Using the Geographic Information System (GIS) in the Sustainable Transportation

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Abstract—The significance of emissions from the road transport sector (such as air pollution, noise, etc) has grown considerably in recent years. In Australia, 14.3% of national greenhouse gas emissions in 2000 were the transport sector's share which 12.9% of net national emissions were related to a road transport alone. Considering the growing attention to the green house gas(GHG) emissions, this paper attempts to provide air pollution modeling aspects of environmental consequences of the road transport by using one of the best computer based tools including the Geographic Information System (GIS). In other word, in this study, GIS and its applications is explained, models which are used to model air pollution and GHG emissions from vehicles are described and GIS is applied in real case study that attempts to forecast GHG emission from people who travel to work by car in 2031 in Melbourne for analysing results as thematic maps.

Keywords—Geographic Information System (GIS), Green House Gas(GHG) emission, sustainable development, transportation

I. INTRODUCTION AND LITERATURE REVIEW

THE growing human population and its demands considering the limited earth's resources cause increasing demand for sustainable practices. The Brundtland Commission defines the Sustainable development as "meet the needs of the present without compromising the ability of future generations to meet their own needs"[17]. Sustainable development is a complicated issue, including economic, social and environmental aspects, requiring an integrated approach. Both temporal and spatial processes are necessary in Sustainable Development; the geographic information system (GIS) is a computer-based tool for visualising, mapping and analysing geographic phenomenon that exists on the earth. GIS is a technological tool designed to evaluate the spatial data that is referenced by geographical coordinates by taking advantages of an integration common database operations including query and statistical analysis with the unique visualization and geographic analysis. These capabilities distinguish GIS from other information systems and make it valuable to public and private enterprises for evaluating events, predicting outcomes, and planning strategies [7]. For instance, by utilizing GIS for environmental modeling air quality, the output of the pollutant records will be provided in the form of spatial records.

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Pollution sources are spatially dispersed or they may be point sources such as large industrial stacks line sources (e.g., highways), and area sources (e.g., urban areas), or power plants [8].

The prediction result mostly can be shown by a map of the value of a given environmental descriptor (e.g., air pollutant concentration) at any location or region within the study area. In the literature review will be discussed about some of the researches have been done in applying GIS in transportation related air pollution modeling. Recently, several attempts have been made for using GIS to map traffic related pollutions and determining pollution patterns in urban areas. While, some of the early forerunners of GIS in late 60's and early 70's were transportation scientists, selecting transportation route to minimize the route's impact on the environment is one of the recent application of GIS as a part of the Comprehensive Environmental Impact assessment (CEIA) process[2]. , the first prevalent use of GIS in transportation research (GIS-T) actually took place in late 80's. However, in early 90's the application of GIS in transportation related air quality modeling and management was started [16]. Bruckman in 1992 recognized many advantages of using GIS in the preparation of mobile emissions model input data such as fleet activity, fleet characteristics, and operating characteristics. Moreover, Souleyrette in 1992 identified the capability of a GIS to manage the complex spatial data often required to refer transportation and air quality analysis issues. They improved a model that investigated the connection between CO concentrations and traffic characteristics including vehicle miles traveled, refueling stations locations, and wind patterns. Another research effort introduced an activity-based model for travel demand forecasting that merged household activities, land use patterns, traffic flow, and regional demographics in a GIS. The model has capability to provide output for analysing problems related to the Clean Air Act Amendments [15]. In another related study, Briggs in 2000 have described about a variety range of line source dispersion models that may be used for the mapping objective and concluded that, generally the performance of line source models has not been useful under urban conditions. Instead, they recommended a GIS based regression-mapping method to model and display spatial patterns of traffic related air pollution for estimating exposure as part of epidemiological studies. Clarmunt in 2000 introduced a new GIS framework for real time integration analysis and visualization of urban traffic data. The framework was established on an interaction between the spatial –

temporal database and visualization level and between the visualization and end- user levels. Ziliskopoulous and Waller in 2000 defined an internet based GIS that get together spatio –temporal data, models and users in a single affective framework, to be utilized for a broad range of transportation applications [1].

However, there has been less consideration given to environmental modeling of networks, especially future flows on networks. Many transport network planning to date still fails to take into account environmental impacts at the time future road network scenarios are being modeled and evaluated despite the potential advantages of integrating transport planning with air pollution management strategies such as: IRTP and SEQRAQS .The planning stage is more efficient through consideration of alternatives, which improve the urban air quality resulting from continued growth in vehicle numbers, increased trip lengths, congestion and increased fuel usage. J.K. Affum in 2003 developed the method for integrating air pollution mathematical models and scenario testing with GIS. He adapted Transport Add-on Environmental Modeling System (TRAEMS) in order to represent Co emission in Brisbane.

II. MODEL SELECTION

Transport Add-on Environmental Modeling System (TRAEMS) is a GIS-based environmental modeling system which is used by transportation planners to evaluate the environmental effects of road traffic plan. The system utilizes the capability of GIS to integrate information about traffic which is usually from travel-forecasting models with land use information, to provide the input data that is used in many different models to estimate pollution from a road traffic system, and the energy consumption of that system. TRAEMS promotes this integration and allows transport and environmental planners to analyse the environmental effects of different road transport network scenarios that are being developed and tested [11].
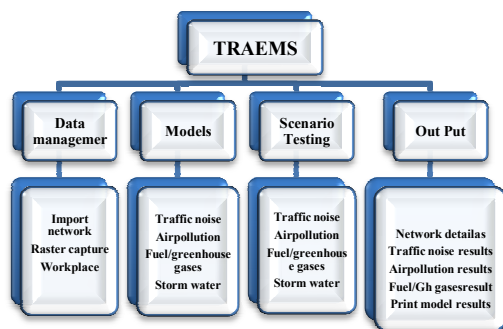

Fig.1 Main components of TRAEMS

After reviewing the TRAEMS definition we are going to introduce and compare some of the models using in TRAEMS in order to choose the most proper model to estimate GHG emission level form the transport section in Melbourne.

A. The Air Pollution Module

The air pollution module in TRAEMS estimates the emission levels and worst-case near field concentration levels. carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), sulfur dioxide (SO2), greenhouse gas carbon dioxide (CO2), and particulate matter in the form of PM10 are the pollutant considered .The emissions for each pollutant are stated as link-based emissions levels emitted by traffic on the modeled road network (in mass per unit length of roadway) and can be utilized and displayed for each link or transformed to grid-based emissions. The study area is divided into cells of size indicated by the user, and the emission levels in each grid cell for each pollutant which is computed by summing the emissions from the individual roadway links within the cell.

The emission rate, or factor, computed as pollutant mass per kilometre travelled per vehicle, and the total amount of traffic are used to Estimate air pollution levels from road traffic [16], [12]. TRAEMS includes alternative methods for estimating air pollution emission levels for each pollutant: the speed-based approach and the road type- based approach. For each method, the TDM network is considered as an independent line source with constant traffic variables for each road link or segment. The TDM output provides Traffic variables including speed, traffic volume, road type, road length, etc. In order to compute air pollution emissions; it is required to classify the vehicle fleet by type of vehicle and fuel used. Because information on vehicle classification of this type is usually not available for each link, is supposed to be uniform across the entire transport network and is taken to be the same as the fleet distribution in the area under consideration.

Generally the components of the air pollution module implemented include [11]:

1. Estimation of the amount of green gas emission like CO, HC, and NOx emissions (in grams per of roadway) produced by the traffic on each link.

2. Division of the study area into grid cells which size indicated by the user and then calculating the total emission levels in each grid cell for each pollutant.

3. Estimation of the near-field impacts on the computed link-based emissions. TRAEMS utilizes the Gaussian based CHOCK distributed model for forecasting air pollution concentration levels near roadways [6] to compute the pollutant concentration levels to the first row of sensitive land uses and dwellings for each link. TRAEMS supposes that chemical reactions involving the pollutants are negligible.

4. Using the ATDL dispersion model [9] to compute the concentration levels of each pollutant. In other hand, using Area-wide dispersion of the grid-based emission levels to provide the final concentration levels over the entire area.

5. Comparison of grid-based emission loadings and the near-field and area-wide concentration levels in order to assist transport planner to evaluate different transport planning scenarios.

a.   The Speed-based Approach

This approach estimates the emission levels along each link of the road network, with link-based speed used to adjust city-wide emission factors. it uses traffic data to estimate emission factors (vehicle s travelled by type of vehicle and speed) .it was adapted first in the USA [16] and New South Wales [13] . In order to estimate emission factors by this method ,the vehicle fleet will be classified into three main types based on the vehicle and fuel used:

- Light-duty petrol vehicles (cars and light commercial vehicles(CV))
- Heavy-duty petrol vehicles (medium and heavy CV and buses)
- Heavy-duty diesel vehicles (medium and heavy CV and buses)

The total emission levels for all vehicle types are calculated from "(1),"

$$E = PF(x) \qquad (1)$$

Where E is estimated speed-based emission in g/km; P is city-cycle emission factor in g/km, which is different for each pollutant and vehicle type; $F(x)$ is speed-related function depends on pollutant and vehicle type.

The capability of this model to take into account differences in speeds ,network and the different type of vehicles and fuel used, allow it to be used comprehensively in the network disaggregate levels which are usually employed in TDM.

b.   The Road-type-based Approach

In this method, the road network is classified into highways, freeways, free flow arterial roads, congested freeway, arterial roads and residentially minor roads. The emission factors are then calculated for each vehicle type by fuel type and road type based; in this approach the travel speed is considered a constant for each road type. The road-type-based emission factors have been adopted from the 1993 Air Emission Inventory [14] as the default emission factors in TRAEMS. The approach depends on which type of emission factors is available.

B.   Energy Consumption and Green House Gas

In this study, the amount of green house gas emission (CO_2 for this study) is calculated based on the total fuel consumed for each type of fuel (petrol, diesel, LPG). There are two models available for estimating fuel consumption from road traffic which was reported by Bowyer in 1985. Depends on the scale and location of the network under investigation we can choose appropriate method.

a.   Running-speed Model

The running-speed model estimates fuel consumption within 10–15% of observed values for travel over road sections of at least 0.7 km length [5]. So, this is appropriate model which is mostly used for strategic planning at the regional and city-wide levels because in these areas only the main roads are modeled and length of links in the network are considerably long. This model is function of the link length, traffic flow, running speed, and stop time. The energy consumption is calculated individually during periods when the vehicle is stopped and when travelling at the link level, and then accumulated to determine the total network energy use. The mean fuel consumed per unit distance (Es in ml/km) is estimated from "(2)," [5].

$$Es = max \{ fr + \frac{\alpha ti}{Xs}, \frac{\alpha ts}{Xs} \} \qquad (2)$$

where Xs is length of road section in km; ts is the travel times along the road section; ti is the idle or stopped time in seconds; α is idle fuel consumption rate in ml/s; fr is function of vehicle mass, engine efficiency, and kinematic parameters and it is per unit distance (in ml/km) excluding stopping time effects.

The running speed on each link is calculated to encompass the impact of acceleration and deceleration delays due to stops and slowdowns along the road section and exclude the consequences of stopped time. Running speed , and idle time can be stated as a function of the average travel speed [5]. This model is useful for the network levels that only average speeds on links are known.

b.   Average-speed Model

The average-speed model is the method which computes the total network energy use based on the average network speed. It is known to give reasonably accurate estimates of fuel consumption over road sections with average speeds less than 50 km/h. It is therefore suitable for use in planning at the local levels, where dense networks representing all the roads in the network are modeled, link's length is short, and speeds are generally low. Data inputs for average-speed model are the total distance travel and average travel speed over the network. The fuel consumed per unit distance fx in ml/km "(3)," states the average-speed model [5].

$$fx = \frac{fi}{vs} + cK \qquad (3)$$

Where vs is average network speed of travel in km/h; fi is the idle fuel consumption rate in ml/h ,c is a regression coefficient derived and K is an adjustment factor which allow for varying vehicle parameters in the vehicle fleet. The constant term (cK) takes into account the drag, inertia and effect of grade on fuel consumption.

Then we will multiply the computed fuel levels for each fuel type by the suitable greenhouse gas emission factor to calculate the total CO_2 gases emitted over the entire network.

C. Comparison Different Methods

Table I represents the comparison among different method for calculating green house gas emissions.

TABLE I
COMPARISON DIFFERENT MODELS

	The speed-based approach	The road-type-based approach	Running-speed model	Average-speed model
GHG calculation Method	GHG emission directly	GHG emission directly	GHG based on fuel consumption	GHG based on fuel consumption
Classification	The vehicle fleet is classified	The road network is classified	-	-
Input data	Traffic data such as vehicle s travelled by type of vehicle and speed	Fuel type & road type Travel speed is constant	the link length, traffic flow, running speed and stop time	Total distance travel and average travel speed over the network
Useful area	the network disaggregate levels	Area with different road network	Useful for regional and city-wide levels and where average speeds on links are known	Useful for the local levels

By comparison of various factors in these four different models and considering the limitation having in a data gathering the average speed model is selected for this specific study.

III. CASE STUDY

Mode of travel (the type of vehicle) can make a big difference in terms of greenhouse gas emissions. There are various vehicle types including: bicycle, city bus, Train, Tram, car. The different modes generate different amounts of greenhouse gas emissions for every travelled. Walking and riding bicycle produce no greenhouse gas emissions at all, no matter how far is destination. In the 8th Cairo International Conference on Energy and Environment, It intended to prove that Melbourne's trams emitted 1.23kg of carbon dioxide (CO2) per passenger, whereas cars emitted just 0.25kg CO2 per passenger. Trains emissions also are as bad as cars; only buses came out a head [3]. Many people prefer to travel to work by car, usually without anyone else in the car. This is an important source of greenhouse gas emissions, urban smog and other air pollution problems. Our purpose is to measure amount of CO2 emission related to these journeys. According to fig.2 gathering by ABS (Australian Bureau of Statistics) a number of people who travel to work by car were increased from 1996 to 2006.
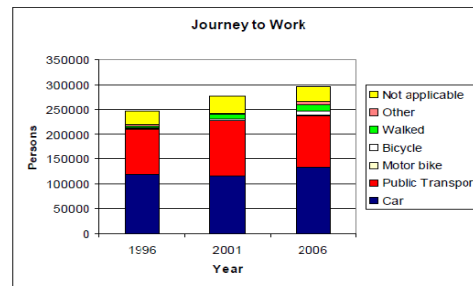

Fig. 2 Journey to work from 1996 to 2006

Vehicle types also have great impact on the amount of green gas emissions. The amount of green gas emissions are different based on the type of vehicles used including light commercial vehicle (CV), medium and heavy CV and buses, etc. Table II gives an indicative guide to annual CO2 tailpipe emissions from petrol vehicles travelling 15,000 km annually.

TABLE II
ANNUAL CO2 TAILPIPE EMISSIONS FROM PETROL VEHICLES

Fuel Consumption	AnnualCO2 Emissions
6 L/100km	2160 kg
8 L/100km	2880 kg
10 L/100km	3600 kg
12 L/100km	4320 kg

Fuels differ in the amount of carbon and energy they include as well as other characteristics, with implications for fuel economy and greenhouse emissions. The table III shows the amount of CO2 emitted from the exhaust for each litre of a specific fuel covered by the calculator.

TABLE III
AMOUNT OF CO2 EMITTED FROM THE EXHAUST

Fuel Type	CO2 Emissions
Petrol	2.24 kg
LPG	1.5 kg
Diesel	2.66 kg

It might seem strange that a greater weight of emissions is generated than the weight of a litre of fuel, but this is mainly because of the addition of oxygen from the atmosphere to the fuel during combustion to form CO2, it also matters how much fuel is consumed to travel a given distance. This research focused on calculating green gas house emissions from people who travel to work by car. Green gas emission is calculated for 78 suburbs in Melbourne by making some assumption such as all cars are Small medium car (4W), and 15000 KM annual distance travelled per year for each car ,also we assume the occupancy one for each car. Then the amount of green gas emission is calculate for different fuel types by supposing all cars use same fuel type. Then ArcGIS is used for analysing and displaying results as thematic maps.

A. Data Collection

First step in every research is gathering a data. A fundamental goal of ArcGIS is to work with our file-based data, DBMS data and also with GIS web services from ArcIMS, ArcGIS Server, and others such as OGC WMS.

ArcGIS gives us the capability to work with a large number of data sources. In this research, we use data for percent of people who travel by car and population density for each suburb in shapefile formats from Australia Bureau Statics (ABS) data bases. In order to reach the number of people who travel to work by car in each suburb, these steps are done:

Firstly, population for each suburb is calculated by multiplying area of each suburb (which is available from Arc GIS toolbars) by population density.

Population density= people per square

Population (for each suburbs) =Population density (each suburbs) × Area in square (each suburbs)

Data are for 2006 and we want to calculate green gas emission for 2031. Therefore we have to forecast population in 2031. Forecasts are available for each year from 2006 to 2031.According to The Melbourne LGA's resident population grew by almost 3600 persons (or 4 per cent) in the 2008-09 year and has grown by 15 per cent since 2006. Moreover, table IV shows the population growth from 2006 to 2031.

TABLE IV
POPULATION GROWTH FROM 2006 TO 2031

Brief statistics	City of Melbourne
Forecast population 2010:	94,851
Change between 2010 and 2031:	57,778
Average annual percentage change between 2010 and 2031 (21 years):	2.29%
Total percentage change between 2010 and 2031 (21 years):	37.85%

At first, we forecast population by using the population growth rate from 2006 to 2010 (4% annually). Then we consider population growth rate 2.29% per annum for period of 2010 to 2031 and forecast population for each suburb. Future population calculates by blew equation.

$P_T=P_0 \times e^{(r \times t)}$

P_T=Future Population

P_0 =Starting population

r = growth rate

t= number of years

where e is a constant equal to 2.71828

Percentage of the people who travel to work by cars related to many factors such as retirement, business growth, employment growth, age, etc. it is hard to forecast this percentages for 2031, so we assume that it remains constant from 2006 to 2030.The shapefile data related to percent of people who travel to work by car in 2006 is available from ABS website. By multiplying percentage of the people who use car and population in each suburb we can gain the number of cars in each suburb which are used for traveling to work.

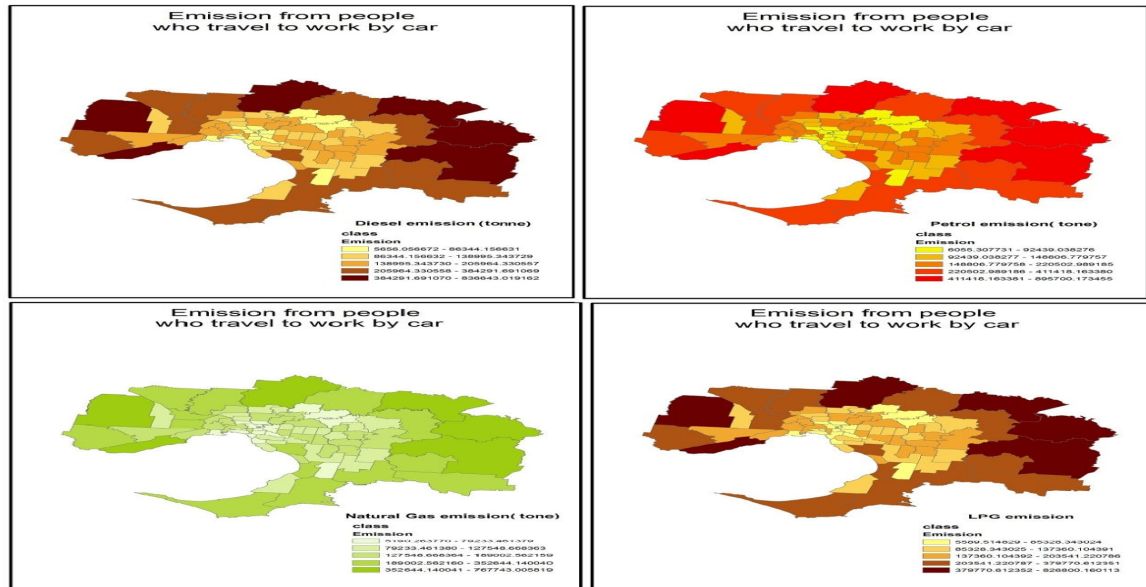Number of people who travel to work by car (each suburbs) = Population× Percentage

Number of car= Number of people (considering occupancy one for each car)

B. Modeling Green House Gas Emission

As mentioned before, there are several methods which can be used for modeling GHG emissions. In this research, we consider different fuel types and calculate the fuel consumption for each car by using average speed method. Running speed method is more comprehensive than average speed method but because the lack of data about the link length, traffic flows, running speed , and stop time, it can't be used in this case study. In order to use average speed model we make some assumption that all cars are small medium cars (4W) and they travel 14000km per year, also we suppose that the average network speed is 50 km/h therefore the amount of GHG emissions would be the same for all car per annum. Note that we just consider CO_2 from green house gases.

C. Integrating Models with GIS

By utilizing GIS environment for modeling air quality, the output of the pollutant records will be provided in the form of spatial records. We use ArcGIS desktop 9.3 for visualizing and analysing the amount of GHG generated in each suburb by people who travel to work by car and calculated with air pollution models. Our purpose from this case study is to answer two questions: "Which area has emitted more GHG?" and "What we can do to mitigate green house gas emissions?" For this reason ArcGIS applied to display the output from emission models in each suburb as a thematic map. Also we comprise emission from different fuel type (Petrol, Diesel.LPG, and Natural Gas) to identify which one has less GHG emissions. Fig.3 shows the output results from ArcGIS desktop 9.3.
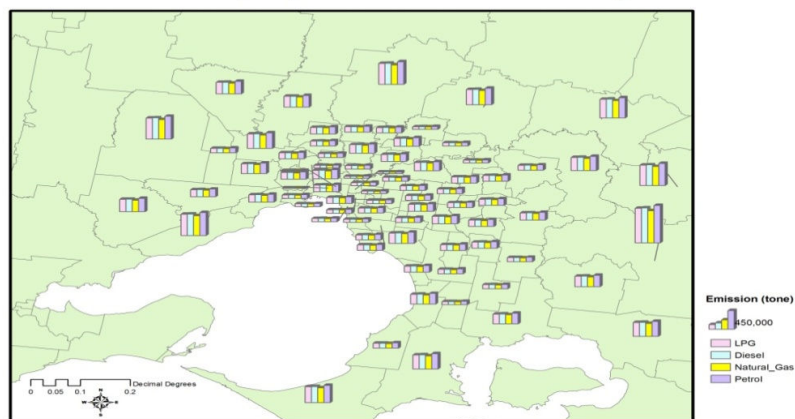
Fig. 3 Arc GIS outputs

Results gained from analysing result maps included:

- LPG produces lower green house gas emissions per litre of fuel consumed than petrol, but also contains lower energy content.
- Diesel green house gas emissions per litre are higher than petrol but engines designed to act on diesel tend to be far more fuel-efficient than petrol engines.
- Natural Gas is the most efficient fuel and it produces less green house gas emission.
- The amount of green house gas emission is in a radial growth outward the city.

According to analysis, if we continue our current transportation disciplines, we will face a serious problems regarding to GHG emissions in 2031.
There are some suggestions to reduce this amount of GHG:

- An urban and rural development that maximizes access to housing, jobs, shopping, services, and leisure time without requiring traveling long distances in individual light-duty vehicles to avoid the growth in emissions . Two examples of urban areas whose development policies supported land uses and development patterns less dependent on automobiles than any of their regional neighbors are Singapore in Asia and Curitiba in Brazil.
- Shifting transport to modes with low-carbon emission per unit of transport produced. For instance shifting transport from car or light truck to bus, rail, or metro,

or maintaining high shares of those modes. Recent developments in bus rapid transit in Jakarta have shifted travelers from individual cars to faster buses.

- Improving operational efficiency and traffic, also selecting different fuels, more efficient vehicle technologies and less powerful, lighter vehicles, which are true "CO2" mitigation measures to reduce emissions in existing and future vehicles and traffic. The People's Republic of China's (PRC) conduct new fuel economy standards for light-duty vehicles, like those in Japan, and it leads to manufacturing and purchase of less fuel economic vehicles.

- In Australia all new light vehicles sold are required to display a Fuel Consumption Label on the front windscreen. This encompasses all passenger cars, four wheel drives and light commercial vehicles up to 3.5 tonnes gross vehicle mass. The label shows the vehicle's fuel consumption in litres of fuel per 100 s (L/100km) and its emissions of carbon dioxide (CO2) in grams per (g/km). The results are established on a standard test procedure therefore consumers can reliably compare the performance of different models under the same test conditions.

IV. CONCLUSION

The importance of emissions from the road transport sector (such as air pollution, noise, etc.) has grown substantially in recent decades. Transport plays critical role in the increasing share of energy related CO2 emission [10]. Therefore, there is a great interest to reduce in GHG from transportation sections. GIS technology has brought new horizons in transportation planning and especially in travel demand modeling. A transportation planner would need to convey ideas and present implications of planning decision for non-planners visually, GIS provides the tool which can help them doing this process. Also it provides communication tools between the public and transportation professionals. GIS technology is widely used for solving environmental, natural resource, urban planning problems, energy efficiency planning and now modeling air pollution and GHG emissions. There are many advantages of using GIS tools for modeling GHG emission from transportation sections:

Multiple scenarios can be run by having the data in the GIS. It helps to evaluate and assess the environmental impacts of different transport planning scenarios. This may use to forecast future changes related to the existing state of the environment like changes between two time periods or comparing the impacts of different future scenarios such as changes between different transport proposals for the same time period which has been done in this paper.

The benefit of GIS compared to other information systems is the high power of analysing of spatial data and handling large spatial databases. But we need more time and money for collecting data which are essential for modeling GHG emissions from transportation sections including: number of vehicles, type of vehicles, for each vehicle type of fuel that is

consumed, etc. Therefore, local planning agencies should incorporate energy efficiency goals into land use planning by using advanced technology available that can improve the decision-making process and facilitate the public comment.

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