption by the vehicles [18, 54]. Thus, the fuel consumption in personal transport sector in India is modeled as follows.

$$\text{Fuel consumption} = \left[\left(\begin{array}{l}((\text{four wheelers on road} * \text{VMT})/\ \text{improved fuel efficiency}) \quad * 365\\ * \text{ TC contribution}\end{array}\right)\right]$$

The GHG emission is modeled as a function of the net fuel consumption as follows.

$$\text{Emissions} = \text{fuel consumption} * \text{conversion factor}$$

The complete causal loop model and the description of the variables used in the causal model can be found in Menon and Mahanty [44]. The complete stock and flow model and the governing equations and parameters for the SD simulation are available upon request [45]. The data for simulation was adopted from United Nations Statistic Division (UNSD, USA), Centre for Monitoring Indian Economy (CMIE, India), and Business Beacon (BB, India), all of which are accepted by the respective governments and the scientific community. The simulation was carried out for two scenarios, namely, scenario 1 which is the base run with no fuel efficiency improvements and scenario 2 which considers the on-going fuel efficiency improvement efforts in the country. The key findings from the prior SD simulation analysis [44] where (1) the energy efficiency improvement policy will increase the demand for fuel efficient cars in the market thereby favoring the sector's growth, (2) the growth in car ownership, in turn, increases the traffic congestion levels thereby resulting in an increase in the energy consumption and emissions in the country, and (3) the energy efficiency improvements trigger more trips and hence the distance traveled resulting in a direct rebound effect which adds up to the energy consumption and emissions in the country. Thus, it was concluded from the previous modeling venture that if the present energy efficiency improvement scenario continues in future, there would be more than two times increase in the levels of energy consumption and GHG emissions by 2020 from personal transport sector in India.

4 System Dynamics Model Validation

Simulation models based on SD methodology are becoming increasingly popular in the analysis of energy policy-related issues which include energy consumption and conservation, energy efficiency improvement, and climate change. The usefulness of these models rests on their ability to link observable patterns of behavior of a system to microlevel structures [50]. This, in turn, is checked through model validation procedures. The primary aim of model validation is to have confidence in the model developed. Two important tests, which are conducted to validate an SD model, are structural validity test and behavior validity test. As the model passes these tests, the confidence level builds from low to high [26]. Validation of the SD model developed is described below.

4.1 Structural Validity Test

The structural validity test of SD models includes dimensional consistency test, extreme condition test, parameter verification test, boundary adequacy test, and structure verification test [50]. Here, the first three tests are carried out for the SD model developed, and the later two tests can be found in Menon and Mahanty [45].

4.1.1 Dimensional Consistency Test

Dimensional consistency test involves checking for each mathematical equation in the model so that the measurement units of all the variables and constants involved in the model are dimensionally consistent [50]. Dimensional consistency of each of the mathematical equations involved in the personal transport sector energy efficiency model was checked. The fuel consumption variable in the SD model developed is utilized for dimensional consistency test and is as follows.

(a) Fuel consumption variable

A key element in the model is fuel consumption and the equation for which is as follows.

$$\text{Fuel consumption} = [((\text{four wheelers on road} * \text{VMT})/\text{improved fuel efficiency}) * \text{traffic congestion contribution}]$$

Here, in the equation for fuel consumption, four wheelers on road is in “No. of four-wheelers”; four-wheeler distance traveled (VMT) is in “kilometers”; improved fuel efficiency is measured as “kilometers per liter”; and traffic congestion contribution is dimensionless in nature. The total fuel consumption by the four-wheeler population in India is expressed in “liters.” Thus, the unit for fuel consumption is computed as follows:

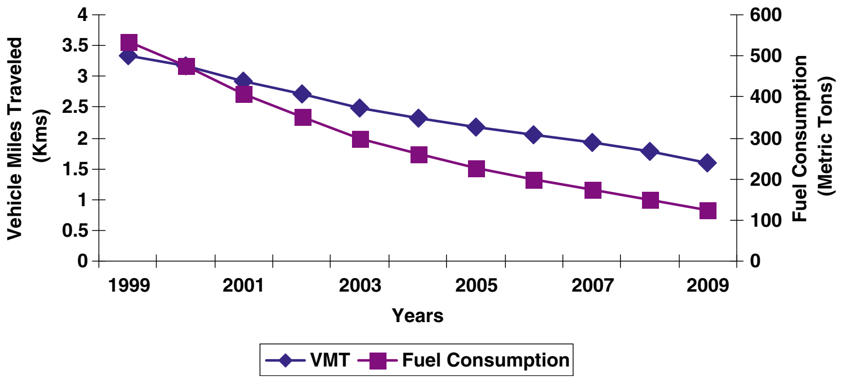
$$\text{Fuel consumption} = [((\text{four wheelers on road} * \text{VMT})/\text{improved fuel efficiency}) * \text{traffic congestion contribution}]$$
$$\text{Liters} = [((\text{no. of four wheelers} * \text{kilometers})/\text{kilometers per liter}) * \text{unit lesstrafficcongestion contribution variable}]$$
$$\text{Hence, } [\text{dimensionless}] = \text{liters}/\ \text{liters} = [\text{dimensionless}]$$

Thus, the equation is found to be dimensionally consistent.

4.1.2 Extreme Condition Test

The model should remain robust in extreme conditions. The model should behave in a realistic fashion no matter how extreme the inputs or policies imposed on it may be [60]. The model-generated behavior under the extreme conditions is compared to the anticipated behavior of the real system [50]. For the present extreme condition testing, fuel tax factor, which is imposed by the government on the fuel sold in India, was increased from 2 % to a high value of 10 %. Increase in fuel price, achieved usually through an increase in fuel taxes or carbon taxes, is adopted as a policy to constrain the four-wheeler distance traveled (VMT) by the user in other countries. An increase in fuel price thus attained increases the travel cost which in turn reduces the VMT leading to a reduction in fuel consumption in the country. Hence, the anticipated behavior of the real-world system at high fuel taxes is a declining pattern for VMT and fuel consumption. Figure 5 shows that

Fig. 5 Model behavior under extreme condition test



VMT and fuel consumption indeed show a sharp declining trend with high fuel tax imposed.

4.1.3 Parameter Verification Test

The parameter verification test is mainly aimed to find whether the parameters in the model are consistent with the relevant descriptive and numerical knowledge of the system being modeled [50]. The values assigned to the parameters of the SD model developed are sourced from the existing knowledge and numerical data provided by Centre for Monitoring Indian Economy [15], Business Beacon [9], International Energy Agency [34], Society of Indian Automobile Manufacturers [55], An et al. [3], and Singh et al. [56]. For illustration purpose, Table 1 lists some of the parameters, their values, and the source.

4.2 Behavior Validity Test

The behavioral validity test conducted for the developed SD model includes comparison to reference mode, behavior replication test, and error analysis for the model using Theil statistics. The details are as follows.

4.2.1 Behavior Replication Test

The main purpose of behavior replication test is to compare the model-generated behavior to the observed behavior of the real system [50]. For the behavior or historical validation, the transport sector fuel consumption variable is selected. The model behavior validation is based on the data collected from India government approved data source of Business Beacon [9]. Data for the year 1999 is incorporated in the model, and projections are made up to the year 2009 for a time horizon of 11 years. The SD model was run in Stella 5.0 software using Euler's method of integration [24]. The model results give good agreement with the actual fuel consumption values. The correlation between the actual and the simulated fuel consumption values was found to be 0.987, and the R^2 value was found to be 0.971, both at a significance level of 0.01. Thus, it can be interpreted that there is high correlation between actual and simulated values. The measure of closeness or the mean absolute error (MAE) between actual and simulated values was also found to be only 22.68.

The error analysis in terms of the root mean squared percent error (RMSPE) and the Theil inequality statistics was suggested by Sterman [59] toward statistical validation of SD models. The RMS percent error (RMSPE) and the Theil inequality statistics for the fuel consumption variable are

Table 1 Parameters of the SD model and their assigned values

Parameters in the model	Assigned values	Source
Efficiency cutoff ratio (ECR)	0.8 (%)	SIAM [55]
Emission conversion factor	8.77 (metric tons)	SIAM [55]
Fuel tax factor	2 (%)	IEA/OECD [34]; Singh et al. [56]
Four wheelers on road	0.75 (%)	BB [9]; CMIE [15]
Fuel efficiency improvement time	1 year	An et al. [3]
Average age four wheelers	15 years	Rodrigues et al. [52]; SIAM [55]
Percentage of disposable income used in travel	0.2 (%)	Rodrigues et al. [52]

Table 2 Error analysis of the model (Theil inequality statistics)

Variable	RMSPE (%)	U^m	U^s	U^c
Fuel consumption	4	0.006	0.210	0.784

presented in Table 2. The RMSPE provides a normalized measure of the magnitude of the error. The Theil statistics U^m, U^S, and U^C reflect the fraction of modeling error due to bias, unequal variance, and unequal covariance, respectively [59]. The RMS percent error is 4 %, which means that the simulated variable behavior correctly matches the actual behavior of the variable which is an indication of increased confidence in the developed SD model. The major portion (nearly 78 %) of the small magnitude error in the simulated behavior of the fuel consumption variable is due to unequal covariation. This indicates that the simulated fuel consumption tracks the underlying trend in the historical fuel consumption almost perfectly but diverges at some points.

4.3 Sensitivity Analysis

Sensitivity analysis is carried out to test for the robustness of the SD model. The robustness of the results generated by the SD model is assessed through the sensitivity analysis of the model. Sensitivity analysis asks whether the conclusions change in ways important to the purpose when assumptions are varied over the plausible range of uncertainty [60].

For the present study, the best and the worst case sensitivity analyses are carried out. The method involves defining of the best and the worst case scenarios. In the best case scenario, all parameters and relationships are set to the values most favorable to the outcomes one desires to test [60]. It is just the reverse in the worst case scenario. The SD model developed in Sect. 3 relates transport sector fuel consumption to improved fuel efficiency, four wheelers on road, fuel price, and percentage of disposable income used in travel. Suppose the model is used to plan for energy savings in the personal transport sector. The energy consumption is to fluctuate with the improvements in car fuel efficiency, the car fleet on road, changes in fuel prices, and the amount spent on traveling by the car user.

The base case scenario involves the values utilized for the base run of the SD model. The worst case scenario to address the concern might assume relatively weak fuel efficiency improvements, high number of four wheelers on road, high fuel prices, and high percentage of disposable income used in travels. The best case scenario might assume strong fuel efficiency improvements, low number of four wheelers on road, low fuel prices, and less percentage of disposable income use in travel. In the base case, the effectiveness of fuel efficiency improvements is 1/year, the four wheelers on road fraction is 0.75 units/day, fuel tax factor is 2 units/liter, and percentage of disposable income used in travel is 0.2 units/day/consumer. The best (worst) case sets effectiveness of fuel efficiency improvements to 2 (0.75), four wheelers on road fraction to 0.563 (0.938), fuel tax factor to 2.5 (1.5), and percentage of disposable income used in travel to 0.15 (0.25). Figure 6 compares the best case and worst case scenarios to the base case.

In the base case, the fuel consumption falls to about one half of the worst case. The implications for fuel conservation are very different for the best and the worst cases. In the best case, faster fuel efficiency improvements combined with higher fuel tax factor drop the fuel consumption substantially. On the other hand, low pace in fuel efficiency improvements, more four wheelers, and so on lead to high fuel consumption rates in the worst case scenario. The best and worst cases provide bounds for the behavior the personal transportation-energy efficiency system is likely to experience. Moreover, these four selected variables/parameters are to have considerable influence on the system behavior. Thus, these high leverage points can be the best intervention points for the application of other energy-related policies.

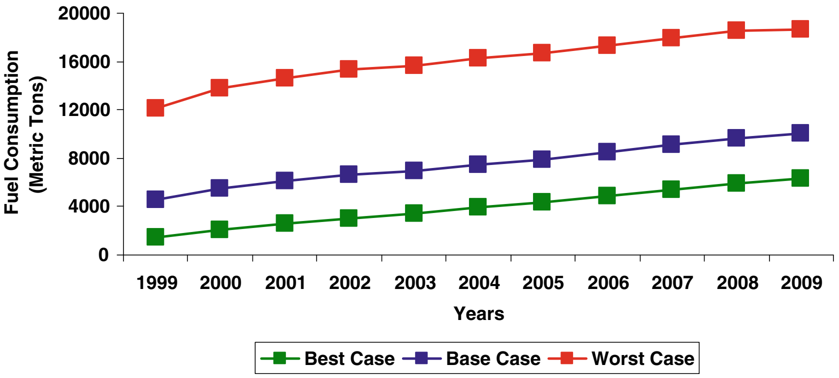


Fig. 6 Base, best, and worst case sensitivity analysis for the SD model

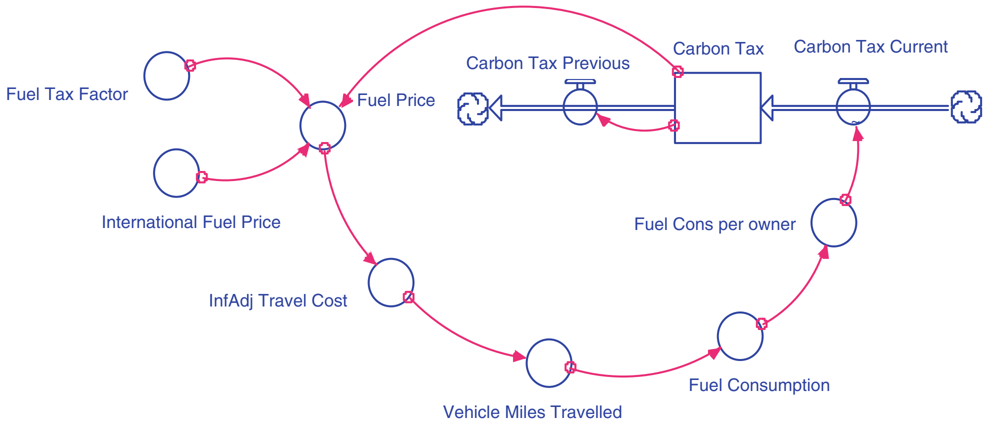


Fig. 7 Stocks and flows to simulate carbon tax flow in the system

5 Policy Experimentation

The personal transportation-energy efficiency model based on SD simulation and developed by the authors in their previous research is further extended for testing alternative policies alongside the energy efficiency improvement policy adopted in India. The alternative policies tested include the carbon tax policy, car sharing policy, car scrappage policy, and combination of these policies, the details of which are given below. These policies are incorporated to the basic stock and flow diagram previously developed by the authors.

SD models are composed of dynamic feedbacks guided by nonlinear differential equations. Each stock in the model has a separate differential equation [11]. The Euler's first-order numerical integration method [24], provided by Stella software, was utilized for solving the guiding differential equations in the model.

5.1 Policy 1: Carbon Tax Policy

Fuel price increase is found to be one of the effective policies to reduce fuel consumption and GHG emissions. This is achieved through taxing the fuel through levying carbon tax. The GHG emissions due to the combustion of fossil fuels (gasoline/diesel) are related to the carbon content in the fuel burnt. Thus, a tax on this GHG emission can be levied by taxing the carbon content in the fossil fuel which in causing this emission. In the context of transportation, carbon taxation involves the charging for the carbon content of fuel, as this has a direct link with carbon dioxide emissions (the most abundant GHG after water vapor) resulting from the combustion of fuel [29]. Carbon taxes have been frequently advocated as a cost-effective instrument for reducing emissions [7]. Carbon tax policy has been adopted in various countries in the world like Finland, Denmark, Sweden, Norway, and Netherlands [13, 39]. At the same time, this policy has failed in the USA [7]. India has imposed carbon tax on coal imports to the country [25, 42]. Yet, this policy has not been tried in the transport sector in India. Carbon taxing is experimented along side the fuel efficiency improvement policy for its effectiveness toward fuel consumption and emission mitigations from the personal transport sector. For experimenting with the carbon tax policy, a carbon tax of 0.028 dollars per liter [20] is incorporated to the already developed SD model. Figure 7 shows the stock and flow model for the carbon tax policy.

The "Carbon Tax Current" is the currently imposed carbon tax for the present year while the "Carbon Tax Previous" is the one that was imposed in the previous year in the country. The

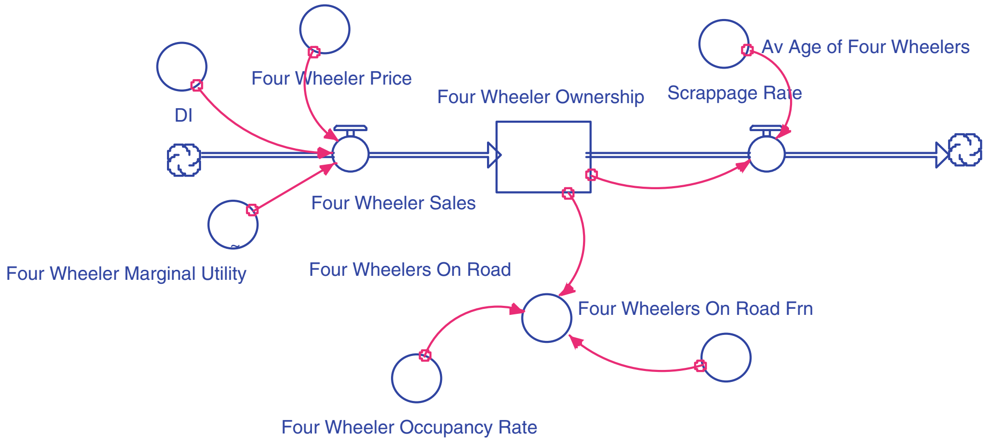


Fig. 8 Stocks and flows to simulate car sharing policy in the system

difference between Carbon Tax Current and Carbon Tax Previous gives the annual changes in carbon tax imposed in India. Then, Carbon Tax will be

$$\begin{aligned}\text{Carbon Tax}(t) &= \text{Carbon Tax}(t-dt)\\ &\quad + (\text{Carbon Tax Current} - \text{Carbon Tax Previous}) * dt\end{aligned}$$

The carbon tax (current) imposed by the government every year will depend on the average fuel consumption per car owners in the country. The more the average fuel consumption per car owner, the more the carbon tax and vice versa. In an increasing fuel consumption regime in the country, the carbon tax imposed is expected to have an increasing trend. The increasing carbon tax in turn will result in the increase in fuel prices. This will lead to an increase in the travel cost for the car owner thereby motivating her to reduce the car travels. This will finally result in the visible reductions in the fuel consumption and emissions in the country.

5.2 Policy 2: Car Sharing Policy

The car sharing or four-wheeler sharing or car clubs (as in UK) involves the usage of cars by more than one commuter on a rental basis for a short period of time. Car sharing involves a group of commuters together sharing a car which in turn lowers down the number of four wheelers on road. The policy of car sharing can help to reduce fuel consumption and protect the environment [36]. The policy of car sharing is currently adopted in many countries like Germany, Netherlands, New Zealand, and Switzerland [22, 23, 40, 43]. Still, this policy is not experimented with for its success in the transport sector in India. Here, the policy of car sharing is tested alongside the fuel efficiency improvement policy already adopted by the government in the country.

Figure 8 depicts the stock and flow diagram for the car sharing policy applied to the personal transportation-energy efficiency system. A “car occupancy factor” (or four-wheeler occupancy rate) of 1.5 is incorporated to the model as it is assumed that there will be a 1.5 times reduction in the four-wheeler (car) population on road due to car sharing by 2 to 3 commuters per car.

As in Fig. 8, the four wheelers on road is a function of four-wheeler ownership, four wheelers on road fraction (*Frn*), and four-wheeler occupancy rate. Four-wheeler occupancy is the maximum number of commuters that can be accommodated in a car. Four-wheeler occupancy rate gives the reduction in the number of four wheelers on road due to car sharing.

$$\begin{aligned}\text{Four wheelers on road} &= \left(\text{four-wheeler ownership}\big/\text{four-wheeler occupancy rate}\right) * \text{four wheelers on road Frn}\\ \text{Four-wheeler ownership }(t) &= \text{four-wheeler ownership }(t-dt) + (\text{four-wheeler sales} - \text{scrappage rate}) * dt\\ \text{Four wheelers on road Frn} &= 0.8\\ \text{Car occupancy factor}\big/\text{four-wheeler occupancy rate} &= 1.5\end{aligned}$$

5.3 Policy 3: Car Scrappage Policy

Car scrappage has been cited as a policy instrument toward energy conservation and environmental protection [6]. Dixon and Garber [19] found that regardless of the low numbers and limited use of old cars (usually more than 15 years of age), these cars contributed the highest amount of vehicle emissions. BenDor and Ford [11] extensively studied the feebates (a combination of “fee” and “rebate”) and scrappage incentives to reduce automobile emissions. The developed SD model has considered 15 years as the average life time of a car in India. In the present policy, the cars will be scrapped proportionally with the increase in fuel consumption in the country. Thus, our model adopted a three times more car

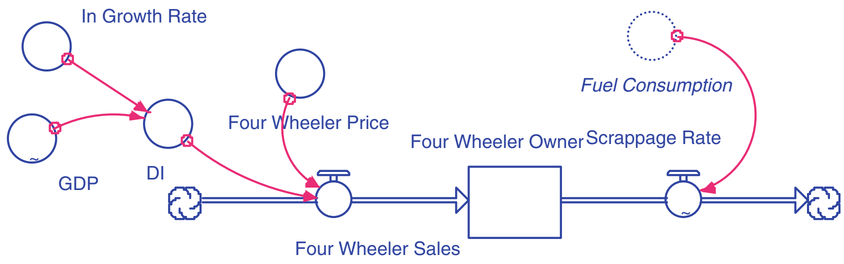
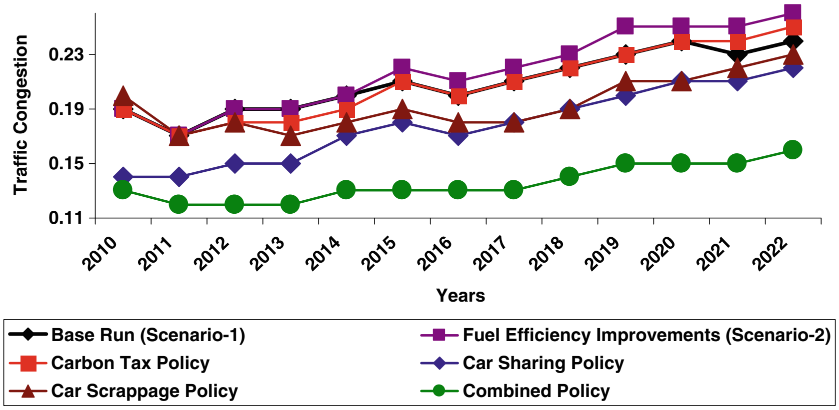


Fig. 9 Stocks and flows to simulate car scrappage policy in the system

Fig. 10 Effect of the policies on traffic congestion



scrappage when the total fuel consumption reaches 20 metric tons in the country. This policy is experimented with a twofold aim, first to curtail the car population, and second to scrap the less fuel efficient old vintages, both leading to a reduction in fuel consumption and GHG emissions in the country. The car scrappage policy applied to the personal transportation-energy efficiency system is depicted through the stocks and flow diagram in Fig. 9. The "scrappage rate" for cars is introduced into the SD model (Fig. 9) as a graph function as follows.

$$\begin{aligned}\text{Scrappagerate} &= \text{GRAPH}(\text{fuelconsumption})(0.00, 0.00),\\ &(2.00, 0.08), (4.00, 0.14), (6.00, 0.24), (8.00, 0.38),\\ &(10.0, 0.49), (12.0, 0.675), (14.0, 0.875), (16.0, 1.17),\\ &(18.0, 1.76), (20.0, 3.00)\end{aligned}$$

The above values (*fuel consumption values*, *scrappage rate values*) will be further taken into the guiding differential equations governing the four-wheeler/car ownership in the country and which is given below.

$$\begin{aligned}&\text{Four–wheeler ownership (t)}\\ &\quad = \text{four–wheeler ownership (t} - \text{dt)}\\ &\qquad + \text{(four–wheeler sales} - \text{scrappage rate)} * \text{dt}\end{aligned}$$

5.4 Policy 4: Combined Policy of Carbon Tax, Car Sharing, and Car Scrappage

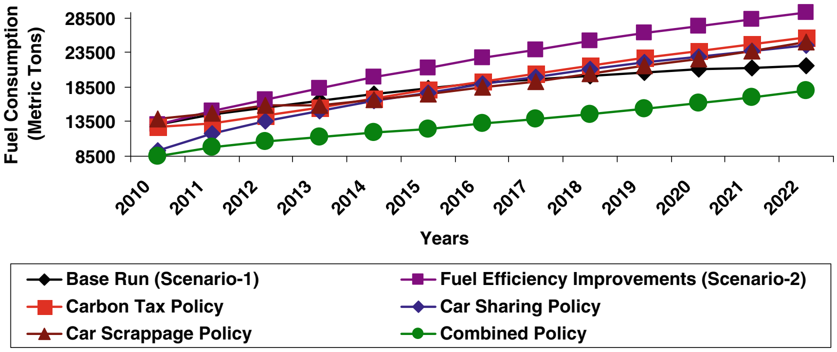
A combination of the policies of carbon tax, car sharing, and car scrappage along with the fuel efficiency improvement policy (scenario 2) was experimented for the combined influence of these policies on traffic congestion, fuel consumption, and GHG emission mitigation in personal transport sector in India. The causal loop models with policies adopted can be found in Menon and Mahanty [45].

6 Results of Policy Experimentations

6.1 Effects on Traffic Congestion, Fuel Consumption, and GHG Emissions

Three separate policies of carbon tax, car sharing, and car scrappage were experimented along side the fuel efficiency

Fig. 11 Effect of the policies on fuel consumption



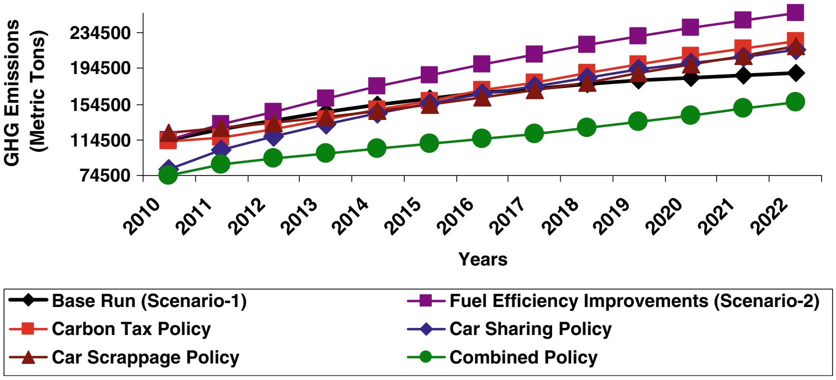


Fig. 12 Effect of the policies on GHG emissions

improvement policy. Finally a combination of all the policies was also tested (combined policy). The results of the experimented policies (carbon tax, car sharing, car scrappage, and combined policies) on traffic congestion, fuel consumption, and GHG emissions are depicted in Figs. 10, 11, and 12, respectively. The policy run results for traffic congestion, fuel consumption, and GHG emissions are summarized in Tables 3, 4, and 5, respectively. These are compared with the outcomes of base run with no fuel efficiency improvements (scenario 1) and with fuel efficiency improvement policy (scenario 2). The policy outcomes are compared with the base run results (scenario 1) as the aim of fuel efficiency improvement policy is to lower the fuel consumption and GHG emission levels below the base run values. Therefore, the alternate policies, tested alongside fuel efficiency improvement policy, are also expected to bring the fuel consumption and GHG emission levels below the base run values.

The carbon tax levied on transportation fuels has not effected any considerable change in traffic congestion compared with scenario 1 and scenario 2. This policy has resulted in the lowering of fuel consumption and GHG emission levels when compared with scenario 2 of fuel efficiency improvements (Figs. 11 and 12). This is attributed to the increase in cost of driving due to carbon tax which has resulted in reduction of distance commuted in car (VMT) by the car users. Therefore, it is evidenced from Figs. 11 and 12 that the policy of carbon taxation has lowered the level of fuel consumption and GHG emissions from the personal transport sector in India after the year 2013 when compared to scenario 2. But, this policy has not improved the system behavior when compared with base run (scenario 1) results (Tables 4 and 5).

The car scrappage policy was found to perform comparatively better than the carbon tax policy as it has curtailed the old car population in the country. Compared to scenario 1 and scenario 2, the car scrappage policy is found to have alleviated the traffic congestion in the long run after 2015. But, in the short run, this policy was found to have no effect over the traffic congestion in the country (Fig. 10). The easing of the traffic congestion due to this policy is visible only after the initial 6 years. Moreover, compared to scenario 2, car scrappage policy was found to be successful in bringing down the fuel consumption and GHG emission levels in the long run.

As evidenced from Figs. 11 and 12, the car scrappage policy has not performed better than the carbon tax policy in lowering the fuel consumption and GHG emission levels in the country. Like in case of carbon tax policy, the car scrappage policy has failed to lower the fuel consumption and emission levels below the base run (scenario 1) values in the long run (Tables 4 and 5). The drawback of the car scrappage policy is that the policy can be expected to create additional sales of new cars as well [38] which require further explorations.

The car sharing policy has performed better than carbon tax and car scrappage policies in fuel consumption and GHG emission alleviation in the context of India. This is attributed to the reduction of four wheelers on-road due to sharing of cars by the

Table 3 System dynamics policy simulation results for traffic congestion (units: dimensionless)

Year	Base run (scenario 1)	Fuel efficiency improvement policy (scenario 2)	Carbon tax policy	Car sharing policy	Car scrappage policy	Combined policy
2010	0.19	0.19	0.19	0.14	0.20	0.13
2012	0.19	0.19	0.18	0.15	0.18	0.12
2014	0.20	0.20	0.19	0.17	0.18	0.13
2016	0.20	0.21	0.2	0.17	0.18	0.13
2018	0.22	0.23	0.22	0.19	0.19	0.14
2020	0.24	0.25	0.24	0.21	0.21	0.15
2022	0.24	0.26	0.25	0.22	0.23	0.16

Table 4 System dynamics policy simulation results for fuel consumption (units: metric tons)

Year	Base run (scenario 1)	Fuel efficiency improvement policy (scenario 2)	Carbon tax policy	Car sharing policy	Car scrappage policy	Combined policy
2010	13072	13072	12823.72	9296.74	13945.10	8549.15
2012	15546	16665	14357.67	13549.20	15917.21	10609.99
2014	17501	19867	16867.75	16490.21	16693.43	11873.08
2016	19070	22749	19356.06	18959.28	18500.57	13189.43
2018	20160	25130	21564.21	21008.97	20414.19	14582.25
2020	21013	27318	23706.22	22871.62	22631.47	16180.29
2022	21644	29234	25689.32	24565.21	24972.90	17925.87

commuters. Thus, this policy has resulted in curtailing the cars on road thereby lowering the traffic congestion, fuel consumption, and GHG emission levels in the country. Finally, the combined policy, which is the combination of the fuel efficiency improvement, carbon tax, car sharing, and car scrappage policies, has outperformed all the other three policies. Thus, the policy synergy is highest for the combined policy than in case of individual policies adopted along with fuel efficiency improvements (scenario 2) and the base case scenario (scenario 1). The combined policy was the most effective in achieving the lowest levels of traffic congestion, fuel consumption, and GHG emissions in the country.

6.2 Effects on Direct Rebound Effect

The effect of the fuel efficiency improvement policy (scenario 2), individual policies of carbon tax, car sharing, and car scrappage along with the fuel efficiency improvement policy, and that of combined policy on the direct rebound effect in Indian personal transport sector was analyzed and is given in Fig. 13.

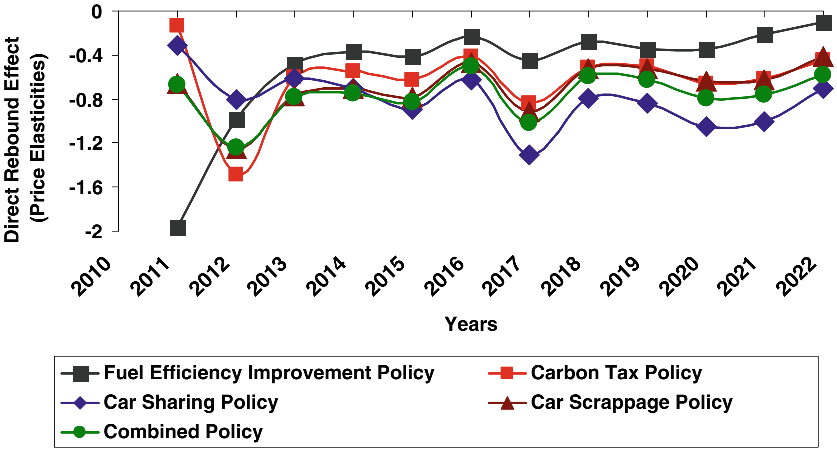
It is evident from Fig. 13 that the value for direct rebound effect (measured in terms of "η" which is defined as the elasticity of energy use with respect to energy efficiency gains, for a description, see Wei [62]) in case of fuel efficiency improvements (scenario 2) and for all the policy runs fall roughly in the range between −1 and 0. As per the conditions for direct rebound effects by Wei [62], this range infers to a partial rebound occurring in the system. Hence, within this partial rebound range, the car sharing policy gives the best scenario in terms of low direct rebound in the long run compared to other policies. Thus, the combined policy (fuel efficiency improvement, carbon tax, car sharing, and car scrappage policies) was found to perform better than car sharing policy in lowering the traffic congestion, fuel consumption, and GHG emission levels in India (Figs. 10, 11, and 12).

The graphs in Figs. 10, 11, and 12 showed similar behavior for the four different policies in case of traffic congestion, fuel consumption, and emission abatements with the combined policy to be the better than the other three policies of carbon tax, car sharing, and car scrappage. But, it was also found that, in case of direct rebound effect, the car sharing policy to perform better than the combined policy in the long run (Fig. 13). The vehicle miles travelled (VMT) by the commuter in case of carbon tax policy, car scrappage policy, and combined policy are slightly more than those in case of car sharing policy. Thus, the vehicle miles travelled is comparatively reduced in case of car sharing policy than in case of carbon tax, car scrappage, and combined policies. In measuring direct rebound effect, a comparatively low value for VMT in case of car sharing policy causes the direct rebound effect values to be low when compared with that for carbon tax, car scrappage, and combined policies. In light of the above policy outcomes,

Table 5 System dynamics policy simulation results for GHG emissions (units: metric tons)

Year	Base run (scenario 1)	Fuel efficiency improvement policy (scenario 2)	Carbon tax policy	Car sharing policy	Car scrappage policy	Combined policy
2010	114638	114638	112464.05	81532.38	122298.57	74976.03
2012	136337	146156	125916.75	118826.49	133279.53	93049.62
2014	153480	174237	147930.14	144619.13	146401.42	104126.89
2016	167242	199510	169752.63	166272.85	162249.96	115671.33
2018	176806	220391	189118.12	184248.67	179032.46	127886.38
2020	184282	239579	207903.56	200584.12	198478.02	141901.14
2022	189817	256384	225295.34	215436.91	219012.37	157209.90

Fig. 13 Effect of tested policies on direct rebound effect



it is concluded that the combined policy is the feasible policy since it alleviates the fuel consumption and GHG emission levels as well as direct rebound effects in the system.

7 Conclusions

The policy of fuel efficiency improvements in Indian personal transport sector is mainly aimed at reducing the fuel consumption and GHG emission levels. The conclusions out of a previous simulation study by the authors [44, 45] showed that this policy has not served its intended purpose and instead has resulted in further increase in fuel consumption and GHG emissions in the country. The study also brought out that this policy has also induced partial direct rebound effect in personal transport sector in India. This is attributed to the exponential growth in personal transport sector in India. This in turn motivates to think over the wisdom once shown by great Mahatma Gandhi as early as 1920s that if India also follows a path of industrialization as west, it can strip the world bare like locusts.

In order to sustain the expected effects of the fuel efficiency improvement policy in the long-term, short-term quick fixes in the structure might not be helpful. Instead, long-term structural changes need to be devised to change the behavior of the system. With this aim, four different complimentary policies of carbon tax, car sharing, car scrappage, and a combination of theses policies were experimented along with the fuel efficiency improvement policy. The conclusions made out of the policy experimentation results are summarized below.

1. The combined policy outperformed the carbon tax, car sharing, and car scrappage policies in the long run in lowering the traffic congestion, fuel consumption, and GHG emission levels than the values that are normally expected.
2. The direct rebound effects found in scenario 2 (fuel efficiency improvement policy) and in carbon tax, car sharing, and car scrappage policies were found to be of partial rebound in nature.
3. Among the various policies considered, the car sharing policy gave the best scenario in terms of low values of direct rebound effects.
4. The combined policy also performed close to car sharing policy in lowering the direct rebound effects in the personal transport sector in the long run.

It is therefore suggested that, for the best results, a combination of carbon tax imposition, car sharing, and car scrappage should be adopted along with fuel efficiency improvement in the personal transport sector in India for lowering the levels of traffic congestion, fuel consumption, GHG emissions, and direct rebound effects than the values that are normally expected.

References

1. Abbas, K. A., & Bell, M. G. H. (1994). System dynamics applicability to transportation modelling. *Transportation Research Part-A, 28*(5), 373–400.
2. Allan, G., Hanley, N., McGregor, P., Swales, J. K., & Turner, K. (2007). The impact of increased efficiency in the industrial use of energy: A computable general equilibrium analysis for the United Kingdom. *Energy Economics, 29*(4), 779–798.
3. An, F., Gordon, D., He, H., Kodjak, D., & Rutherford, D. (2007). *Passenger vehicle greenhouse gas and fuel economy standards: A global update* (pp. 1–34). Washington, DC: International Council on Clean Transportation.
4. Anand, A. (2008). Indian passenger car market – challenges. In B. V. S. Prasad & K. G. Shankar (Eds.), *The Passenger Car Market in India* (pp. 61–73). India: The Icfai University Press.
5. Arora, S., Vyas, A., & Johnson, L. R. (2011). Projections of highway vehicle population, energy demand, and CO2 emissions in India to 2040. *Natural Resources Forum, 35*, 49–62.
6. Baltas, N. C., & Xepapadeas, A. (1999). Accelerating vehicle replacement and environmental protection: The case of passenger cars

in Greece. *Journal of Transport Economics and Policy, 33*(3), 329–342.

7. Baranzini, A., Goldemberg, J., & Speck, S. (2000). A future for carbon taxes. *Ecological Economics, 32*, 395–412.
8. Barker, T., Dagoumas, A., & Rubin, J. (2009). The macroeconomic rebound effect and the world economy. *Energy Efficiency, 2*, 411–427.
9. BB. (2012). Petroleum statistics of India. Business Beacon. http://www.business-beacon.com/. Accessed 12 June 2012.
10. BEE (2009). Standard Labelling Programme. Bureau of Energy Efficiency, New Delhi. www.bee-india.nic.in/.
11. BenDor, T., & Ford, A. (2006). Simulating a combination of feebates and scrappage incentives to reduce automobile emissions. *Energy, 31*, 1197–1214.
12. Bhattacharyya, S., & Timilsina, G. R. (2010). A review of energy system models. *International Journal of Energy Sector Management, 4*(4), 494–518.
13. Cansier, D., & Krumm, R. (1997). Air pollutant taxation: An empirical survey. *Ecological Economics, 23*(1), 59–70.
14. Chandra, S., & Kumar, U. (2003). Effect of lane width on capacity under mixed traffic conditions in India. *Journal of Transportation Engineering, 155–160*.
15. CMIE. (2012). Fuel statistics of India. http://www.cmie.com/. Accessed 24 May 2012.
16. Coyle, R. G. (1977). *Management System Dynamics*. London: Wiley.
17. Davidsen, P. I., Sterman, J. D., & Richardson, G. P. (1990). A petroleum life cycle model for the US with endogenous technology, exploration, recovery, and demand. *System Dynamics Review, 6*(1), 66–93.
18. De Vlieger, I., De Keukeleere, D., & Kretzschmar, J. G. (2000). Environmental effects of driving behaviour and congestion related to passenger cars. *Atmospheric Environment, 34*, 4649–4655.
19. Dixon L., & Garber S. (2001). Fighting air pollution in Southern California by scrapping old vehicles. Rand Institute. Doc. No.:MR-1256-ICJ/PPIC.
20. EIA. (2008). Fuel and energy source codes and emission coefficients: Voluntary reporting of greenhouse gases program. U.S. Department of Energy, Energy Information Administration.
21. Elias, A. A. (2008). Energy efficiency in New Zealand's residential sector: A systemic analysis. *Energy Policy, 36*, 3278–3285.
22. Elias, A. A. (2012). A system dynamics model for stakeholder analysis in environmental conflicts. *Journal of Environmental Planning and Management, 55*(3), 387–406.
23. Enoch, M. P., & Taylor, J. (2006). A worldwide review of support mechanisms for car clubs. *Transport Policy, 13*, 434–443.
24. Euler Method. (2011). Encyclopaedia of Mathematics. Springer, Berlin. www.encyclopediaofmath.org/index.php/Euler_method. Accessed 5 December 2011.
25. Fisher-Vanden, K. A., Shukla, P. R., Edmonds, J. A., Kima, S. H., & Pitcher, H. M. (1997). Carbon taxes and India. *Energy Economics, 19*(3), 289–325.
26. Forrester, J. W., & Senge, P. M. (1980). Tests for building confidence in system dynamics models. *TIME Studies in the Management Science, 14*, 209–228.
27. Ghosh, S. (2005). Future demand of petroleum products in India. *Energy Policy, 34*, 2032–2037.
28. Gillingham, K., & Leaver, J. (2008). Impact of carbon policy on the composition of the vehicle fleet in New Zealand. Paper presented at Energy, Transport and Sustainability Symposium.
29. Grazi, F., & Van Den Bergh, J. C. J. M. (2008). Spatial organization, transport, and climate change: Comparing instruments of spatial planning and policy. *Ecological Economics, 67*, 630–639.
30. Greene, D. L. (2010). Rebound 2007: Analysis of U.S. light-duty vehicle travel statistics. *Energy Policy, 41*, 2–15.
31. Gupta, E. (2008). Oil vulnerability index of oil-importing countries. *Energy Policy, 36*, 1195–1211.
32. Herring, H., & Sorrell, S. (2009). Introduction. In H. Herring & S. Sorrell (Eds.), *Energy Efficiency and Sustainable Consumption: The Rebound Effect* (pp. 1–19). UK: Palgrave Macmillan.
33. IEA. (2011). Carbon dioxide emissions from fuel combustion-Highlights. International Energy Agency, 1-122.
34. IEA/OECD. (2006), Petroleum product pricing in India. International Energy Agency.
35. INCCA. (2010). India: Greenhouse gas emissions 2007. Indian Network for Climate Change Assessment, Ministry of Environment and Forests, Government of India, 1-63.
36. Katzev, R. (2003). Car sharing: A new approach to urban transportation problems. *Analysis of Social Issues and Public Policy, 3*(1), 65–83.
37. Kiani, B., Mirzamohammadi, S., & Hosseini, S. H. (2010). A survey on the role of system dynamics methodology on fossil fuel resources analysis. *International Business Research, 3*(3), 84–93.
38. Kim, H. C., Ross, M. H., & Keoleian, G. A. (2004). Optimal fleet conversion policy from a life cycle perspective. *Transportation Research Part D, 9*, 229–249.
39. Liang, Q. M., Fan, Y., & Wei, Y. M. (2007). Carbon taxation policy in China: How to protect energy- and trade-intensive sectors? *Journal of Policy Modeling, 29*, 311–333.
40. Loose, W., Mohr, M., & Nobis, C. (2006). Assessment of the future development of car sharing in Germany and related opportunities. *Transport Reviews, 26*(3), 365–382.
41. Meadows, D., Randers, J., & Meadows, D. (2004). *The Limits to Growth*. White River Junction: Chelsea Green Publishing.
42. MEF. (2010). India: Taking on climate change. *Ministry of Environment and Forest, 1–8*.
43. Meijkamp, R. (1998). Changing consumer behaviour through eco-efficient services: An empirical study of car sharing in the Netherlands. *Business Strategy and the Environment, 7*(4), 234–244.
44. Menon, B. G., & Mahanty, B. (2012). Effects of fuel efficiency improvements in personal transportation: Case of four-wheelers in India. *International Journal of Energy Sector Management, 6*(3), 397–416.
45. Menon, B.G., & Mahanty, B. (2013). Modeling the effects of energy efficiency improvements in personal transport sector in India. Full Thesis, Dept. of Industrial and Systems Engineering, Indian Institute of Technology Kharagpur, 1-197.
46. MRTH. (2011). Basic road statistics of India. Ministry of Road Transport & Highways. http://morth.nic.in/index2.asp?slid=314&sublinkid=142&lang=1. Accessed 16 February 2012.
47. Naill, R.F. (1972). Managing the discovery life cycle of a finite resource: a case study of US natural gas. Master's thesis. Submitted to the Alfred P. Sloan School of Management, Massachusetts Institute of Technology, Cambridge.
48. NHAI. (2012). Indian road network. National Highway Authority of India. http://www.nhai.org/. Accessed 16 February 2012.
49. Piattelli, M. L., Cuneo, M. A., Bianchi, N. P., & Giuseppe, S. (2002). The control of goods transportation growth by modal share re-planning: the role of a carbon tax. *System Dynamics Review, 18*, 47–69.
50. Qudrat-Ullah, H., & Seong, B. S. (2010). How to do structural validity of a system dynamics type simulation model: The case of an energy policy model. *Energy Policy, 38*, 2216–2224.
51. Ritterspach, F.A.A.B..., & Ritterspach, J.C.E.B. (2009). The development of India's small car path. Management Online Review.
52. Rodrigues, L. L. R., Gupta, K., & Motlagh, F. G. (2012). *Vehicle fuel consumption modelling: A system dynamics approach*. London: Proceedings of the World Congress on Engineering, III.
53. Roy, J. (2000). The rebound effect: some empirical evidence from India. *Energy Policy, 28*, 433–438.
54. Saboohi, Y., & Farzaneh, H. (2009). Model for developing an eco-driving strategy of a passenger vehicle based on the least fuel consumption. *Applied Energy, 86*, 1925–1932.

55. SIAM. (2011). Emission norms. www.siamindia.com/scripts/emission-standards.aspx. Accessed 15 February 2012.
56. Singh, A., Gangopadhyay, S., Nanda, P. K., Bhattacharya, S., Sharma, C., & Bhan, C. (2008). Trends of greenhouse gas emissions from the road transport sector in India. *Science of the Total Environment, 390*, 124–131.
57. Sorrell, S., & Dimitropoulos, J. (2008). The rebound effect: Microeconomic definitions, limitations and extensions. *Ecological Economics, 65*, 636–649.
58. Sorrell, S., Dimitropoulos, J., & Sommerville, M. (2009). Empirical estimates of the direct rebound effect: A review. *Energy Policy, 37*, 1356–1371.
59. Sterman, J. D. (1984). Appropriate summary statistics for evaluating the historical fit of system dynamics models. *Dynamica, 10*, 51–66.
60. Sterman, J. D. (2000). *Business Dynamics: Systems Thinking and Modeling for a Complex World*. New York: McGraw Hill.
61. Wang, J., Lu, H., & Peng, H. (2008). System dynamics model of urban transportation system and its application. *Journal of Transportation Systems Engineering and Information Technology, 8*, 83–89.
62. Wei, T. (2010). A general equilibrium view of global rebound effects. *Energy Economics, 32*, 661–672.
63. Wolstenholme, E. F., & Coyle, R. G. (1983). The development of system dynamics as a methodology. *Journal of the Operational Research Society, 34*(7), 569–581.