

GUIDEBOOK

The Co-benefits Evaluation Tool for the Urban Transport Sector



UNITED NATIONS
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UNU-IAS

GUIDEBOOK
**The Co-benefits Evaluation Tool for
the Urban Transport Sector**

March 2014

Table of Contents

1. Introduction.....	5
1.1 What are co-benefits, how are they defined for the purpose of this guidebook.....	5
1.2 Why is it important.....	5
1.3 What does the tool do?.....	5
1.4 Access to the download link.....	7
2. General description of the tool.....	8
2.1 Calculation flow of the spreadsheet.....	11
2.2 How to choose between options.....	12
2.3 Future projection.....	13
2.3.1 Projection of vehicle population.....	13
2.3.2. Projection of road-based passenger mobility (PKM).....	15
3. Organization of the tool.....	16
3.1 Maximum input capabilities of the tool.....	16
3.2 Execution of the tool.....	16
3.3 Some preliminaries.....	17
3.4 Cell “Notes”.....	17
3.5 Getting Started.....	18
3.6 Data Initialization worksheet.....	18
3.6.1 Number of Vehicles.....	19
3.6.2 Utilisation Rate.....	19
3.6.3 Average Travel Distance.....	19
3.6.4 Average Occupancy (Load Factor).....	20
3.6.5 Modal Share.....	20
3.6.6 Fuel Efficiency.....	20
3.7 Output Panel worksheet.....	22
3.7.1 Results section.....	22
3.7.2 Policy interventions section.....	23
3.7.3 Dynamic Graph.....	25
3.8 Report worksheet.....	26

3.9 Future Projection worksheet	27
3.9.1 Baseline scenario.....	27
3.9.2 Future estimates for PKM	31
3.9.3 New scenario definition	31
3.10 Database worksheet.....	33
4. Understanding the result	35
5. Concluding Remarks.....	36
6. Where to find data	37
7. References.....	42

1. Introduction

Emissions from the transport sector around 20 % of global carbon emissions, however they are notoriously hard to reduce because of the fundamental importance mobility plays in social, economic and cultural activities. Nonetheless, there are a range of strategies available to the policymaker to change the composition of the transport sector which preserves mobility whilst lowering the emissions to the local and global environment.

1.1 What are co-benefits, how are they defined for the purpose of this guidebook

The basic concept of co-benefits is to understand the multiple dimensions of a policy beyond its intended benefit. As such, co-benefits can have many different definitions. For the purpose of this guidebook, we define co-benefits as the simultaneous reduction of greenhouse gas (GHG) and local air pollutant emissions. This is because carbon reductions are rarely explicitly considered as a benefit, yet much as so much development is occurring in developing countries, there is a window of opportunity to explicitly address global climate considerations in their plans, and this may best be achieved by linking it to a local benefit. The local benefit in this case is local air pollution emissions; however it should become apparent that there are wider co-benefits associated with this, most obviously better respiratory health outcomes.

1.2 Why is it important

Many countries in the developing world with large populations are experiencing rapid rates of urban growth. Crucially, infrastructure that will last decades is being considered and implemented now, which makes the task of choosing the right policies vitally important. Yet, with often limited resources at their disposal, aligning global climate concerns with other aspects of local development can be an efficient way of achieving multiple outcomes with one policy. The dual issues of reducing carbon emissions and local air pollution can be addressed through intelligent choices.

1.3 What does the tool do?

The Evaluation Tool combines a quantitative spreadsheet of a simplified representation of the transport sector with an institutional evaluation to evaluate not just the magnitude of emission reductions from local air pollution and carbon emissions but also to determine barriers to implementation of policies and projects. It uses the ASIF framework of Schipper

al. (2000), which set the standard for low carbon transport modelling. In particular, it has the following features:

Scalable approach: There are currently a number of methodologies developed to calculate the GHG and other environmental impacts. Many of them are project specific, trying to identify the emission reduction of a project. The IAS tool covers the city-wide transport system, thus impacts of a multiple of transport choices can be assessed. Thus, whereas most tools which calculate the effects of a pre-determined *project*, this tool is more exploratory and allows the user to see the effect of *different types of changes* to the transport systems according to three categories of intervention.

Ex or Post-Ante Evaluation: Most of the similar methodologies try to identify the effects of a project after an investment has completed. Depending on the range of data available, the IAS tool allows for either ex-post (project data assessment) or ex-ante (scenario based assessments) with explicit consideration of the environmental co-benefits *as the intended benefit* and then allows decision makers to decide which options offer the best return *before* they conceive of the policy and project.

Policy tool with implementation consideration: The IAS tool extends conventional tools with the loose coupling of an institutional assessment. This again relates to the biggest difference of the IAS tool from other methodologies. The IAS tool is, in principle, a policy tool, rather than a transport model. Whereas most of the existing methodologies are the models to simulate and evaluate the effect of a project in one way or other, the IAS tool is a mechanism that allows the policy makers to identify potential to make scenarios over different policy interventions *in the context of the city*. It provides policy makers with chances to understand the range of variations on GHGs and LAPs reduction when they envisage and implement different policies.

As this is a policy tool rather than an engineering simulation, the data required for the IAS tool is simple and robust, following a well established method of calculating emission reductions, and where it differs is the general flexibility of the tool and guidance on governance, informed by case studies, which advises how the quantitative calculation may be effectively implemented. It is understood in the developing countries, there are severe limitations on data availability, thus the IAS tool is not excessively data intensive, and equations are not designed to accommodate all the elements that modelling exercise usually have. It is more looking at which parameters could provide changes to improve local environmental conditions.

The tool is a linear representation of the public transport system in a city, from which the implementation of policies in four areas can be evaluated in terms of its carbon and local air pollution emissions. It is intended to provide a **first order screening of possible options** that can be further investigated using more sophisticated which have a better representation of travel demand tailored to the city in question. Such models are to be

used once the policy has been selected and been further elaborated, this tool can be regarded as the preliminary process allowing planners and policy makers to evaluate how a city's transport infrastructure can be developed before deciding on targeted interventions.

1.4 Access to the download link

The toolkit is freely available for download and use to the users through the UNU-IAS online website: <http://tools.ias.unu.edu>

At first, the users need to register in order to create their own account. Then, the users must register their baseline scenario (input data described in this guide) by filling out the input data forms. These forms provide the initial data which will be required to set up the database of the toolkit. After submitting the input forms, the download link will be accessible. Users can then download the tool on their personal computer. Upon opening the tool, the user enters their username/password and their data will be downloaded into the tool. Over time, users will be able to compare results with those of other users. Full details are to be found in the "How to Use" tab at the website.

2. General description of the tool

There are two separate elements to the tool, an institutional/governance dimension and a technical analysis which taken together given bring a qualitative dimension to the quantitative evaluation. The technical conceptualisation of co-benefits in the transport sector is explained in Doll et al. (2011). It starts from an intended benefit, which is met through a set of policy instruments and targets. Whilst the stimuli of transport policies can be various, climate considerations are rarely if ever a driving factor, especially in developing countries. This assessment tool uses the framework to consider what co-benefits would accrue if local air quality and carbon emissions were the main criteria used in the decision-making process.

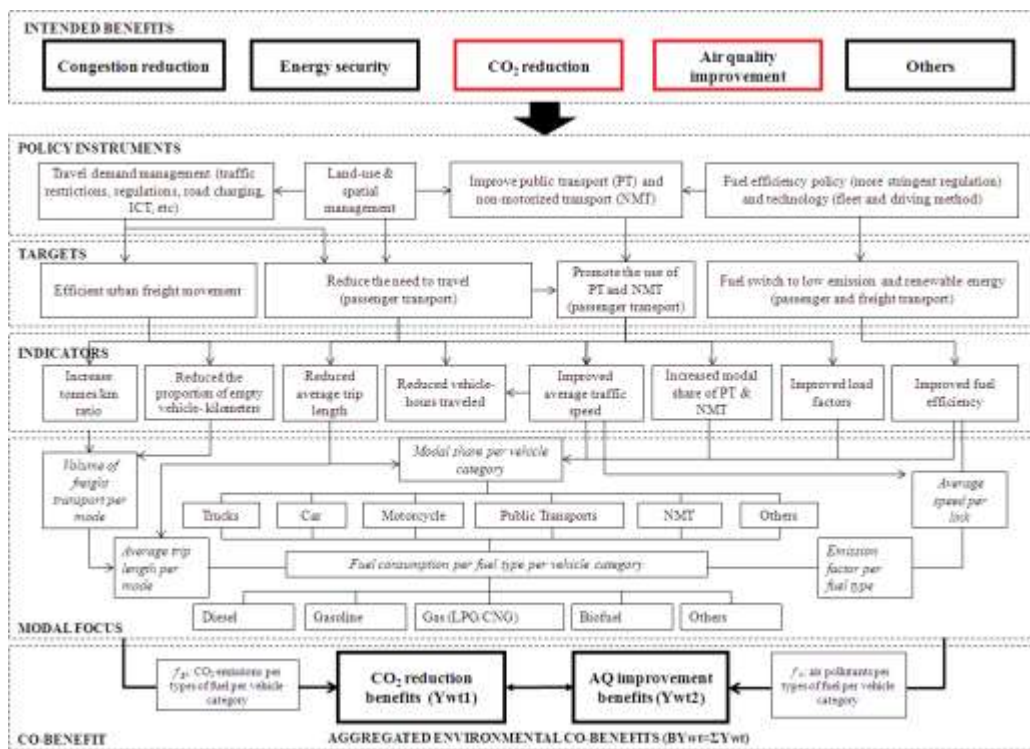


Figure 1. Conceptual Framework for Measuring Co-Benefits in the Transport Sector

The proposed methodology combines quantitative city level institutional analysis with a technical analysis of the transport portfolio in the city. In this way, we conceptualise the assessment of co-benefits through the simultaneous consideration of institutional and governance factors with the technical assessment of the co-benefits that can be achieved from a set of policy options. Taken together, we suggest that the process can be conceptualised in a two-dimensions as set of technical and elements in the transport sector which are mediated by institutional and governance issues, which can affect the effectiveness of technical plans made (Figure 2). Therefore both elements need to be

evaluated in order to understand what the constraints are on achieving the technical reductions calculated by the tool.

This guide deals exclusively with the quantitative technical [T] part of the guide. The [G] dimension is covered in the accompanying governance tool and guidebook. Taken together they would form the basis for a general procedure which may be used in two ways (first flow A in Figure 2):

1. Establish a baseline inventory of vehicles and usage data in the city to assess the status of emissions. Green boxes in Figure 1.
2. Understand the context [G] – Understand what are the relative capacities and obstacles are in the city regarding culture, institutions, implementation and political will and rank most implementable policies.
3. Evaluate co-benefits of options [T]. Using the spreadsheet Examine co-benefits of different policies, which are informed by points (1) and (2).

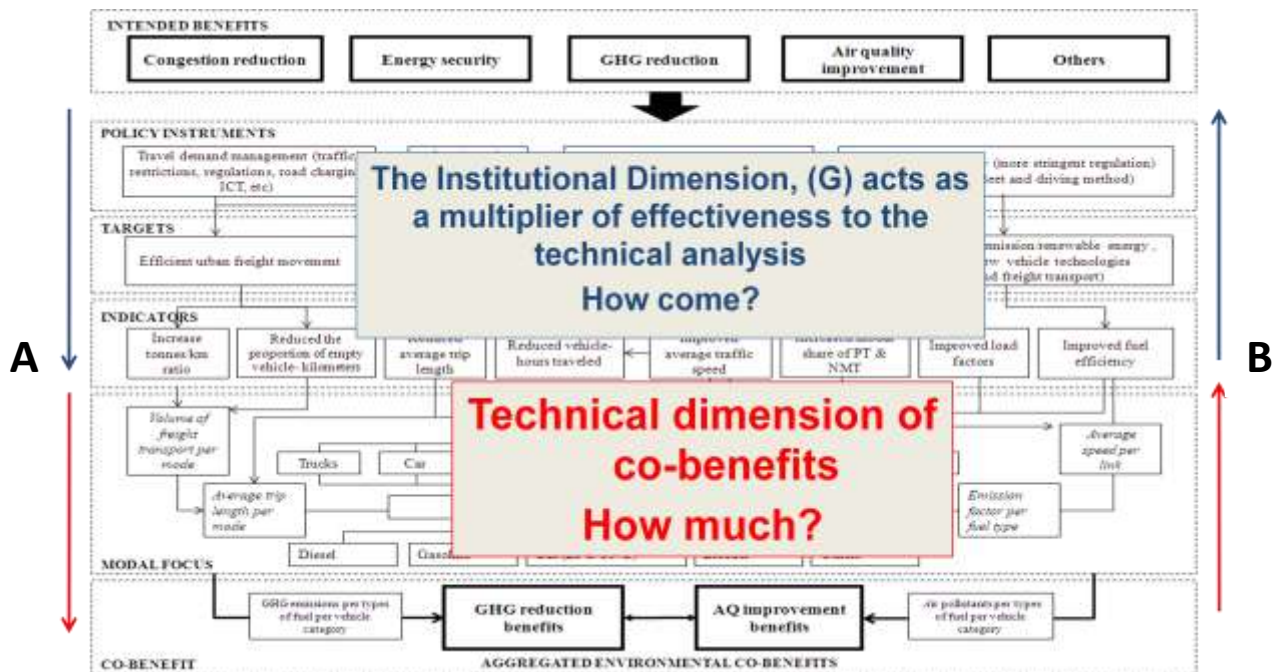


Figure 2. Two dimensions of co-benefits assessment, showing two regimes of analysis. This guidebook refers to the technical part in red

An alternative procedure (flow B in Figure 2) may be as follows:

1. Establish a baseline inventory of vehicles and usage data in the city to assess the status of emissions. Green boxes in Figure 1.

2. Explore [T] options to develop goals. Using the spreadsheet Examine co-benefits of different policies, using the tool to understand what magnitude of change would be required in the transport system. Blue boxes in Figure 1 - Section 4 of this guide
3. Understand the context [G] – Based on the co-benefits evaluation, use the self-assessment governance tool to understand which policies are more or less implementable and which areas of governance (e.g. culture, institutions, implementation and political will) need to be strengthened to enhance the implementation.

This evaluation tool (lower red part of Figure 2) is a simulation model designed for evaluating the climate co-benefits of the city’s transport sector through the following modes:

- 1- Before and after analysis: the methodology which has been applied through developing the tool in this mode is based on the scenario approach. In the tool approach a "scenario" is viewed as a consistent description of a possible short-term development pattern of a city’s transport sector, characterized mainly in terms of direction of local governmental policy, which is named as policy intervention (option) in this tool.
- 2- Future Projection: to generate mid-to long-term forecasts (up to 2050) of transportation energy demand and its related emissions at the census division level in support of the development of the future policy actions.

The tool evaluates co-benefits produced from four different transport policy options. They are:

- A – Activity – Travel Demand Management
- S – Shift – Mode Shift
- I – Improve (Fuel Efficiency)
- F –Fuel (Switch Fuel)

The tool uses the ASIF framework which calculates emissions by each mode according to the following formula:

(1)

$$\sum_{Modes} A \times S \times I \times F$$

Where:

A : Total Travel Demand in passenger kilometres defined as:

(2)

$$A = \sum_{Modes} \#vehicles \times Utilisation\ Rate \times Annual\ Distance\ travelled \times Occupancy\ Rate$$

Where:

S : Percent share of each mode; Calculated from A

I : Intensity of the mode defined as:

(3)

$$I = \frac{1}{Fuel\ Efficiency \times Occupancy\ Rate}$$

F : Emission Factor of each pollutant for each fuel

2.1 Calculation flow of the spreadsheet

The quantitative part of the tool allows for variations in four different policy areas to assess the magnitude of changes in both GHG emissions and air pollution. It can be conceptualised in the flow chart shown in Figure 3. The green highlighted area refers to the baseline evaluation and the blue boxes to the evaluation through scenario input.

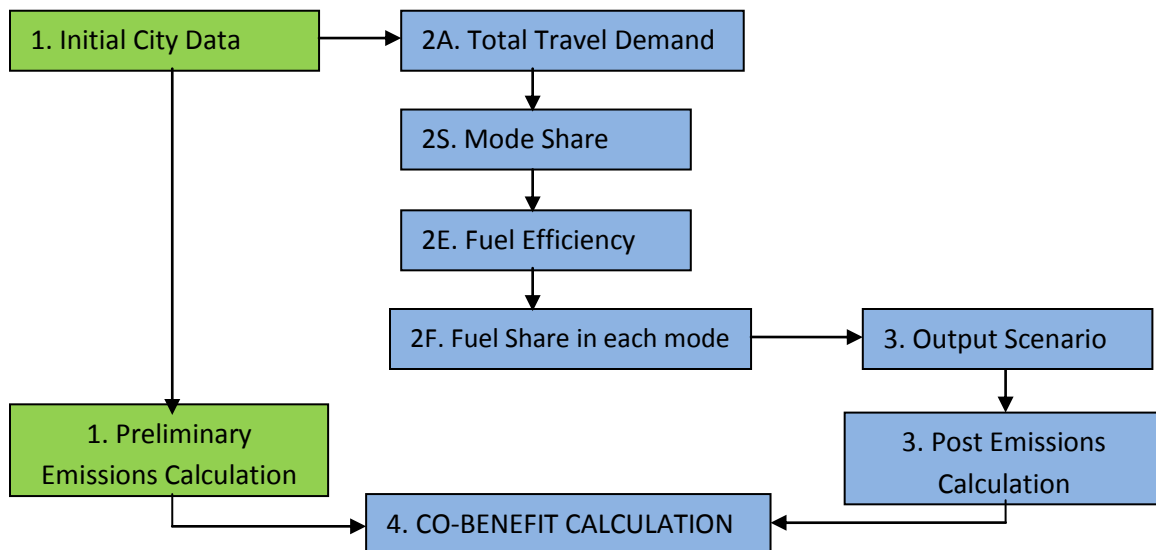


Figure 3. Flow chart of the evaluation tool

The first step of the evaluation is to understand the city in question. This is done in two ways, the first of which is to establish a baseline for the city. The quantitative part of the tool relies on data shown in Table 1. Those highlighted in yellow are elements which the user is required to seek. Whilst the tool does provide emission factors and some fuel efficiency data, we recommend that as much local data as possible local data is obtained. **The better the quality and accuracy of the input data, the more accurate the emission estimations will be.**

Table 1. Structure of the data fields both used in the tool.

Data	Source	Units/Definition
Number of vehicles	User Input	Units
Utilisation factor	User Input	%
Fuel Share of vehicle fleet	User Input	%
Average annual distance travelled	User Input	Km
Total Vehicle km (VKT)	Calculated	Product of above (km)
Vehicle occupancy (Vac)	User Input	Persons
Total Passenger km (pass.km)	Calculated	VKT.VOc (person.km)
Mode share (in pass.km)	Calculated	%
Fuel Efficiency (FE)	Provided/User Input	l/km
Intensity	Calculated	$1/(FE.VOc)$
Emission Factors	Provided/User Input	g/l
Emissions	Calculated	g (any pollutant)

With this in mind, consideration turns to the practicalities of different policy options covered in the tool.

2.2 How to choose between options

The tool allows for four different options to be evaluated. These vary in the ease of decision making and implementation. Having collected and input the data, the user will by now have an understanding of the public transport sector in the city in terms of the mode structure, fuels and transport demand and significantly, the levels of emissions associated with this transport portfolio. The next step involves understanding the implications of the four policy choices reflected in the model. We suggest further steps, which will help the

user understand not only which changes are technically possible but which are most likely to be achieved. These are covered by the related governance tool for the transport sector and can be used in conjunction with this tool to help understand the implications of different sets of policies.

2.3 Future projection

Projecting transport sector energy demand and its related emissions into the future is challenging in the urban context because there is paucity of data on vehicle population and utilization and therefore assumption had to be made around the scrapping factors, vehicle mileage, fuel economy and emission factors. The tool uses the elasticity method to project on-road vehicle emissions based on the availability of historical data. The steps are categorized as follows:

2.3.1 Projection of vehicle population

The tool relates vehicle population to certain economic parameter (per-capita GDP) by using a sigmoid-shape function, which assumes that the long-term trend in vehicle growth follows an S-shape curve, with three phases: a slow-growth period in the beginning (when economic levels are low), a boom period, and a saturated period (when vehicle population growth approaches the saturation level). A number of sigmoid functions for simulating vehicle stocks have been demonstrated: the modified logistic function by Button et al. (1993) and Ingram and Liu (1997), as well as the Gompertz function by Dargay and Gately (1999) and Zachariadis et al. (1995). In this tool, the Gompertz function is used to simulate the growth of the vehicle population as follow:

(4)

$$V_i = V e^{\delta e^{\mu GDP_i}}$$

Where:

V_i Vehicle in use in year i (vehicles per 1,000 people);

V Ultimate saturation level of vehicle ownership (vehicles per 1,000 people);

δ and μ – The two parameters that determine the shape of the S-shape curve of vehicle ownership growth over economic growth.

As Equation (4) shows, the Gompertz function predicts vehicle ownership per 1,000 people on the basis of economic growth. Thus, with projected total population, total vehicle stock in city can be predicted from the projected vehicles per 1,000 people.

The saturation level of vehicle ownership per 1,000 people, V , is a key factor in estimating total vehicle population. Dargay and Gately (1999) assumed a saturation level of 850 of all vehicles per 1,000 people and 620 cars per 1,000 people for the 26 countries that they studied. Other necessary data (such as future GDP growth and national demographic forecasts up to 2050) can be obtained from United Nation, Department of economic and social affairs population division and International Monetary Fund.

The number of registered vehicles and vehicle survival rates are key factors in determining V_i in a particular year. The determination of vehicle survival rates normally requires substantive historical information about vehicle fleets. Because they have had a long period to accumulate registration information and survey data, the United States and other developed countries have been able to generate survival rates for their vehicle fleets. The rate at which vehicle remaining operational is defined in the tool by Weibull cumulative distribution function, shown below:

(5)

$$F(x) = e^{-\left(\frac{x}{\varphi}\right)^\rho}$$

Where, x is age of the vehicle and ρ and φ are constants.

Multiplying the total number of vehicle type registered in a particular year by the appreciate survival rate will yield the probable number of vehicle in use in a future base year. Thus historical registration or sale data can be converted to an approximation of vehicle stoke (in use) for a given year. The vehicle class Weibull coefficients which have been used in this tool are represented in Table 2.

Table 2. Vehicle class Weibull coefficients based on SA national octane study (2010)

Vehicle Category	ρ	φ
Diesel PC	22	3
Gasoline PC	23	2
CNG PC	23	3
Hybrid PC	22	3

Diesel Bus	30	3
CNG Bus	30	3
Motorcycle	16	3

2.3.2. Projection of road-based passenger mobility (PKM)

The growth in per capita mobility over time typically follows a sigmoid or S-shaped curve. The logistic function which has been use in the tool can be represented by the following formula:

(6)

$$\left(\frac{PKM}{cap}\right)_t = \frac{\alpha}{1 + \gamma \exp(-\beta(time)_t)}$$

Where, α is the saturation level which can be calculated on the basis of time budget and average speed of mobility in city. It's possible to get a reliable estimate of the saturation level by making a reasonable assumption about the time spent on travel per person per day (i.e., travel time budget) and average speed of vehicles. For example, if all demands are met at an average speed of 30 km/hour and the travel time budget is fixed at 1.1 hour/capita/day, the total annual distance travel would be around 12000 km/capita. Schafer (1998) shows that the time spent on travel per person per day are virtually unchanged with respect to per capita income across the countries. Although the reason for travel time budget stability is not very clear, Marchetti (1994) argued that a travel time budget of around one hour per capita per day reflects a basic human instinct.

β and γ are positive coefficients. The logistic function ranges from 0 to α as $time$ ranges from $-\infty$ to $+\infty$. $time$ is 1 for 1950-51, 2 for 1955-56, 3 for 1960-61,....., and 17 for 2030-31, ...

3. Organization of the tool

The software tool is provided in EXCEL Workbook. The workbook contains several worksheets devoted to various sub-sectors and end-use activities included in the tool. All worksheets have several Microsoft Visual Basic macros for performing certain functions, explained in the subsequent chapters, and executing the computations.

3.1 Maximum input capabilities of the tool

Table 3 summarizes maximum input capabilities of the tool.

Table 3. Maximum input capabilities of the tool

Parameter	Max. Allowance
Vehicle groups	10
Fuel types	7
Pollutants	11

3.2 Execution of the tool

The toolkit operates under the Microsoft Excel software (Ver. 2007 and 2010) and can be readily installed on a PC operating in a Windows environment by downloading the file from the UNU-IAS website to any selected directory (e.g. C: /programs/TRANSPORTTOOL) on the user's computer.

This section provides an overview of the worksheets associated with the Excel workbook and describes the execution of the tool.

The excel-based tool consists of six main worksheets as:

- Home (Start Page)
- Data Initialization
- Output Panel
- Future Projection
- Database
- Reports

Microsoft Visual Basic subroutines have been used in the Microsoft Excel environment to automatically generate the equations and tables of the tool. A brief description of various parts follows.

3.3 Some preliminaries

Upon opening the file, a dialogue box will appear on the monitor screen asking the user if the Microsoft Visual Basic macros present in the workbook should be enabled. Click the “Yes” or the “Enable Macros” button as the macros provided in the worksheet are necessary for the proper operation of the program.



Figure 4. Snapshots of the dialogue box asking about the enabling of the Macros

3.4 Cell “Notes”

A snapshot of the worksheet cells “Notes” is given in Figure 5. This snapshot contains information about the color code conventions used in various worksheets for making a distinction between the types of information contained in various cells, what are the data that may be entered/changed in various data worksheets and to indicate whether the cells are locked or not:



Figure 5. Snapshot of the worksheet cells “Notes”

3.5 Getting Started

Before processing with a new data entry, the first step is the pre-initialization of the tool. In this step, the user must define the corresponding method to use the tool, vehicle types and refueling methods as shown in figure 6. For the mode selection, there are two options: 1) before/After analysis and 2) future projection which have been described before in section of general description of the tool. Flues are listed in the tool as: Diesel, Ultra low Sulphur Diesel (ULSD), CNG, Petrol, Hybrid, electric and other. Fuels explicitly listed (e.g. biofuels) can be accounted for in the ‘Other’ category of each mode. The TOOL provides an easy-access menu to navigate user path through using the tool.

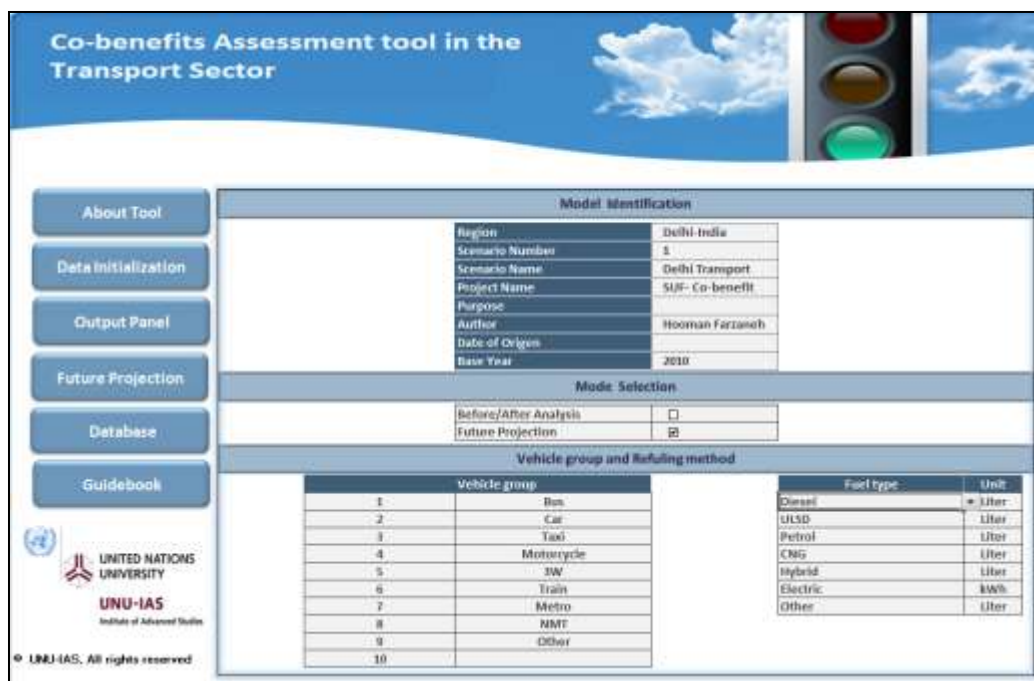


Figure 6. Snapshot of the worksheet “Home”

3.6 Data Initialization worksheet

The tool is designed to be used with a basic set of data which can be collected at the city level (and possibly national level for the case of efficiencies) (Figure 7). Table 1 showed how these elements provide the data flow in Figure 1. Specific emission factors are provided in the database worksheet, these are currently tailored to the regional context but should specific emission factors be required, they can be found from the available database for different counties (See the Database section).

The key parameter upon which the calculator hinges is the number of passenger kilometres by mode and by fuel type. In the spreadsheet we calculate it as follows:

PKM

$$= \text{vehicles} \times \text{Utilisation Rate} \times \text{Annual Distance travelled} \times \text{Occupancy Rate}$$

	Home	Data Initialization	Output Panel	Future Projections	Emission Factors	Help			
Bus									
Total number of vehicles		62,471							
Fuel type		Diesel	UKSD	Petrol	CNG	Hybrid	Electric	Other	Total
Share of vehicles by fuel use		0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%
Utilization rate		60.0%	60.0%	60.0%	60.0%	60.0%	60.0%	60.0%	60.0%
Annual average distance travelled (km)		0	0	0	87651	0	0	0	87651
Occupancy rate		41.34	41.34	41.34	41.34	41.34	41.34	41.34	41.34
Fuel Efficiency (km/Liter)		3.520	3.900	2.420	2.420	1.800	3.080	1.000	2.420
Car									
Total number of vehicles		3,175,326							
Fuel type		Diesel	UKSD	Petrol	CNG	Hybrid	Electric	Other	Total
Share of vehicles by fuel use		10.5%	0.0%	87.0%	7.5%	0.0%	0.0%	0.0%	12.1%
Utilization rate		60.0%	60.0%	60.0%	60.0%	60.0%	60.0%	60.0%	60.0%
Annual average distance travelled (km)		30956	0	30956	30956	0	0	0	10950
Occupancy rate		2.18	2.18	2.18	2.18	2.18	2.18	2.18	2.18
Fuel Efficiency (km/Liter)		13.350	14.800	14.800	15.310	1.800	3.080	1.000	11.796
Taxi									
Total number of vehicles		52,958							
Fuel type		Diesel	UKSD	Petrol	CNG	Hybrid	Electric	Other	Total
Share of vehicles by fuel use		0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%
Utilization rate		60.0%	60.0%	60.0%	60.0%	60.0%	60.0%	60.0%	60.0%
Annual average distance travelled (km)		0	0	0	29700	0	0	0	29700
Occupancy rate		1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92
Fuel Efficiency (km/Liter)		11.250	10.000	14.000	15.840	1.800	3.080	1.000	15.840
Motorcycles									
Total number of vehicles		4,142,901							
Fuel type		Diesel	UKSD	Petrol	CNG	Hybrid	Electric	Other	Total
Share of vehicles by fuel use		0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Utilization rate		0.0%	0.0%	60.0%	0.0%	0.0%	0.0%	0.0%	60.0%
Annual average distance travelled (km)		0	0	9225	0	0	0	0	9225
Occupancy rate		1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26
Fuel Efficiency (km/Liter)		1.800	1.800	17.380	1.800	1.800	3.080	1.000	17.380

Figure 7. Snapshot of the worksheet “Data Initialization”

3.6.1 Number of Vehicles

The main source for such data would be the local governments in every city. This data is not very difficult to obtain, as vehicles have to be registered and licensed in almost every city. Therefore transport divisions of city governments are the primary address to obtain the data on vehicle numbers.

Besides, this data could also be obtained from secondary sources such as academic research and publications. In some research, primary data is collected through transport surveys to make estimations on travel demand for instance. Such research could be useful to find the data on vehicle numbers.

3.6.2 Utilisation Rate

The utilisation rate takes into account that figures from vehicle registries are frequently inaccurate as they vehicles that have been taken of the road are not accounted for as efficiently as those registered. Hence it is the ratio of operational to registered vehicles. For new vehicle fleets and in areas which are experiencing rapid growth it will can be quite high. The number can be obtained from other vehicle data such as permits issued for public transport operators by route.

3.6.3 Average Travel Distance

This data shows the daily run (in km) of different modes that prevail in transport sector of a given city.

Another way to obtain this data is to generate it through surveys. The average daily run of private modes such as cars, motorcycles, taxis and also three-wheelers could be gathered by making questionnaire surveys with users of private modes. In this case, sampling should be carefully determined. The daily run of public transport modes is easier to obtain as opposed to that of private modes. In cities where public transportation is run by the local government, such data could be taken from the relevant division of the local government. In cases where private sector is responsible for running the public transport systems, the data could be collected by getting in touch with the companies in the sector.

3.6.4 Average Occupancy (Load Factor)

This data shows the average number of riders per trip on different modes that prevail in transport sector of a given city.

Another way to obtain this data is to generate it through surveys. The average number of users on private modes such as cars, motorcycles, taxis and also three-wheelers could be gathered by making field surveys like for instance, observations on main transport roads in the city. Besides, questionnaires could be made with users of private modes to find out the average number of users on each mode. In this case, sampling should be carefully determined. As for the occupancy on public transport modes, the data on fare boxes could be used to estimate the average number of riders on modes based on the revenues gathered in these modes.

3.6.5 Modal Share

The data on modal share indicate the extent to which each mode receives patronage. In the co-benefits calculator, the modal share data is not taken from secondary sources but calculated from the inputs listed above (the data on vehicle numbers, utilisation, average travel distance and occupancy). All these data are used to calculate the total passenger kilometres (PKM) per year and by using the total passenger kilometres by modes, the share of each mode in total PKM is calculated.

Modal share data could also be obtained from secondary sources especially research reports and academic publication on urban passenger transportation. An alternative way of calculating passenger kilometres for each mode would be number of trips x average trip length, which requires less data but for purpose of the ASIF framework is also less flexible.

3.6.6 Fuel Efficiency

This data shows the average distance travelled per unit of energy consumed. This measure is used to compare energy consumption of alternative fuel vehicles, plug-in electric vehicles and other advanced technology vehicles with the fuel economy of conventional internal combustion vehicles expressed as “km/ energy unit”. The main

source for such data would be the available international standards such as the U.S. Environmental Protection Agency or through surveys.

Another way to obtain this data is to use the “Speed dependency of fuel consumption factors” which has been provided in the tool. This worksheet will be available to use by pushing on the brown button “Speed Dependency” as represented in figure 8. Here, the fuel efficiency is provided as a function of speed for different vehicle group (i.e. car, motorcycle and bus) per different fuel type (Gasoline, Diesel and Hybrid) and different engine size (for car : cc < 1.4 l, 1.4 l < cc < 2.0 l, cc > 2.0 l ; for motorcycle: Two Stroke cc > 50, Two Stroke cc < 50, Four Stroke cc<250, Four Stroke 250<cc<750 and Four Stroke cc>750). Different vehicle classes are considered in estimation of fuel efficiency-speed dependency as follows:

- ✓ Pre ECE vehicles
- ✓ ECE-15.00
- ✓ ECE 15.01
- ✓ ECE-15.02
- ✓ ECE-15.03
- ✓ ECE-15.04
- ✓ Improved conventional (Regular catalysts)
- ✓ Open loop catalysts (Three-way, but no lambda control)

The user can enter a desired value of speed for the selected vehicle group in the green color cells and then, copy the estimated value of fuel efficiency from the orange color cells and finally, paste the value in the fuel efficiency cell of the data initialization worksheet.

Speed-Efficiency Relationships

Please insert your desired speed in blue cells. The results will be shown in red column.

Vehicle Type	Fuel Type	Type	Speed Range km/h	Fuel consumption Factor g/km	Desired Speed km/h	Fuel consumption liter/km	Fuel Efficiency km/liter	Total Fuel Efficiency km/liter
Car	Gasoline	cc < 1.4 l	10-50	0.27V - 0.554	20	0.000	0.00	1
			60-75	55		0.000	0.00	
			80-130	0.386V + 24.143		0.000	0.00	
		1.4 l < cc < 2.0 l	10-60	0.07V - 0.583		0.000	0.00	
			80-80	67		0.000	0.00	
			80-130	0.473V + 23.288		0.000	0.00	
	cc > 2.0 l	10-60	0.79V - 0.628	0.000	0.00			
		80-80	88	0.000	0.00			
		80-130	0.434V + 48.867	0.000	0.00			
		80-130	0.434V + 48.867	0.000	0.00			
Diesel	AF capacities	10-130	118.489 - 2.084V + 0.014V ²	90	0.053	18.77	18.77	
Hybrid	AF capacities	10-130	38.2.956 - 0.1V + 2.996 - 0.1V ²	50	0.041	24.41	24.41	

Vehicle Type	Fuel Type	Type	Speed Range km/h	Fuel consumption Factor g/km	Desired Speed km/h	Fuel consumption liter/km	Fuel Efficiency km/liter	Total Fuel Efficiency km/liter
Truck	Gasoline	cc < 1.4 l	10-50	0.27V - 0.554	20	0.000	0.00	1
			60-75	55		0.000	0.00	
			80-130	0.386V + 24.143		0.000	0.00	
		1.4 l < cc < 2.0 l	10-60	0.07V - 0.583		0.000	0.00	
			80-80	67		0.000	0.00	
			80-130	0.473V + 23.288		0.000	0.00	
	cc > 2.0 l	10-60	0.79V - 0.628	0.000	0.00			
		80-80	88	0.000	0.00			
		80-130	0.434V + 48.867	0.000	0.00			
		80-130	0.434V + 48.867	0.000	0.00			
Diesel	AF capacities	10-130	118.489 - 2.084V + 0.014V ²	80	0.050	20.11	20.11	
Hybrid	AF capacities	10-130	38.2.956 - 0.1V + 2.996 - 0.1V ²	8	0.051	19.78	1	

Figure 8. Snapshot of the worksheet “Fuel efficiency- Speed dependency”

Having entered these data, an initial emissions assessment of the transport sector is calculated, which details the **annual** status of both GHG and air pollution emissions in the city. The user then moves to the “Output Panel” worksheet which allows for viewing these results, which can be disaggregated by mode and fuel type to help understand emission sources and magnitudes, which in turn facilitates policy formulation.

3.7 Output Panel worksheet

This worksheet serves as the output results from the Before/After analysis mode. It consists of different parts as follows (See figure 9):

3.7.1 Results section

This part of the Output Panel worksheet is provided to show the co-benefits assessment of the transport sector on the basis of before/after analysis. The results section gives the post intervention emissions scenario akin to that in the data initialization sheet. Subtraction of results of before and after intervention gives the co-benefit assessment of emission reduction and fuel saving. The results can be shown for each vehicle group and also the whole transport sector from the provided list in the results table section of the sheet.

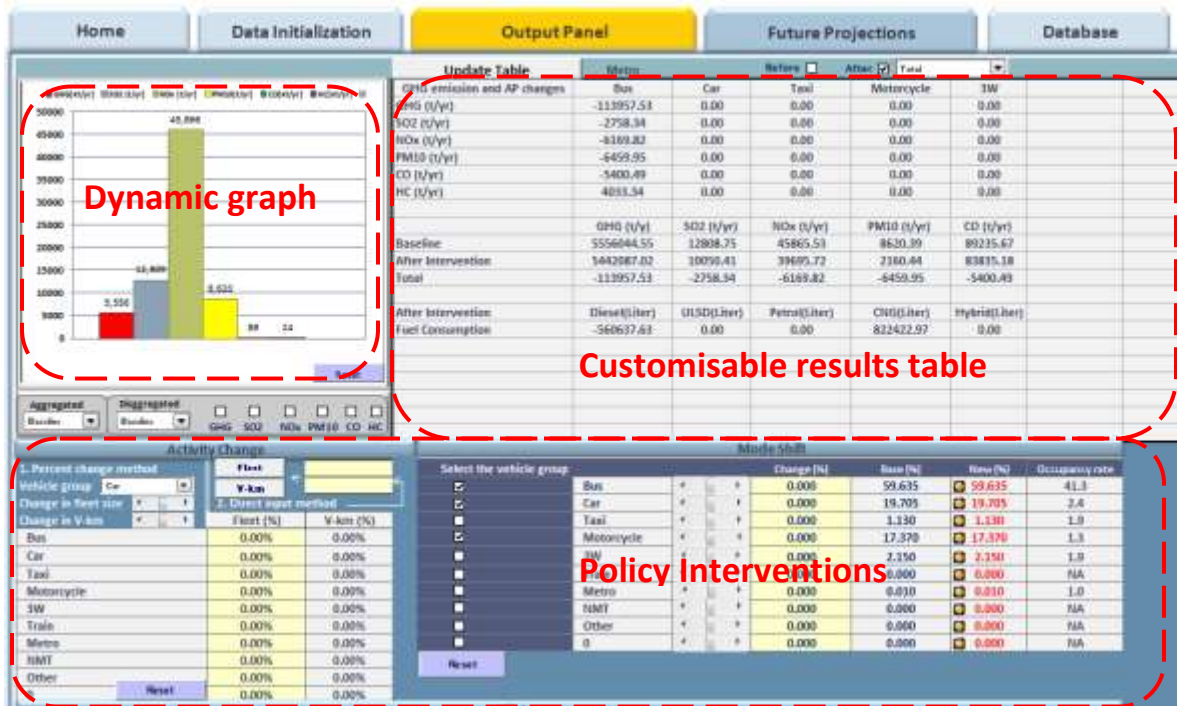


Figure 9. Snapshot of the worksheet “Output Panel”

3.7.2 Policy interventions section

Activity change

This part of Output Panel worksheet deals with changes to the total travel demand of motorised transport. This is done by changes in mobility (vehicle-kms) or size (numbers of fleet) of each vehicle group. This is the first change in to the transport system. The user can specify desired activity changes either by direct input or a percentage change. Upon changing this value, all others are kept constant, thereby increasing travel demand in each mode according to the initially determined mode share. Figure 10 shows how the input would look for a 4% decrease in total car kilometres with the relevant results (for the city of Delhi).

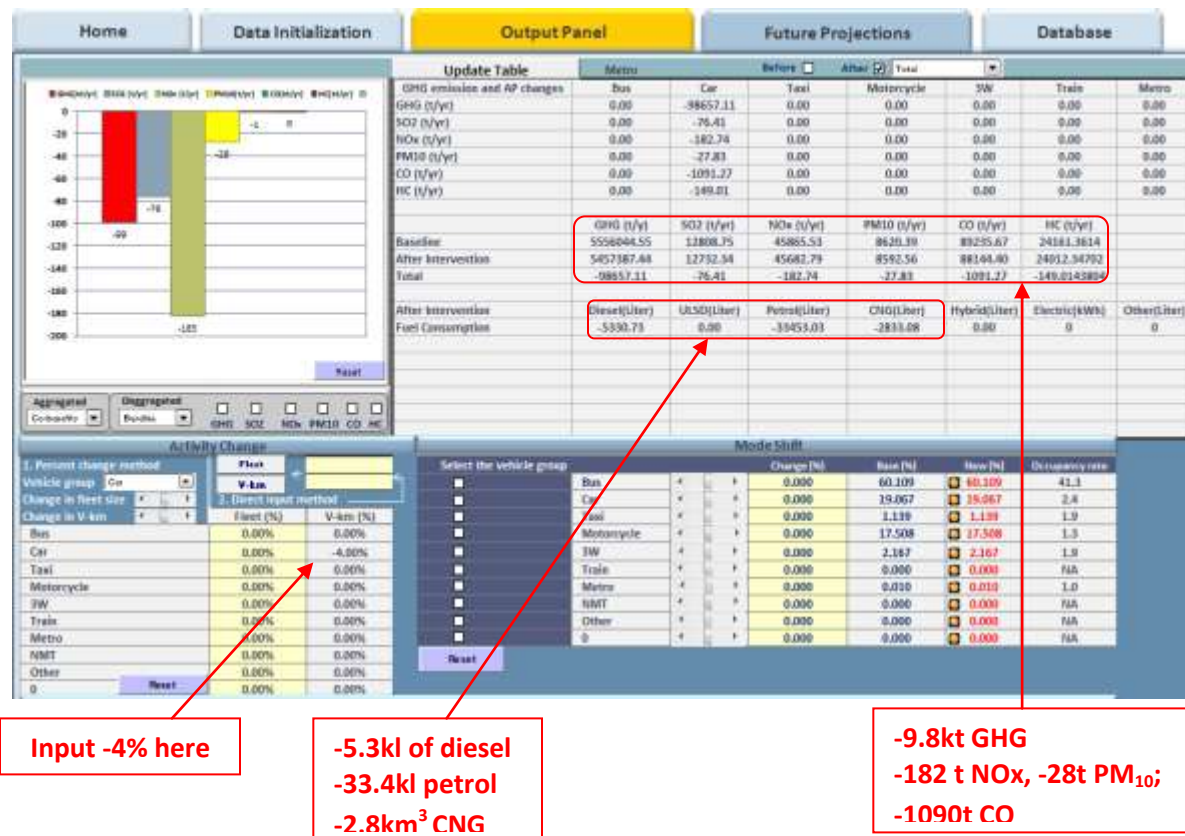


Figure 10. Example of 4% decrease in car vehicle kilometres

3.7.2.1 Mode Share

Having determined the new activity level, this can then be distributed amongst the modes for which the user is interested in the model. As mode share is calculated as the share of total pass.km, the shift is reflected as percentage points of this unit. Since mode share cannot exceed 100% the tool dynamically adjusts mode share such that a change in one mode is automatically contributed from all the other other modes in their original proportions. Mode share is adjust by clicking the checkbox next to the mode that is to be changed. When only one mode is selected, other modes will change in the manner described. Should the user wish to define specific contributions to mode shares, this can be done by checking the specific modes to change. An example is shown in Figure 6 showing how specific shifts can be set. In this case the **total mode share** shift of -2% from cars, is met with an increase in 1.5% going to buses and 0.5% going to motorcycles. Note that the check boxes for bus, car and motorcycles are checked.

Select the vehicle group		Change (%)	Base (%)	New (%)	Occupancy rate
<input checked="" type="checkbox"/>	Bus	1.50	59.060	60.56	42.4
<input checked="" type="checkbox"/>	Car	-2.00	19.515	17.51	2.1
<input type="checkbox"/>	Taxi	0.00	1.120	1.12	1.9
<input checked="" type="checkbox"/>	Motorcycle	0.50	17.202	17.70	1.3
<input type="checkbox"/>	3W	0.00	2.129	2.13	1.9
<input type="checkbox"/>	Train	0.00	0.000	0.00	NA
<input type="checkbox"/>	Metro	0.00	0.975	0.97	100.0
<input type="checkbox"/>	NMT	0.00	0.000	0.00	NA
<input type="checkbox"/>	Other	0.00	0.000	0.00	NA
<input type="checkbox"/>	0	0.00	0.000	0.00	NA

Reset

Figure 11. Mode share example input

3.7.2.2 Efficiency Improvement

Having allocated the mode share to the travel demand, the user can then specify desired fuel efficiencies for the vehicles in the portfolio; this is done by direct input (rather than a % change) and should be based on knowledge of available technologies. The input value is entered in the yellow cells (Figure 12).

Efficiency Improvement							
Insert new efficiency (km/Unit)	Diesel	ULSD	Petrol	CNG	Hybrid	Electric	Other
Bus	3.550	3.900	2.420	2.420	1.000	1.000	1.000
Car	11.250	16.000	14.000	15.120	1.000	1.000	1.000
Taxi	11.250	16.000	14.000	15.840	1.000	1.000	1.000
Motorcycle	1.000	1.000	57.200	1.000	1.000	1.000	1.000
3W	1.000	1.000	1.000	32.333	1.000	1.000	1.000
Train	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Metro	1.000	1.000	1.000	1.000	1.000	0.014	1.000
NMT	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Other	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Figure 12. Efficiency improvement example input

3.7.2.3 Fuel Share

The final intervention is to allocate shares in Fuel for the modes under consideration. As with Fuel Efficiency, this is done through the direct input of new shares rather than a percentage point increase. Initial values are given as a reference and should be maintained as the default if no change in fuel share is desired. Figure 13 shows an example where the fuel shares for cars is shifted to 10.5% Diesel; 82.5% Petrol; 7.5% CNG. As with mode share, the user needs to ensure increases in one mode are reflected by decreases in other modes.

Fuel Switch							
Insert new shift in fuel share (%)	Diesel	ULSD	Petrol	CNG	Hybrid	Electric	Other
Bus	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%
Car	10.50%	0.00%	82.00%	7.50%	0.00%	0.00%	0.00%
Taxi	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%
Motorcycle	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%
3W	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%
Train	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Metro	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%
NMT	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Other	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%
0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Figure 13. Fuel share change entry

3.7.3 Dynamic Graph

A dynamic graph in the top left of the sheet automatically reflects changes in term of GHG, Air pollution reduction and fuel saving potentials. The bars change automatically as sliders in the policy intervention area take different positions. Note that different parameters can also be plotted on the graph depending on what is selected in the drop down menu (See figure 14). These can be either aggregated or disaggregated by mode. In the disaggregated view, pollutants of interest can be selected by checking the relevant boxes.

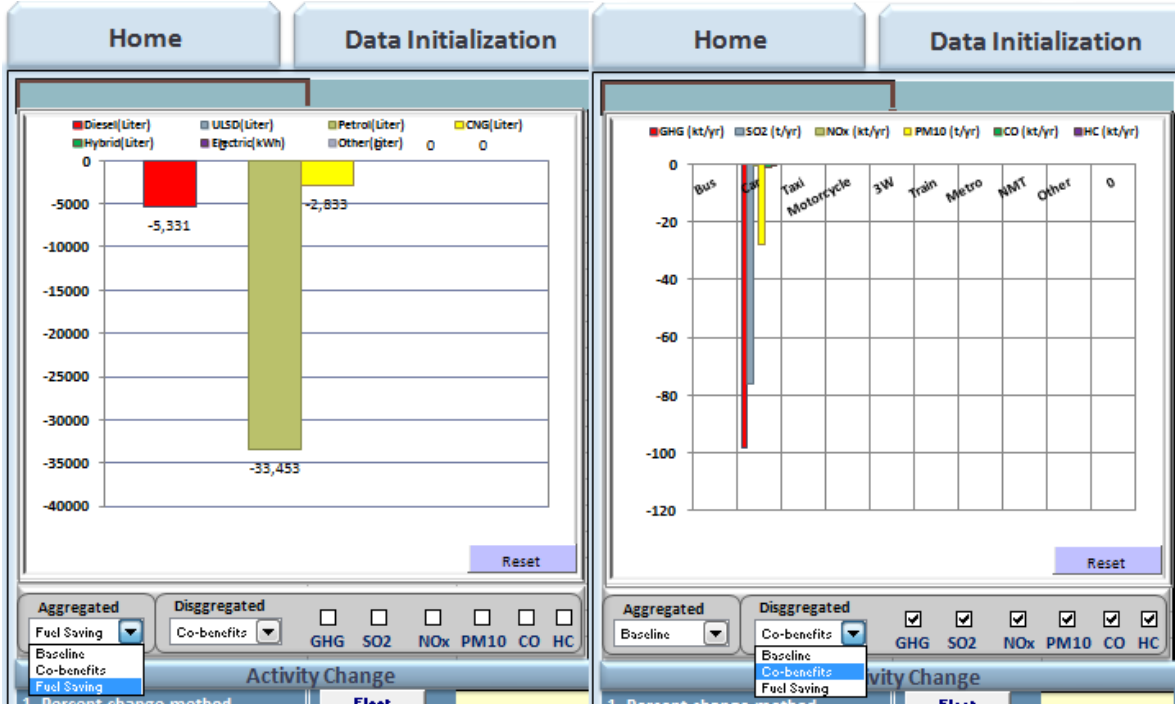


Figure 14. Tool sheet detail showing the graphs for fuel saving (left) and disaggregated co-benefits (right) of 4% reduction in car vehicle km based on the relevant selection of the menu

3.8 Report worksheet

A comprehensive report on GHG emission and air pollution for each vehicle group can be observed in this worksheet. The report is provided for both of base year (Before) and intervention policy (After) scenarios.

After Intervention Report

←
Previous

Bus								
Fuel type	Diesel	ULSD	Petrol	CNG	Hybrid	Electric	Other	Total
Number of vehicles by fuel use	0.00	0.00	0.00	61471.00	0.00	0.00	0.00	61471.00
Share of vehicles by fuel use	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.91%
Utilization rate	60.00%	60.00%	60.00%	60.00%	60.00%	60.00%	60.00%	60.00%
Annual average distance travelled (km)	0.00	0.00	0.00	67452.66	0.00	0.00	0.00	67452.66
Vehicle kilometers	0.00	0.00	0.00	2487829477.72	0.00	0.00	0.00	2487829477.72
Occupancy rate	41.34	41.34	41.34	41.34	41.34	41.34	41.34	41.34
Annual Passenger kilometers	0.00	0.00	0.00	105458967210.80	0.00	0.00	0.00	105458967210.80
Made share	0.00	0.00	0.00	0.61	0.00	0.00	0.00	0.61
Fuel Efficiency (km/l)	3.25	3.50	2.42	2.42	1.00	1.00	1.00	2.42
Intensity (l/passengers.km)	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.01
Greenhouse gas emissions								
CO2 (tCO2/yr)	0.00	0.00	0.00	1712975.39	0.00	0.00	0.00	1712975.39
CH4 (tCO2e/yr)	0.00	0.00	0.00	1707.70	0.00	0.00	0.00	35861.80
N2O (tCO2e/yr)	0.00	0.00	0.00	125.44	0.00	0.00	0.00	36887.18
Air pollutants								
SO2 (t/yr)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NOx (t/yr)	0.00	0.00	0.00	25295.05	0.00	0.00	0.00	25295.05
PM10 (t/yr)	0.00	0.00	0.00	127.55	0.00	0.00	0.00	127.55
CO (t/yr)	0.00	0.00	0.00	2887.00	0.00	0.00	0.00	2887.00
HC (t/yr)	0.00	0.00	0.00	7678.35	0.00	0.00	0.00	7678.35

←
Previous

Car								
Fuel type	Diesel	ULSD	Petrol	CNG	Hybrid	Electric	Other	Total
Number of vehicles by fuel use	228198.92	0.00	1782124.86	62995.23	0.00	0.00	0.00	2173323.00
Share of vehicles by fuel use	10.50%	0.00%	82.00%	7.50%	0.00%	0.00%	0.00%	32.33%
Utilization rate	60.00%	60.00%	60.00%	60.00%	60.00%	60.00%	60.00%	60.00%
Annual average distance travelled (km)	1149.75	0.00	8079.00	821.25	0.00	0.00	0.00	10950.00
Vehicle kilometers	15742302151	0.00	1461019470.76	8037868.12	0.00	0.00	0.00	14278732110.00
Occupancy rate	2.38	2.38	2.38	2.38	2.38	2.38	2.38	2.38
Annual Passenger kilometers	3202598830.01	0.00	25010459434.34	2287542021.43	0.00	0.00	0.00	30500960285.77
Made share	0.02	0.00	0.14	0.01	0.00	0.00	0.00	0.18
Fuel Efficiency (km/l)	11.25	16.00	14.00	15.12	1.00	1.00	1.00	13.80
Intensity (l/passengers.km)	0.04	0.03	0.03	0.03	0.42	0.42	0.42	0.03
Greenhouse gas emissions								
CO2 (tCO2/yr)	270577.52	0.00	171855.51	123830.97	0.00	0.00	0.00	2102664.01
CH4 (tCO2e/yr)	8.13	0.00	114.09	187.40	0.00	0.00	0.00	6502.75
N2O (tCO2e/yr)	25.96	0.00	271.72	7.12	0.00	0.00	0.00	94487.16
Air pollutants								
SO2 (t/yr)	588.48	0.00	1025.92	0.00	0.00	0.00	0.00	1714.40
NOx (t/yr)	735.60	0.00	3082.77	281.93	0.00	0.00	0.00	4100.30
PM10 (t/yr)	242.21	0.00	350.29	32.04	0.00	0.00	0.00	624.54
CO (t/yr)	1202.08	0.00	2332.45	1561.16	0.00	0.00	0.00	24485.70
HC (t/yr)	246.76	0.00	2837.32	259.49	0.00	0.00	0.00	2343.56

Figure 15. Sample of comprehensive report for after intervention

3.9 Future Projection worksheet

Corresponding specifications for projecting transport sector energy demand and its related emissions into the future must be defined in this worksheet. Two scenarios are associated with this worksheet, the baseline and the new scenarios.

3.9.1 Baseline scenario

Historical time series

In CAST, a separated worksheet is designed to provide historical data which is needed to use as the time series in equations 4-6 .Figure 16 shows the collected historical data for the city of Delhi. The time series consist of: numbers of in-use road vehicle per each group, GDP PPP per capita, total road PKM per capita and survival rates per each group. The

minimum number for data recodes is limited to 16 (in case of Delhi; 21 records between 1990 to 2010). For a new city, the user needs to collect these data from available sources in city level. Number of vehicles could be obtained from the transport divisions of city governments (for Delhi case; www.delhi.gov.in). PKM data could also be obtained from secondary sources such as academic research and publications.

← Previous

Historical Data

Following data are provided for Delhi city as case study. You can change it based on your case

	Road Vehicle Population (1000)					total	GDP PPP Per Capita (\$)	Road PKM/Capita
	Bus	Car	Taxi	Motor	3W			
1990	1858	386479	10157	1220640	3892	1812967	200.7	1709.2
1991	20201	440166	10694	1317180	4735	1962998	252.3	1822.5
1992	23221	477783	11365	1403050	5761	2097155	317.7	1944.2
1993	24211	523264	11846	1492201	7008	2239003	399.7	2073.6
1994	26202	575762	12547	1617732	8526	2432298	502.3	2211.6
1995	27989	633602	13765	1741260	10372	2629645	632.8	2329.2
1996	29572	705923	15015	1876013	12613	2847695	803.1	2474.5
1997	32333	765470	16654	1991710	15350	3033045	730.3	2629.7
1998	35254	818962	17136	2101876	18674	3210456	791.8	2754.2
1999	38933	857333	17482	2169162	22718	3283343	846.7	2969.0
2000	41483	895744	18362	2314861	27637	3456579	904.0	3106.5
2001	41964	954251	19756	2434955	33622	3647318	941.7	3283.3
2002	42354	1013724	21203	2553797	40903	3838758	1007.5	3474.3
2003	42618	1073622	22697	2670674	49760	4030136	1089.0	3674.3
2004	42834	1134134	24231	2784913	60335	4220775	1211.2	3883.7
2005	43500	1194438	25798	2895893	73644	4410616	1354.3	4035.4
2006	46381	1254215	27383	3003082	74189	4585808	1560.3	4243.6
2007	52763	1313150	28993	3105997	75297	4759330	1748.7	4462.4
2008	55148	1370897	30603	3204260	83948	4910537	1936.6	4692.5
2009	58047	1427137	32208	3297575	86482	5099464	2124.5	4934.5
2010	61471	1473323	37958	3347403	88181	5223336	2312.4	5084.2

Figure 16. Sample of historical data for city of Delhi

To provide short- and long- term projections, the fuel fleet average efficiency is considered to have an annual increase as indicated by Graham et al. and BITRE/CSIRO (See figure 17)

	Petrol		Diesel		LPG		CNG (m ³ & LNG (L))		B95		B20		E85		E10		H ₂ (m ³ /100km)		BTU/GTL/CTL /STL diesel		
	2006	2050	2006	2050	2006	2050	2006	2050	2006	2050	2006	2050	2006	2050	2006	2050	2006	2050	2006	2050	
Passenger Cars																					
Light	9.1	6.8	6.3	5.4	12.1	8.6	8.0	5.5	7.7	6.3	6.5	5.6	12.8	8.6	9.5	7.1	36.7	23.3	6.6	5.7	
Medium	10.2	7.6	7.1	6.1	13.6	9.6	9.0	6.2	8.6	7.1	7.3	6.3	14.3	9.6	10.6	7.9	41.1	26.1	7.4	6.4	
Heavy	14.0	10.4	9.7	8.3	18.6	13.2	12.3	8.5	11.8	9.7	10.0	8.6	19.6	13.2	14.5	10.8	56.3	35.7	10.1	8.7	
LCVs																					
Light	10.4	7.8	7.2	6.2	13.8	9.8	9.2	6.3	8.8	7.2	7.4	6.4	14.6	9.8	10.8	8.0	41.8	26.6	7.5	6.5	
Medium	11.6	8.7	8.1	7.0	15.5	11.0	10.3	7.0	9.8	8.1	8.3	7.2	16.4	11.0	12.1	9.0	46.9	29.7	8.4	7.2	
Heavy	15.9	11.9	11.1	9.5	21.2	15.0	14.0	9.6	13.5	11.0	11.4	9.8	22.4	15.0	16.5	12.3	64.2	40.7	11.5	9.9	
Trucks & Buses																					
Rigid	39.2	29.3	28.9	24.9	52.2	37.0	34.5	23.7	35.2	28.8	29.8	25.6	55.1	37.0	40.6	30.3	157.8	100.1	30.1	25.9	
Art'd	73.1	54.6	54.0	46.4	85.2	69.7	83.4	68.3	65.7	53.8	55.6	47.8	89.9	69.6	75.8	56.6	257.6	199.4	56.2	48.4	
Buses	36.2	27.0	26.7	23.0	48.1	34.1	31.9	21.9	32.5	26.6	27.5	23.6	50.8	34.1	37.5	28.0	145.6	92.4	27.8	23.9	

Sources: Graham et al. (2008); BITRE and CSIRO (2008).

Figure 17. Assumed fleet average fuel efficiency by engine type in the baseline scenario in the tool

Having entered historical data, figures 18 to 20 show how the future projection would look for the transport sector of city of Delhi.

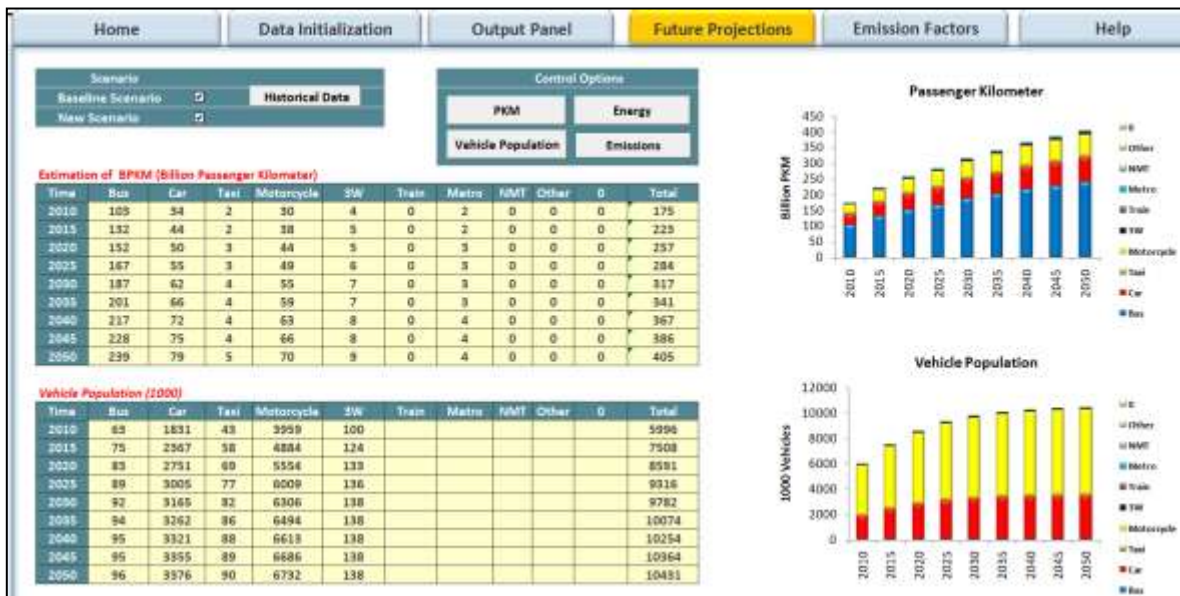


Figure 18. Projection of PKM and vehicle population of city of Delhi

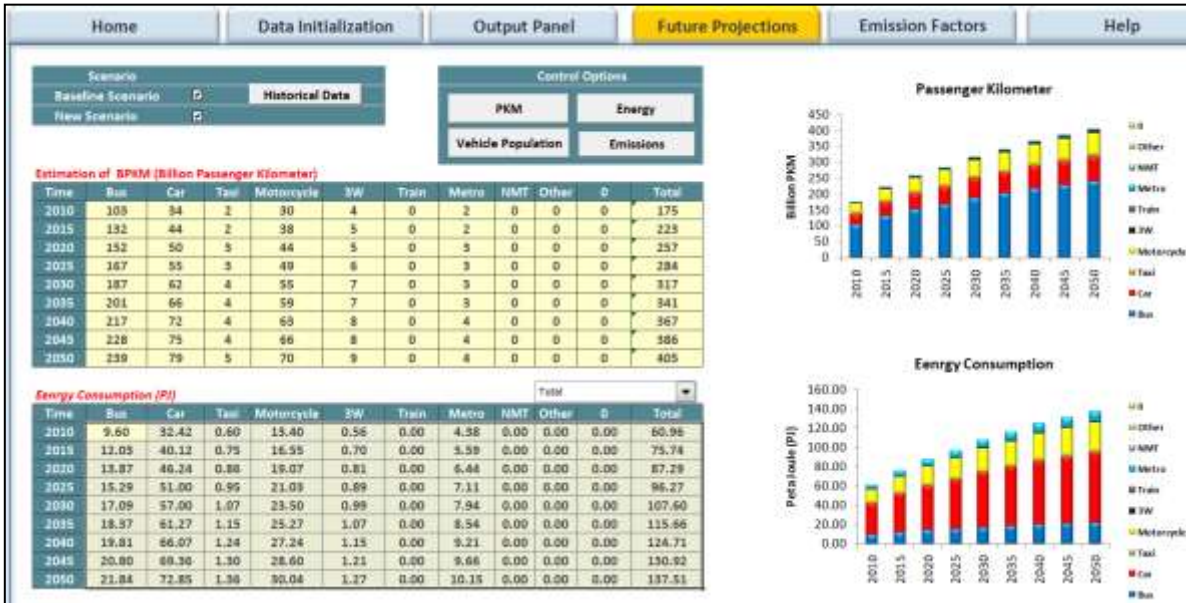


Figure 19. Projection of energy consumption in the transport sector of city of Delhi

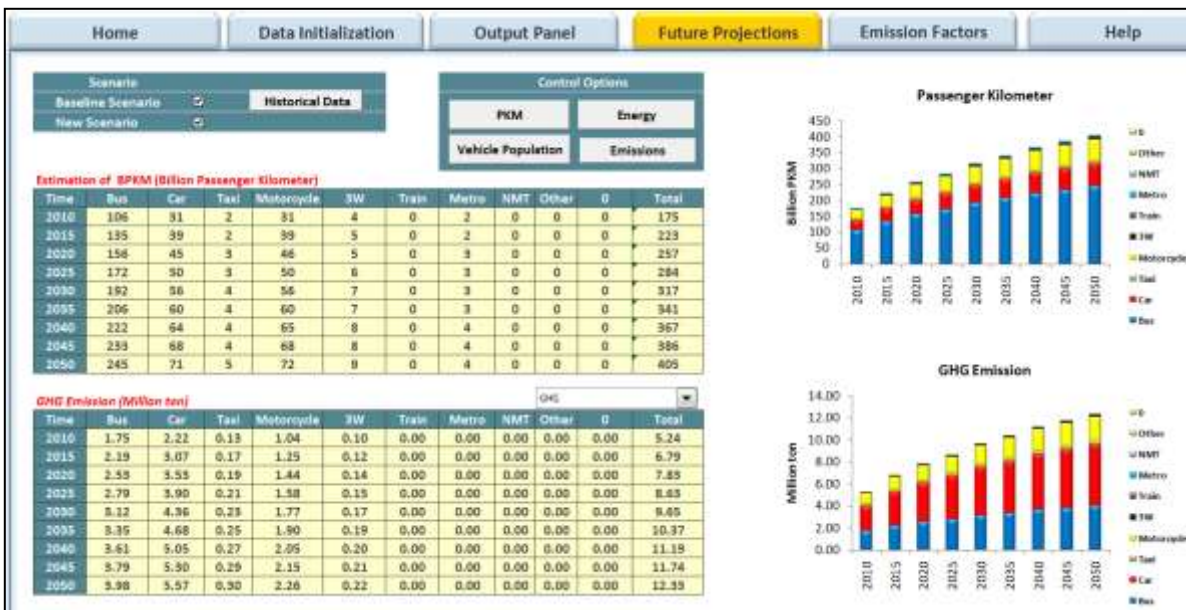


Figure 20. Projection of GHG emission in the transport sector of Delhi

3.9.2 Future estimates for PKM

PKM serves as the metric of activity in the transport sector. As the PKM is a common measure of passenger mobility in city, it has been traditionally used to determine the need for new infrastructure in the transport sector. The user can use an estimate for the PKM by direct input to access the future projection of energy demand and emissions in the transport sector. This method can also be used when the historical data are not available. Figure 21 shows the results of future projection for energy demand by having assumptions about annual average growth rates of PKM for the city of Delhi as: 1% for bus, 5% for car, 3% for motorcycle, 3% for 3W and 1% for metro.

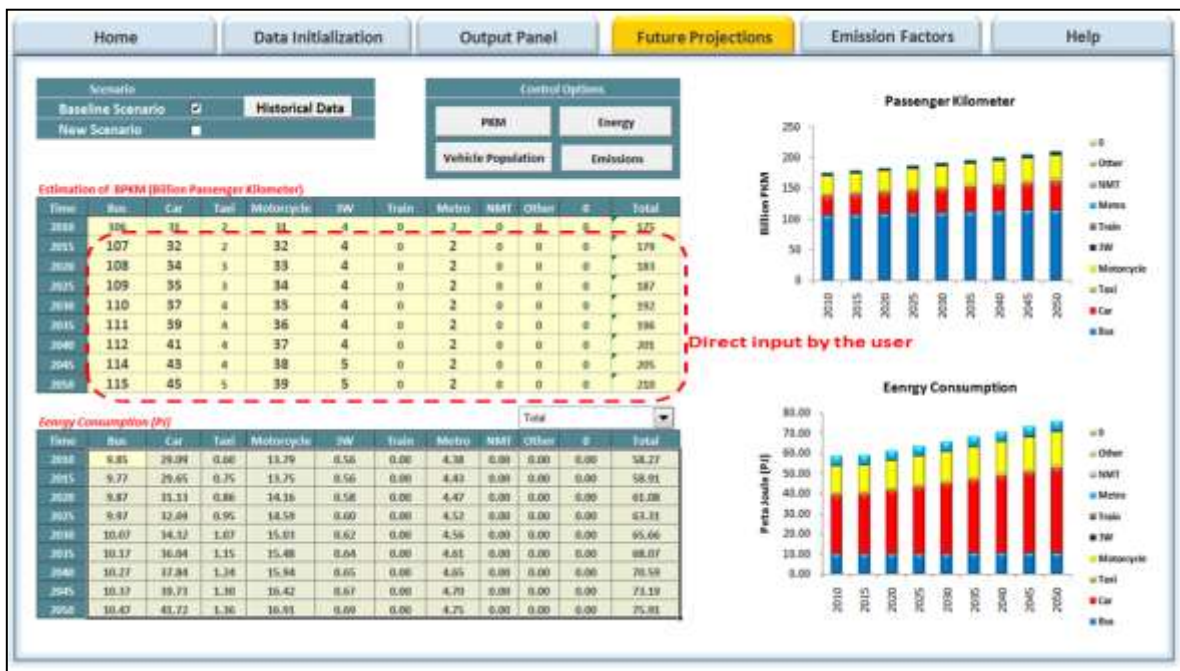


Figure 21. Projection of energy demand based on the direct input estimates for PKM in city of Delhi

3.9.3 New scenario definition

This option is designed to provide a stratification mechanism to allocate the definition of new scenario for the future projections. The primary concern in defining a new scenario is to address those effects that are liable to alter the energy demand and its related emissions growth trends in the transport sector. The three factors considered to have the greatest potential affect on future trends are: mode share, fuel efficiency and switching

from conventional fuel type to an alternative one. The new scenario can be designed and developed by the user through changing the values of the aforesaid three factors as depicted in figure 22. This figure shows an example of new scenario which is defined as follows:

- 5% increase in mode share of bus in 2050 by decreasing 2% and 3% in modal shares of car and motorcycle, respectively.
- 2% increase in fuel efficiency of petrol passenger vehicle (car)
- 2% increase in using of CNG through 2% decrease in using of petrol in passenger vehicles

The projections for PKM and petrol consumption can be observed in figure 23.

1. Modal Share Change(%)											
Time	Bus	Car	Taxi	Motorcycle	3W	Train	Metro	NMT	Other	0	Sum
2010	59.63	19.70	1.13	17.37	2.15	0.00	0.01	0.00	0.00	0.00	100.00
2015	59.63	19.70	1.13	17.37	2.15	0.00	0.01	0.00	0.00	0.00	100.00
2020	59.63	19.70	1.13	17.37	2.15	0.00	0.01	0.00	0.00	0.00	100.00
2025	59.63	19.70	1.13	17.37	2.15	0.00	0.01	0.00	0.00	0.00	100.00
2030	59.63	19.70	1.13	17.37	2.15	0.00	0.01	0.00	0.00	0.00	100.00
2035	59.63	19.70	1.13	17.37	2.15	0.00	0.01	0.00	0.00	0.00	100.00
2040	59.63	19.70	1.13	17.37	2.15	0.00	0.01	0.00	0.00	0.00	100.00
2045	59.63	19.70	1.13	17.37	2.15	0.00	0.01	0.00	0.00	0.00	100.00
2050	64.64	17.70	1.13	14.37	2.15	0.00	0.01	0.00	0.00	0.00	100.00

2. Fuel Efficiency and Fuel share changes								
Process	Car	Diesel	ULSD	Petrol	CNG	Hybrid	Electric	Other
Fuel Share	2015	10.50%	0.00%	82.00%	7.50%	0.00%	0.00%	0.00%
	2020	10.50%	0.00%	82.00%	7.50%	0.00%	0.00%	0.00%
	2025	10.50%	0.00%	82.00%	7.50%	0.00%	0.00%	0.00%
Car	2030	10.50%	0.00%	82.00%	7.50%	0.00%	0.00%	0.00%
	2035	10.50%	0.00%	82.00%	7.50%	0.00%	0.00%	0.00%
	2040	10.50%	0.00%	82.00%	7.50%	0.00%	0.00%	0.00%
	2045	10.50%	0.00%	82.00%	7.50%	0.00%	0.00%	0.00%
Save	2050	10.50%	0.00%	80.00%	9.50%	0.00%	0.00%	0.00%

Figure 22. Sample of scenario definition for the transport sector of the city of Delhi

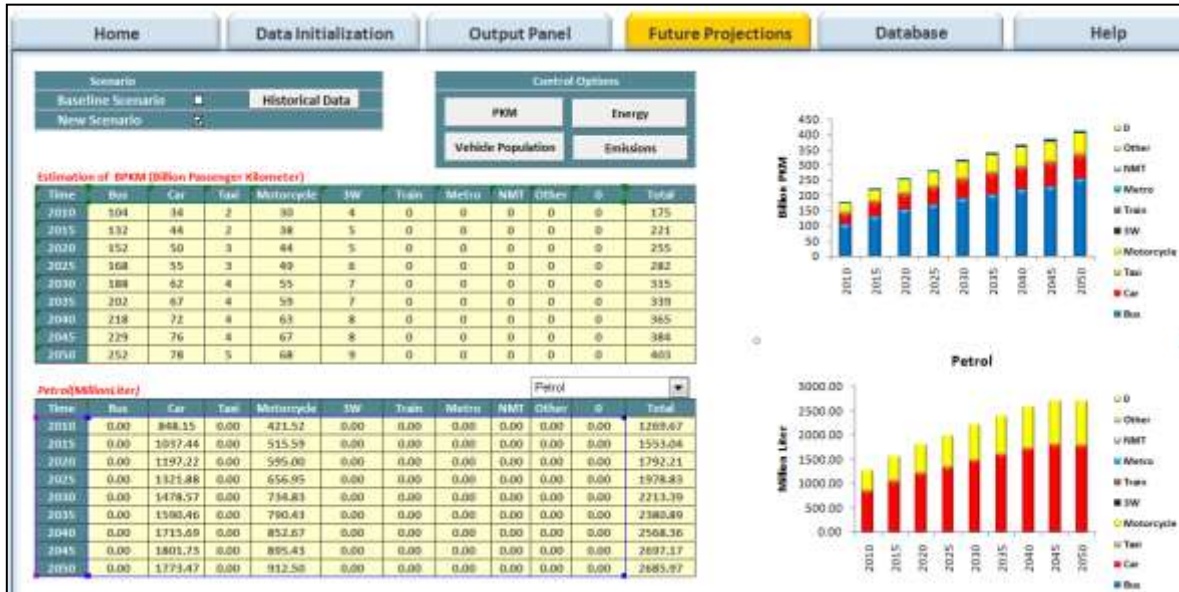


Figure 23. Projection of PKM and petrol consumption based on the new scenario

3.10 Database worksheet

This worksheet provides information about the standards for emission factor for different categories of pollutants including: CO₂, CH₄, N₂O, CO, SO₂, NO_x, PM, HC, Black carbon and VOC. These factors are expressed in term of gram per liter of fuel. While the physico-chemical properties of fuels, particularly hydrocarbons, depend on the origin and method used to obtain the flues, a comprehensive dataset of emission factors for different regions of the world is provided to support the co-benefits evaluation in the transport sector in different cities. This kind of data can be found from international or national organizations who conduct research on emissions, such as the IPCC and NAIE UK Transport.

	Home		Data Initialization					Output Panel				Future Projections				Database				Help																																																														
Vehicle Group																	Fuel																																																																	
Fuel Type	Diesel	GLD	Petrol	CNG	Hybrid	Electric	Other	Bioeth	MSB	Petrol	CNG	Hybrid	Electric	Other	Diesel	GLD	Petrol	CNG	Hyd																																																															
Greenhouse gases CO2eq	2691.07	0.09		1485.81			2116.05	2324.70		2498.41	2095.63	2425.42	890.00	405.83	2715.45		2384.44	2047.71	2384																																																															
CO2	2661.00			1475.98			2066.00	2261.00		2380.00	2048.00	2289.88	890.00	364.20	2643.88		2289.00	1888.00	2289																																																															
CH4	0.53			1.42			4.11	4.07		0.15	2.95	0.15	0.00	0.57	0.06		0.18	1.39	1.39																																																															
N2O	0.04			0.32			0.15	0.23		0.06	0.11	0.06	0.00	0.22	0.22		0.30	0.09	0.30																																																															
Particulates																																																																																		
SO2	4.93							4.61		3.90			0.20		4.92			5.50	3.00																																																															
Nox	46.19	51.78		23.96				6.15	6.75	4.11	6.44		7.70		6.15	6.75	4.31	4.44																																																																
PM10	11.70			0.32				7.00	1.49	0.87	0.90				7.20		2.27	5.50																																																																
PM2.5																																																																																		
Black Carbon													0.06																																																																					
CO	15.97	4.31		2.55				10.05	4.14	28.47	30.83				35.05	4.31	28.47	30.69																																																																
VOC																																																																																		
HC	3.49	1.08		7.29				2.06	0.98	3.78	4.08				7.06	0.98	3.78	4.08																																																																
Unit: for fossil fuel - g/l for electricity: g/kWh																																																																																		
	<div style="display: flex; align-items: center;"> <div style="border: 1px solid black; padding: 5px; margin-right: 20px;"> <p style="background-color: #d9ead3; padding: 2px;">Regional Road Emission Factor Inventory (g/l)</p> <p style="font-size: small;">Select your region: Gwalior</p> <table border="1" style="font-size: x-small; border-collapse: collapse;"> <thead> <tr> <th>Vehicle Group</th> <th colspan="3">Bus</th> <th colspan="2">Car</th> <th>Motorcycle</th> </tr> <tr> <th>Fuel Type</th> <th>Diesel</th> <th>Diesel</th> <th>Petrol</th> <th>Petrol</th> <th>Petrol</th> <th></th> </tr> </thead> <tbody> <tr> <td>Greenhouse gases CO2eq</td> <td>2617.71</td> <td>2617.63</td> <td>2379.82</td> <td>2375.68</td> <td></td> <td></td> </tr> <tr> <td>CO2</td> <td>2617.44</td> <td>2617.44</td> <td>2379.00</td> <td>2370.00</td> <td></td> <td></td> </tr> <tr> <td>CH4</td> <td>0.27</td> <td>0.18</td> <td>0.82</td> <td>5.89</td> <td></td> <td></td> </tr> <tr> <td>Nox</td> <td>42.20</td> <td>9.88</td> <td>6.38</td> <td>2.81</td> <td></td> <td></td> </tr> <tr> <td>PM10</td> <td>1.20</td> <td>1.91</td> <td>0.62</td> <td>4.41</td> <td></td> <td></td> </tr> <tr> <td>CO</td> <td>8.15</td> <td>5.87</td> <td>100.50</td> <td>100.00</td> <td></td> <td></td> </tr> <tr> <td>VOC</td> <td>2.38</td> <td>1.20</td> <td>11.78</td> <td>113.58</td> <td></td> <td></td> </tr> </tbody> </table> </div> <div style="text-align: center;"> <p>Copy/paste</p> <p>Select your value</p> </div> <div style="margin-left: 20px;"> <ol style="list-style-type: none"> 1. Select your region 2. Copy the emission factor from the table 3. Paste the value in above table </div> </div>																			Vehicle Group	Bus			Car		Motorcycle	Fuel Type	Diesel	Diesel	Petrol	Petrol	Petrol		Greenhouse gases CO2eq	2617.71	2617.63	2379.82	2375.68			CO2	2617.44	2617.44	2379.00	2370.00			CH4	0.27	0.18	0.82	5.89			Nox	42.20	9.88	6.38	2.81			PM10	1.20	1.91	0.62	4.41			CO	8.15	5.87	100.50	100.00			VOC	2.38	1.20	11.78	113.58		
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Figure 24. Snapshot of part of the worksheet “Database”

4. Understanding the result

Because the calculation is made in order of the inputs, in this case the 2% increase in travel demand by bus is distributed according to the initial mode share (BAU). The mode shifts can apply to the whole transport sector not just the increased demand portion, as the does the fuel share for cars.

In this case, what we see is that the 2% increase in travel demand (as input in the travel demand sheet). This is offset by in part by the mode shift but more so by the fuel switch in cars for the carbon emissions. However, although there are reductions in some elements of air pollution from the mode shift and the fuel switch, we can see which pollutants are increasing or decreasing. This makes the **assumption that emission reductions may be perfectly summed from each intervention** (i.e. there are no feedbacks between the interventions). This may not be the case between Activity and mode share for example. These precise relationships could be understood by constructing regression models over time to see how sensitive one factor is in relation to another.

5. Concluding Remarks

This guidebook outlines a methodology for evaluating co-benefits in the transport sector. The method presents both a quantitative tool emissions calculator and a qualitative guide for city level understanding of the transport portfolio and changes along four policy lines common to transport planning.

Whilst the spreadsheet should be able to operate at different scales, this ultimately depends on the quality of the data, as the level of analysis becomes more disaggregated, so does the demands on the data. In principle it should be able to operate at the city and perhaps the district level.

There spreadsheet has limitations, both in the structure of the model and in the requirements for good quality data. For example, it has no spatial element in it and so it is not possible to talk about the differential impacts within the city or locality. It also has no behavioural element to it and therefore assumes that people will behave in the way that the model determines rather than their actual behaviour.

With these considerations in mind, we suggest that it is best considered as a screening tool that will help policymakers' scope transport project potential for both local and climate impacts. A more detailed model which factors in travel demand will be needed for detailed plans and projects.

However, whilst transport portfolios differ from city to city, the general sense of the tool is that shifting people from private to public transport offers the greatest emissions reductions. Ultimately, demand management - shifting from to non-motorised transport (walking and cycling) would be the best way of cutting emissions, this is likely to hard to implement for reasons of modernisation implicitly linked to motorisation (Wright and Fulton, 2005).

The explicit inclusion of a qualitative approach embedded within the methodology highlights the importance of implementation; more sophisticated quantitative assessments may have little bearing on the actual outcomes if policies are not implemented effectively. Although public transport shifts are predicted to have the best carbon emission reduction potential, it should be noted that in the case of Delhi, its metro ridership (and metros in general) does not meet the expectation of the plan. It is hoped the in following this process the policymaker is made keenly aware of the critical importance of data acquisition to the model.

6. Where to find data

Number of Vehicles

The data on number of vehicles in Delhi is taken from the website of Government of National Capital Territory of Delhi, which is the local government.

Average Occupancy (Load Factor)

The data on average occupancy for the Delhi case is taken from the following publication. It is not directly on Delhi but they are default values for average occupancy for Asian countries. Therefore, one potential source to find this data is academic publications and research on urban passenger transportation.

“Manual for Calculating Greenhouse Gas Benefits of Global Environment Facility Transportation Projects”, Prepared by the *Institute for Transportation and Development Policy* For the *Scientific and Technical Advisory Panel of the Global Environment Facility*. Available at: http://www.thegef.org/gef/sites/thegef.org/files/publication/GEF_CalculatingGHGbenefits_webCD.pdf

Average Travel Distance

The data on the Delhi case is obtained from the following source.

RITES (1995a), Integrated Multi-Modal Mass Rapid Transport System for Delhi, Economic Analysis for Modified First Phase CITED IN M N, Murty, Dhavala, Kishore Kumar, Ghosh, Meenakshi and Singh, Rashmi (2006) Social Cost-Benefit Analysis of Delhi Metro, Institute of Economic Growth, Delhi. Available at: http://mpra.ub.uni-muenchen.de/14465/1/MPRA_paper_14465.pdf

Emission Factors [g/km]

For India:

ARAI 2007, “Emission Factor development for Indian vehicles”, Draft report for *Air Quality Monitoring Project-Indian Clean Air Programme (ICAP)*, The Automotive Research Association of India, Pune

Price and Infrastructure Costing.

Other sources:

Institute of Global Environmental Strategies (IGES). *Mainstreaming Transport Co-benefits Approach: A Guide to Evaluating Transport Project*, Draft 2.

Guttikunda, S., 2008. *Air Pollution & Co-Benefits Analysis for Hyderabad, India*.

Walker, S., 2008. *UK National Atmospheric Emission Inventory*.
http://naei.defra.gov.uk/datachunk.php?f_datachunk_id=307

IPCC 2006, *Guidelines for National Greenhouse Gas Inventories: Workbook*.

When collecting the emission factors for India, the data from *IES Guttikunda, Price and Infrastructure Costing* and *ICAP 2007* were used because they were India specific. These data can usually be found from papers the Indian government has published or have data from the Research Institutes or individual researchers on the vehicular emissions.

In order to compare the India specific data, it is necessary to find a standard for emission factors. This kind of data can be found from international or national organizations who conduct research on emissions, such as the IPCC and NAIE UK Transport. Furthermore, international organizations such as IGES have conducted research to calculate the emissions in Manila. The data in this can be used to compare the India specific data.

Fuel Efficiency [km/L]

For India:

Pricing and Infrastructure Costing Report, Mumbai, India

Other sources:

The fuel efficiency could be found on the same papers as the papers with the emission factors. For example, the *Pricing and Infrastructure Costing* paper gave the emission factors along with the fuel efficiencies. This allows the emission factor and the fuel efficiency to have correlation.

When the fuel efficiency is not given in the paper, it is important to find the fuel efficiencies for vehicles in the same area as where the emission factors are given, or find those of the same euro standards.

Emission Factor [g/L]

For India:

Pricing and Infrastructure Costing Report, Mumbai, India

Other sources:

Transport Canada 2011, *Urban Transportation Emission Calculator: GHG Emission Factors*, <http://wwwapps.tc.gc.ca/Prog/2/UTECE-CETU/GhgEmissionFactors.aspx?lang=eng>

Emission Factors tend to be expressed in [g/km], creating the need to convert this into [g/L] using the fuel efficiencies. Therefore, it is necessary to find a paper including the data for both fuel efficiency and emission factors, or have a reliable fuel efficiency data which can be used on any emission factor data you have collected.

There are official websites, such as the Canadian Transport, which give the GHG emission factors in these units.

Fuel Type, Pollutants, & Mode

For India:

Government of India, 2001. *India: State of the Environment*. http://moef.nic.in/soer/2001/ind_air.pdf

When considering the modes, it is important to know the mode share of the area. Depending on the area, the modes you consider are different, and this data can easily be found on any papers on transport or emissions of that area. Many governments have yearly updated data on their websites as well. The pollutants the project should focus on depend on the fuel used in that area. In some cases, there is no recent data on the pollutants that need to be considered, hence, the pollutants given in the international standard (IPCC, IGES) can be used.

Grid Electricity Emission Factors [g/kWh]

For India:

The Energy and Resources Institute 2001. <http://www.teriin.org/ee/pdf/fca.pdf>

Bhawan, S., Puram, R.K., 2008. *CO2 Baseline Database for the Indian Power Sector*, Version 4.0. Government of India, Ministry of Power, Central Electricity Authority. http://www.cea.nic.in/reports/planning/cdm_co2/user_guide_ver4.pdf

GDP PPP per capita

For Delhi:

ECONOMIC SURVEY OF DELHI, 2012-13,

http://www.delhi.gov.in/wps/wcm/connect/DOIT_DES/des/our+services/publications/list+of+publications/state+domestic+product+and+capital+formation

Population growth rate

For Delhi:

http://mospi.nic.in/Mospi_New/site/India_Statistics.aspx

Road vehicle population

For Delhi:

http://delhi.gov.in/wps/wcm/connect/DoIT_Planning/planning/economic+survey+of+delhi/content/transport

http://delhi.gov.in/wps/wcm/connect/doit_transport/Transport/Home/Vehicle+Registration/Total+Vehicle+Registered

Other sources:

Ranjan Kumar Bose* and V Srinivasachary.1997. Policies to reduce energy use and environmental emissions in the transport sector, EnergyPolicy,Vol.25, Nos 14--15,pp. 1137-1150, 1997

Life Cycle Assessment Database Japan, Federation of Electric Power Companies, <http://lca-forum.org/seminar/pdf/93.pdf>

Ari, I. and Koksai, M. A.,2011.*Carbon dioxide emission from the Turkish electricity sector and its imitgation options*, Energy Policy, 39 (6120-6135) Available through: sciencedirect. <http://www.sciencedirect.com/science/article/pii/S0301421511005350>

Tanatvanit, S., Limmeechokchai, B., and Shrestha, R.M.,2004.*CO2 mitigation and power generation implications of clean supply-side and demand-side technologies in Thailand*, Energy Policy, 32 (83-90). Available through: science direct. <http://www.thailand-energy.info/Article/Ts-3%20co2%20mitigation%20and%20power%20generation%20implications%20of%20clean%20supply-side%20and%20demand-side%20technologies%20in%20thailand.pdf>

The grid electricity emission factors are very difficult to find unless the data is specifically given by the government. In many cases, the emission factors given in the papers only considers one type of the power plants, such as coal, thermal, nuclear, when what is need is the total. The data collected for Japan considers all these plants, and this data was given from the Federation of Electric Power Companies in Japan. The grid electricity emission factors can be collected in a similar way from Electric Power Companies of that area.

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For Copenhagen case, please see Santos, G., Behrendt, H., Teytelboym, A. (2010), Part II: Policy Instruments for Sustainable Road Transport, *Research in Transportation Economics*, 28, 46-91.

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Authors:

Christopher Doll
Hooman Farzaneh

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**UNITED NATIONS
UNIVERSITY**

UNU-IAS

United Nations University

Institute of Advanced Studies

6F International Organizations Center
Pacifico Yokohama, 1-1-1 Minato Mirai
Nishi-ku, Yokohama 220-8502
JAPAN

Tel: +81-45-221-2300

Fax: +81-45-221-2302

Email: unuias@ias.unu.edu

Website: www.ias.unu.edu