Mitigation of road transport carbon emissions in Argentina

S. Enrique Puliafito*

Consejo Nacional de Investigaciones
Científicas y Técnicas (CONICET),
Grupo Estudios Atmosféricos y Ambientales,
Universidad Tecnológica Nacional,
Rodríguez 273, 5500, Mendoza, Argentina
and
Facultad Regional Buenos Aires,
Universidad Tecnológica Nacional,
Medrano 951, 1179, Buenos Aires, Argentina
Email: epuliafito@frm.utn.edu.ar
*Corresponding author

Fernando Castro and David Allende

Consejo Nacional de Investigaciones
Científicas y Técnicas (CONICET),
Grupo Estudios Atmosféricos y Ambientales,
Universidad Tecnológica Nacional,
Rodríguez 273, 5500, Mendoza, Argentina
Email: ferhcastro@gmail.com
Email: david.allende@frm.utn.edu.ar

Paula Castesana

Facultad Regional Buenos Aires,
Universidad Tecnológica Nacional,
Medrano 951, 1179, Buenos Aires, Argentina
Email: pcastesana@gmail.com

Abstract: This study describes a model to calculate energy consumption and CO_2 emissions into the atmosphere by the road transport sector in Argentina from 1960 to 2050. The model analyses different mitigation scenarios to determine effective options to produce a sensitive decrease in carbon emissions. The results of this study show that by reducing the use of private vehicles while increasing the use of public transport, combined with a high rate of conversion of gasoline vehicles into hybrid electric vehicles, CO_2 emissions could be reduced up to 9% (or 7.7 Tg). However, without further technological improvements and higher modal transfer to low carbon/less energy-intensive modes, it will be difficult to obtain emission stabilisation of transport emissions under 80 Tg by 2050, which represent approximately twice the current values.

Keywords: environment; road transport; mitigation; carbon emissions; pollution; hybrid vehicles; Argentina.

Reference to this paper should be made as follows: Puliafito, S.E., Castro, F., Allende, D. and Castesana, P. (2014) 'Mitigation of road transport carbon emissions in Argentina', *Int. J. Environment and Pollution*, Vol. 56, Nos. 1/2/3/4, pp.129–152.

Biographical notes: S. Enrique Puliafito received his Bachelor in Electronics and Electricity (1983) from the University of Mendoza, Argentina, and PhD in Engineering (1989) from the University of Braunschweig, Germany. He has participated in research projects on topics related to the determination of stratospheric ozone and tropospheric water vapour at institutes in Germany, Switzerland and the USA. He is an independent Researcher of CONICET and Professor at the National Technological University in Argentina, specialising in environmental issues, with focus on monitoring and modelling of air quality.

Fernando Castro received his Bachelor in Industrial Engineering (2003) from the Universidad Nacional de Cuyo in Mendoza, and his Master in Environmental Management from the Scuola Superiore Sant'Anna, Italy (2005). He is currently finishing his PhD in Engineering in the Cuyo National University. He has been involved in research projects with focus on monitoring and modelling of air quality. Currently, he is working to quantify vehicular emission in Argentinean cities.

David Allende graduated with a Degree in Chemical Engineering at the Universidad Tecnológica Nacional (UTN) in 2001 and received his PhD degree in 2011 at the Engineering Faculty of the Universidad Nacional de Cuyo both in Mendoza, Argentina. Currently, he is a Research Assistant at UTN working on regional scale Air Quality Modeling. His current area of work relates to the influence of anthropogenic aerosols in the hydrological cycle.

Paula Castesana received her Bachelor in Chemical Engineering (2004) Universidad Tecnológica Nacional, Buenos Aires and her PhD degree in 2014 from the Universidad Nacional de Cuyo in Mendoza, both cities in Argentina. She is a Research Assistant at UTN Buenos Aires and has been involved in research projects with focus on estimating carbon emissions using agent-based models. Currently, she is working on preparing national emission inventories in Argentinean cities.

1 Introduction

In recent decades, the rapid growth of traffic, industry and energy consumption worldwide has contributed to increasing air pollution, noise and emissions of greenhouse gases (GHGs). In Latin America (and Argentina), transportation problems arising from this rapid urbanisation have increased motorisation, traffic jams and accidents to the detriment of public and non-motorised transport (i.e., walking and biking). Mobility and accessibility are strongly related to economic growth and personal freedoms; therefore, any mitigation strategies suggested should take into account a realistic framework of current mobility needs. A literature review on transportation and mitigation shows controversy about the effectiveness of increasing mass transit transportation systems (Litman, 2007; Hensher, 2007; Poudenx, 2008; Bouf and

Hensher; 2007). Some scholars (O'Toole, 2004; Stopher, 2004; Taylor, 2004, Winston and Maheshri, 2007) point out that in developed countries, including Europe and the USA, mass transportation systems have systematically failed for several reasons, including growing state grants for maintaining the system in operation and decreasing modal share over the use of private cars. Suburban rail systems, streetcars, subways, LRT and BRT have only provided greater access to public transport to low-income and non-motorised sectors, but have not resulted in new mass transit users. Despite the strong education and awareness campaigns promoting social and environmental benefits of public transport use, and the increasing car tax burden, private car users hardly leave their vehicles (seen as private goods) in order to use public transport (seen as a public and social good). Although Latin American cities face similar problems, there might still be some opportunities for low carbon transportation options.

In this study, we developed a top-down model to calculate fuel consumption and CO_2 emissions into the atmosphere by the road transport sector (TS) in Argentina. We followed a similar approach to that presented in Hao et al. (2011), which describes options of GHG emissions mitigation for the passenger vehicle fleet, and in Hao et al. (2012), which evaluates the CO_2 emissions of the on-road truck sector, both in China. Other related emissions transport models in the literature are described in Yan and Crookes (2009), and Bastani et al. (2012).

The model here proposed is set to test several mitigation scenarios for years 2010 to 2050. The main purpose of this study is to provide an answer to the following questions: Which is the most effective subsector to produce a sensitive mitigation policy for Argentina? What are the windows of opportunity to stabilise and reduce CO_2 emissions? Will technological changes produce their own stabilisation of CO_2 emissions within the period of the model? The methodology applied and the analysis developed in this study in connection with Argentina is easily applicable to other developing countries undergoing rapid development.

2 Materials and methods

We performed an updated GHG emissions inventory of the TS in Argentina from year 1960 to 2010. A model was developed to analyse future trends of energy demand and GHG emissions in the road TS of Argentina up to year 2050, considering several possible national strategies (Argentina, 2007). Emissions were calculated based on an activity approach, and calibrated against historical records of fuel sales, vehicle registration, freight and public transport data. A Monte Carlo sensitivity analysis was also performed to evaluate the effect of parameter uncertainties on the model results.

2.1 Model structure

The amount of CO_2 emitted into the atmosphere by the TS is directly proportional to the fuel consumption of motor vehicles and the carbon content of each fuel (IPCC, 2007). Although Energy State Agencies generally keep records on fuel sales, they do not usually collect information regarding vehicle fuel consumption and efficiencies by fuel type. Therefore, other transportation indexes are used in GHG accounting, such as vehicle kilometres travelled (VKT) for motor vehicles, person kilometres travelled (PKT) for transit modes, or transported ton-kilometre for freight (TKT). This information is used in the so-called ASIF methodology (Schipper et al., 2000), which combines *activity* $A(j, n, y)$ like VKT, PKT and TKT for year y, mode n and fuel type j; *modal structure*: $S(n)$ or shares by mode, with modal energy *Intensity* $I(n)$ and a *fuel* emission factor $F(j)$:

$$C(y) = \sum_{y} \left[A(j,n,y) \times S(n) \times I(n) \times F(j) \right] \tag{1}$$

where C (g/year) is the total (annual) emission of carbon dioxide at year y for all types of fuels j considered. The modal energy intensity $I(n)$ represents energy use for each mode n (i.e., MJ/passenger-km or MJ/ton-km). $F(j)$ (g/MJ) is the carbon content for each particular fuel. The product $A \times S \times I$ will give the energy consumption E by fuel, mode and activity (i.e., energy from diesel fuel consumed by buses in public transportation). Emissions of other GHG gases are typically reported in terms of CO_2 equivalent to provide a common unit of measure.

Road transport calculations per sector activity were divided into three main modes: VKT for private cars, PKT for public transportation and TKT for freight modes. These activity modes correlate with two main national variables: population (P) and gross domestic product (GDP). Figure 1 shows the data for population and GDP for Argentina for years 1960 to 2010; and Figure 2 shows the strong connection between the per capita GDP and the motorisation rate, expressed in number of vehicles per 1,000 inhabitants.

Figure 1 Main drivers in Argentina TS: population (million inhabitants) and GDP billion USD

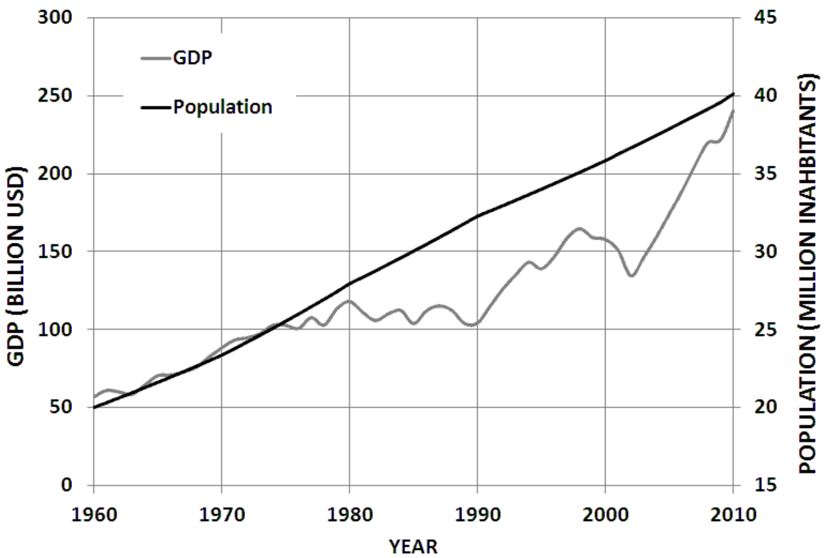
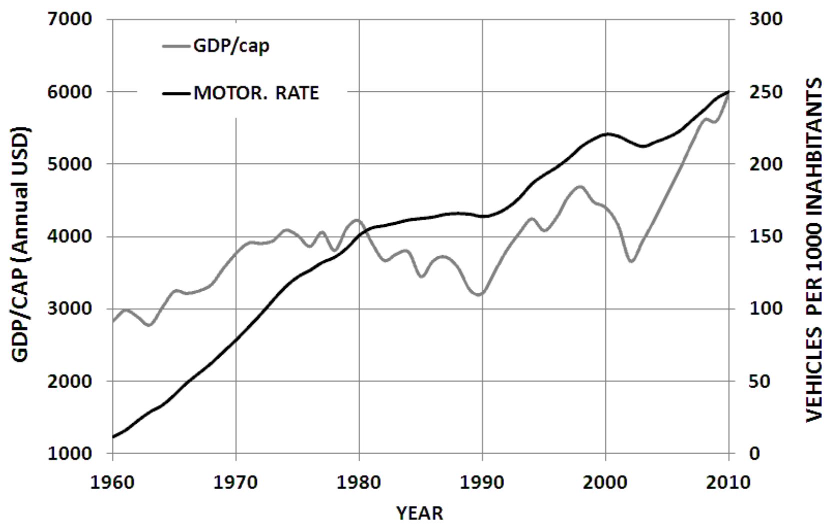


Figure 2 Main drivers in Argentina TS: per capita GDP (USD) and motorisation rate (vehicles per 1,000 inhabitants)



2.2 Characteristics of the on road vehicle fleet

Vehicle fleet data in Argentina are organised in several groups: light passenger cars (LPC), commercial light duty-load vehicles (CLD < 2 tons); light-duty truck (LDT < 2 tons); medium-duty truck (MDT < 4 tons); semi-trailer towing-truck (SST < 20 tons); heavy-duty truck (HDT >20 tons); gasoline medium-duty truck (GMDT < 4 tons) and buses. With regard to fuel type, LPC and CLD use gasoline, natural compressed gas (NCG for vehicles) and diesel; MDT uses mainly diesel, but a small proportion use gasoline; HDT, SST and buses use mainly diesel. LPC and LDC are further subdivided into private cars and taxis based on their use. For the calculation of scenarios, we also included hybrid electric vehicles (HEV).

The active annual fleet V (number of vehicles) is calculated as a function of the GDP G and population P (Figure 3). New vehicles NV at year y are calculated as follows:

$$NV(y) = {dV}/{dt}(y) = a_1 \, {dG}/{dt} + a_2 \, {dP}/{dt} \tag{2}$$

where a_1 = 40 veh./million USD and a_2 = 400 veh./thousand inhabitants. Total accumulated vehicles $V(y)$ at year y is the sum of registered vehicles at year $V(y-1)$ plus new vehicles $NV(y)$ minus scrapped vehicles $SV(y)$:

$$V(y) = \sum_{\tau=0}^{\tau=y-1} V(\tau) + NV(y) - SV(y) \tag{3}$$

The distribution of vehicle age in a given vehicle fleet is important for the calculation of fuel consumption in the fleet (Figure 4). Each year, a new cohort of vehicles will enter the active fleet, and that cohort is defined by its fuel efficiency and a mix of fuels. Also, each year, a fraction of the fleet is deregistered. The survival probability rate B

($SV = 1 - B$) follows a Weibull's distribution (with coefficients b_1, b_2 and b_3 in Table 1) as per Mobile6 (2001); $\tau = y - y_0$, y being the present year; y_0, a past reference year and k, the vehicle class as defined above.

$$B(y, \tau, k) = \left\{ b_1 \times \exp\left(-\frac{\tau}{b_2} \right)^{b_3} \right\} \tag{4}$$

Figure 3 Changes in GDP (black line) compared to new vehicle registrations (grey line with circles) for Argentina (1960–2010)

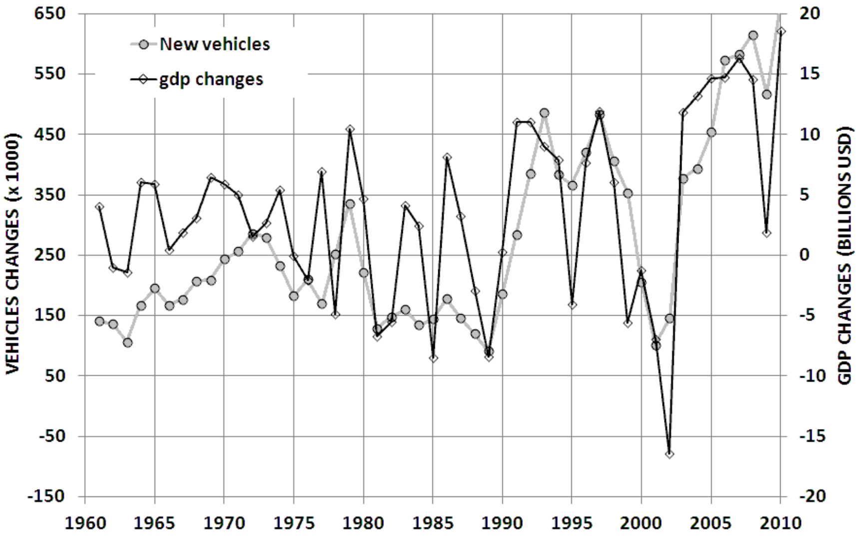
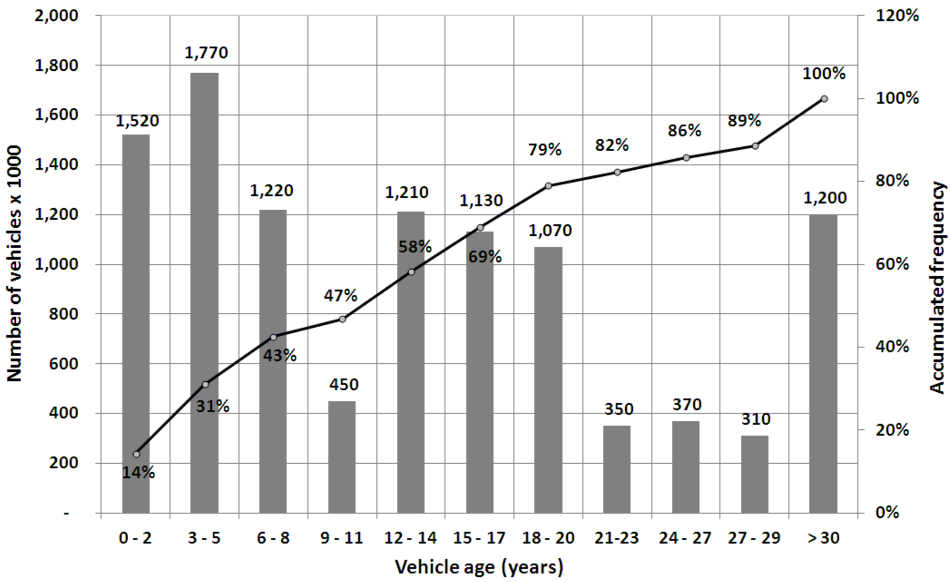


Figure 4 Distribution of the active vehicle fleet age for Argentina in 2010



A fraction Z of the fleet corresponds to vehicles with fuel or technology j: gasoline, diesel, NCG, hybrid, biodiesel or any new vehicle technology. The share of each technology is introduced in the model by:

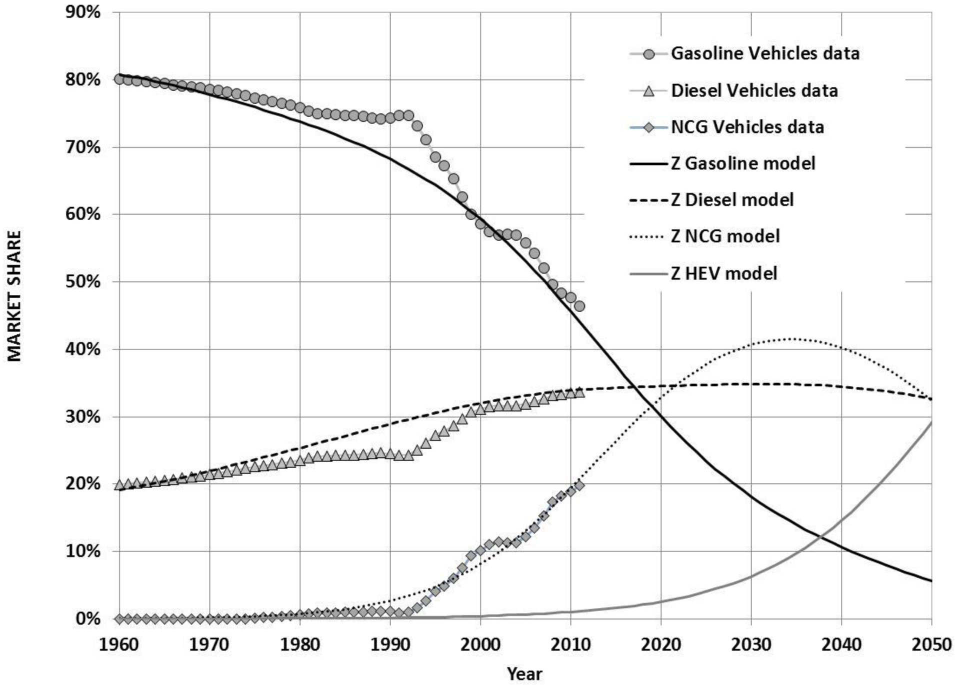
$$V(y, j) = V(y) \times Z(j) \tag{5}$$

where $V(y, j)$ is the amount of vehicles at year y, with technology or fuel j. The market share Z (%) of technology j is calculated by solving the logistic diffusion equation generalised for all technologies (Bass, 1969):

$$\frac{dz}{dt}(j) = q(j)Z(j)\left(1 - \sum\nolimits_i Z(i)\right), \, i = 1, ..., n; \, i \neq j \tag{6}$$

where (qZ) are the adopters of the technology j, and $\left(1 - \sum Z\right)$ are the yet non-adopters, which include all other alternative technologies i (Table 1 and Figure 5). In the model, a fraction of LPC is converted from gasoline into NCG following a market-share penetration scheme. A similar scheme is followed for HEV.

Figure 5 Vehicular market share (data: symbols; and model: lines) for Argentine vehicles



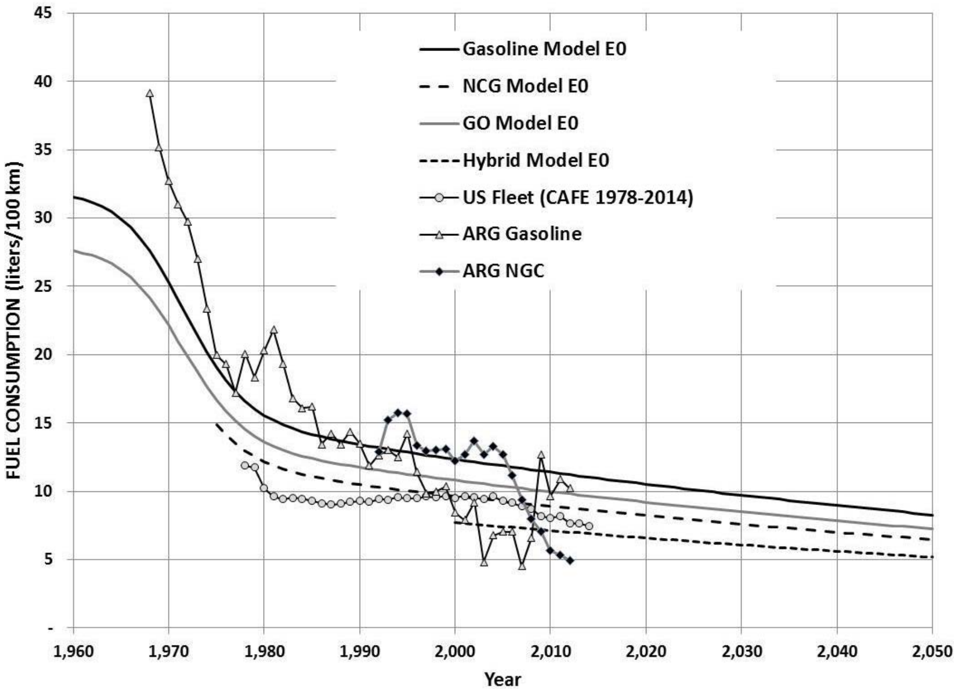
Notes: Data (symbols: circle. gasoline vehicles –GV-; triangles diesel vehicles –DV-; diamonds: natural compressed gas vehicles – NCGV) from 1960 to 2010; model (lines: continuous black: GV; discontinuous lines: DV, dotted lines: NCGV) from 1960 to 2050 (see also Table 1).

Annual mobility M is estimated for each cohort year and for each type of vehicle and fuel following the variations in GDP:

$$M(j, k, y) = a_3 G(y) + a_4 \tag{7}$$

where a_3 and a_4 are vehicle and fuel dependent (i.e., a_3 = 5 km/USD year, a_4 = 10,000 km for private gasoline cars: PGC). Diesel and NCG car activity was 25% higher than PGC. Taxis had four times as much activity as PGC, and commercial light duty vehicles had twice as high activity as PGC. Mobility decreases for older vehicles following a 0.1% annual reduction rate.

Figure 6 Evolution and projected fuel economy of Argentine passenger vehicles



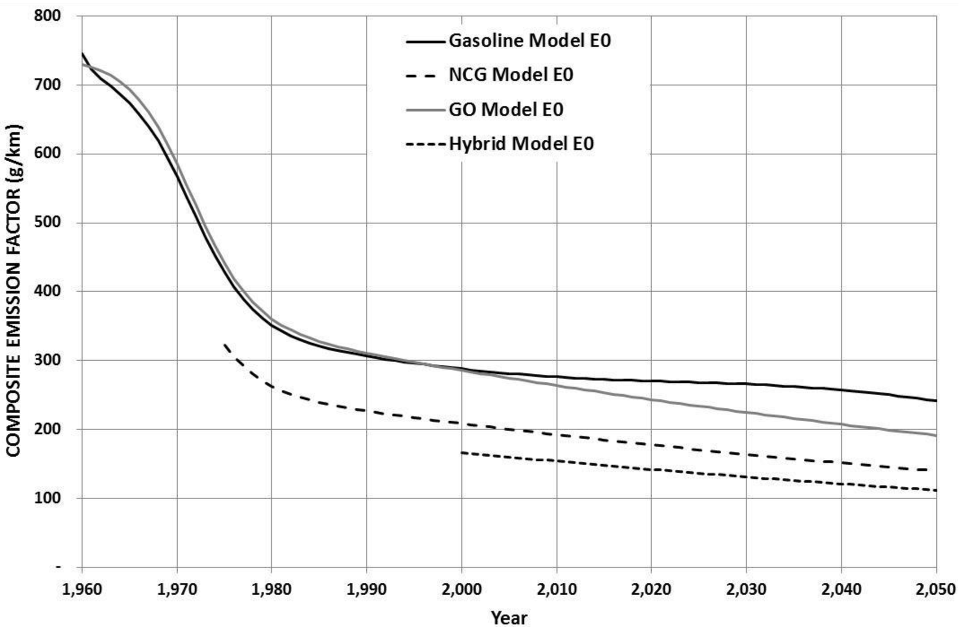
Notes: Lines: continuous black: gasoline; grey line diesel: discontinuous lines: NCG; dotted lines: hybrid vehicles). Symbols: black line with grey triangles: estimated Argentine gasoline consumption rate based on 13,000 annual km per vehicle; grey line with black diamonds: estimated Argentine NCG consumption rate based on 13,000 annual km per vehicle; black line with grey circles: US passenger fleet fuel consumption.

Fuel efficiency evolution and its corresponding emission factors are presented in Figures 6 and 7, respectively. Data from 1975 to 2009 are taken from EPA (2009), NHTSA (2014) and also compared with Bastani et al. (2012). Fuel efficiency L is calculated using a generalised logistic function, which takes two different slopes of technological fuel economy improvements into account: 1960 to 2000 and 2000 to 2050. During the first period, there was a substantial improvement in efficiencies and size of engines. However, as new features were incorporated into vehicles (e.g., air conditioning, safety, comfort, 4 × 4 wheel drive), there was an increase in energy consumption, thus decreasing the fuel/emissions efficiencies of cars.

$$L(j,k,y) = a_5\left[1 + a_6\exp\left(-\frac{y}{a_7}\right)\right] \Big/ \left[1 + a_8\exp\left(-\frac{y}{a_9}\right)\right] \tag{8}$$

where L (m^3/100 km or litres/100 km) is the fuel consumed by a vehicle in 100 km (see Table 1 for corresponding coefficient values).

Figure 7 Evolution and projected carbon equivalent emission factors for Argentine passenger vehicles



Notes: Lines: continuous black: gasoline; grey line diesel: discontinuous lines: NCG; dotted lines: hybrid vehicles.

Table 1 Fuel and vehicle parameters

Fuel type	*Market share parameters*		*Energy intensity*	*Fuel economy*					*Survival parameters*		
	Initial value	*Growth*		*Model parameters*							
	Z	*q*	*TJ/m*^{3}	a_5(*)	a_6	a_7	a_8	a_9	b_1	b_2	b_3
Gasoline	0.8	0.3	0.0318	28	0.009	0.25	0.011	0.26	0.98	32	3.5
Diesel	0.19	0.02	0.0361	25	0.009	0.25	0.011	0.26	0.98	32	4.5
NCG	0.0006	0.18	0.0389	15	0.009	0.25	0.011	0.26	0.98	32	3.5
Hybrid	0.0004	0.06	0.0372	8	0.009	0.25	0.011	0.26	-	-	-

Notes: NCG: natural compressed gas for vehicles. (*) Initial values for 1960.

2.3 Private vehicle activity VKT

The annual activity of passenger cars, taxis and light duty commercial vehicles was estimated at a disaggregated level based on the number and type of vehicles and fuel usage and an estimate of their fuel economy:

$$VKT(j,k,y)=\sum\nolimits_{t=y_0}^{t=y}\left[V(j,k,t)\times B(j,k,y-t)\times M(j,k,t)\times L(j,k,t)\right] \tag{9}$$

where VKT (m^3) is the private activity for each fuel type j and vehicle class k at year y; M (km/veh.) is the average annual distance travelled in km per vehicle; L (m^3/km or litres/km) is the fuel efficiency associated with each vehicle, fuel type and manufacturing year t; $V(j, k, t)$ are the numbers of vehicles manufactured at year t. B is a factor that includes the probability that a vehicle will remain in the fleet after $\tau = y - t$ years.

2.4 Public transportation activity PKT

National records of public transport include transported passenger-km (PKT) for rail, buses and subways. We found that variations in GDP appear to be an adequate long term indicator of public transportation activity (Figure 8):

$$PT(y)=a_{10}G(y)+a_{11}P(y) \tag{10}$$

where a_{10} = 80 (pass-km/USD) and a_{11} = 1,000 pass-km/inhab.). PKT are further distributed in several modes (n): electric suburban train (EST), LRT or metro, BRT, metropolitan urban bus (MUB) and intercity bus (IBU). Energy intensity I_{PKT} and modal share S_{PKT} will depend on the selected transport mode n and fuel share Z_{PKT} (Table 2).

$$PKT(j,n,y)=PT(y)\times S_{PKT}(n)\times Z_{PKT}(j) \tag{11}$$

Figure 8 GDP (billions USD) – black line – compared to freight activity TKT (billions ton-km) – grey line with circles – and PKT (billion pass-km) – discontinuous line with diamonds

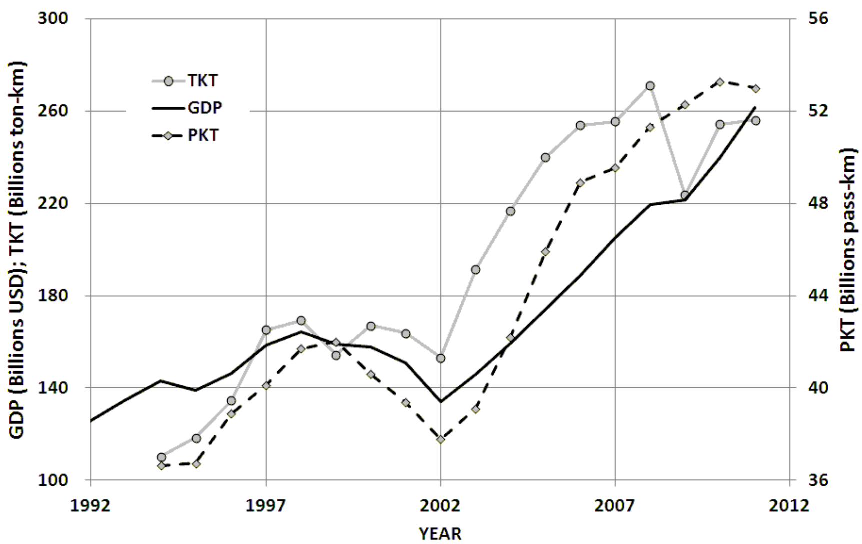


Table 2 Fuel efficiencies and shares for public passenger transport

PKT type	*Modal share*	*Average fuel consumption*	*Average load*	*Energy efficiency*
	%	*L/100 km*	*Pass./km*	*MJ/pass.-km*
EST	35 (a_{14})	25	12	0.81 (a_{20})
LRT	7 (a_{15})	25	11	0.88 (a_{21})
ELE	3 (a_{16})	25	13	0.69 (a_{22})
BRT	42 (a_{17})	35	8	1.58 (a_{23})
MUB	8 (a_{18})	42	8	1.89 (a_{24})
IBU	5 (a_{19})	35	17	0.74 (a_{25})

Notes: EST: electric suburban train, LRT: light rail train or metro; ELE: tram or trolley bus; BRT: bus rapid transit; MUB: metropolitan urban bus; IBU: intercity bus. In brackets (a_i): model parameters.

2.5 Freight activity TKT

Freight activity is usually described in terms of ton-kilometre of cargo transported (TKT). This activity was also estimated from data provided by provincial and national transport agencies. Diesel trucks concentrate 95% of the road freight share with a mean distance of 300 km, while rail freight (RFT) with a 500 km mean travel distance takes the rest. National aerial fluvial or maritime freight was not included in the calculations. Total TKT activity has been growing at a faster rate than the GDP and can be modelled as:

$$FT(y) = G(y)^{a_{12}} + a_{13} \tag{12}$$

where a_{12} = 1.05, a_{13} = –40 (billion ton-km). On-road truck TKT is further divided into different modes: light-duty truck (LDT < 2 tons); medium-duty truck (MDT < 4 tons); semi-trailer towing-truck (SST < 20 tons); heavy-duty truck (HDT > 20 tons); Gasoline medium-duty truck (GMDT < 4 tons). Modal share S_{TKT} and energy intensity I_{TKT} for each mode and fuel share Z_{TKT} are presented in Table 3.

$$TKT(j, n, y) = FT(y) \times S_{TKT}(n) \times Z_{TKT}(j) \tag{13}$$

Table 3 Fuel efficiencies and shares for truck freight transport

TKT	*Modal share*	*Average fuel consumption*	*Average load*	*Energy efficiency*	*Survival parameters*		
Vehicle type	*%*	*Litres/100 km*	*Ton-km*	*MJ/ton-km*	b_1	b_2	b_3
STT	12 (a_{26})	45	25	0.6 (a_{31})	0.96	32	4.5
HDT	15 (a_{27})	40	18	0.8 (a^{32})	0.96	32	4.5
MDT	25 (a_{28})	38	4	3.4 (a_{33})	0.96	32	3.5
LDT	22 (a_{29})	16	1.2	4.8 (a_{34})	0.94	34	3.5
GMDT	10 (a_{30})	37	8	1.7 (a_{35})	0.94	35	4.5

Notes: LDT: light-duty-truck (< 2 tons); MDT: medium duty truck (< 4 tons); SST: semi trailer towing-truck (< 20 tons); HDT: heavy duty truck (> 20 tons); GMDT: gasoline medium duty truck (< 4 tons). In brackets (a_i): model parameters.

2.6 Energy and carbon emissions

Energy consumptions *E* (MJ) for VKT, PKT and TKT sectors are calculated as the product of the activity (AKT) and energy intensity factor *I*:

$$E_{AKT}(j, n, y) = AKT(j, n, y) \times I_{AKT}(j, n) \tag{14}$$

where *AKT* is *VKT* for private transportation, *PKT* for public transport and TKT for freight activity respectively; I_{VKT} (MJ/m^3) – Table 1 –, I_{PKT} (MJ/pas-km) – Table 2 – and I_{TKT} (MJ/ton-km) – Table 3 – are the energy intensity factors for the private activity, public transport and the freight modal sector respectively. Once energy *E*(*j*, *n*, *y*) is calculated for each mode *n* and fuel type *j*, the total annual carbon emission *C* (Tg/year) is calculated as:

$$C(y) = \sum_{1}^{y} F_E(j) \times \sum_{1}^{n} E(j, n, y) \tag{15}$$

Table 4 Transport costs

Description	*Initial value*	*Description*	*Initial value*
Fuel costs		Public transport	
Gasoline*	800 USD/m^3	Operative*	360 USD/m^3 fuel usage
NCG*	0.210 USD/m^3	Maintenance	0.015 USD/pas-km
Diesel*	480 USD/m^3	New equipment	0.020 USD/pas-km
Hybrid*		Road maintenance	0.005 USD/pas-km
Vehicle costs		Freight activitybyTruck	
Initial cost (**)	8,000 USD	Truck operative* (fuel)	360 USD/m^3
Maintenance	0.15 USD/veh-km	Maintenance	0.0025 USD/ton-km
NCG conversion	1,000 USD	New equipment	0.0035 USD/ton-km
HEV initial	9,500 USD	Public road maintenance	0.003 USD/ton-km
Public road maintenance	0.002 USD/veh-km	Freight activity by rail	
		Rail operative* (fuel)	360 USD/m^3
		Maintenance	0.004 USD/ton-km
		New equipment	0.003 USD/ton-km
		Railroad maintenance	0.005 USD/ton-km

Notes: (*) Fuel and operative costs are increased 0.6% per year, (**) gasoline/diesel vehicles

2.7 Description of scenarios

All scenarios maintain the same population and GDP growth: for Argentina, we assume a population growth from 40 million inhabitants in 2010 to 72 million in 2050; coupled with a change in the annual growth rate from 1.6% in 1960 to 1.1% in 2010, gradually decreasing to 1% in 2050, and totalling a 74% growth in 40 years. GDP has shown an average growth rate of 2.6% for the period 1960 to 2010, but with high inter-annual variations of 11% with respect to a linear growth. We assume an average growth rate of 2.5% from 2010 to 2050, totalling a 170% growth in 40 years, which entails an increase from 362 billion USD in 2010 to 974 billion USD in 2050. Fuel cost was only included to calculate the transport cost, but was not fed back into the model to affect vehicle registration or activity rates. Table 4 shows the assumed transport cost. These values are only taken as reference in order to assess the relative impact of different scenarios. Fuel prices will have a steady growth rate of 0.6% annually, going from 800 USD/m^3 in 1960 to 1,380 USD/m^3 in 2050. All scenarios consider an annual technological improvement in fuel efficiencies as in (7). Energy intensity factors I_{PKT} and I_{TKT} improve at an annual rate of $\Delta I = \exp(-0.01 \times t)$, where $t = y - y_0$; $y_0 = 1{,}960$.

- *Baseline scenario E*0. It uses all coefficients defined in equation (1) through equation (15) above. This scenario included the penetration for HEV vehicles starting at 2020 and the use of NCG replacing gasoline and diesel for private vehicles. PKT included SEV, BRT, LRT, MUB and IBU (Table 2). For TKT, it is supposed to be performed in a 95% is developed by truck and 5% by railroad. Truck activity is further distributed in LDT, MDT, GMDT, HDT and SST (Table 3).
- *Scenario E*1: In this scenario we assumed a 100% growth of public transport activity in 2050, as compared to *E*0. For each new public transport passenger-km (with respect to *E*0), the procedure reduces private vehicle activity taking vehicles from the road as per the annual mobility M and the motorisation rate. $\Delta veh = \Delta pkt \times (mot/M)$. Δveh is the vehicle reduction [veh]; Δpkt is the increase in public passengers transport [pass-km]; M is the annual private car mobility [km] and $mot = V/P$ [veh./1,000 inhab.] is the annual motorisation rate (Figure 2). 65% of Δveh is represented by gasoline vehicles and 35% by diesel vehicles fleet.
- *Scenario E*2: In this scenario, we assumed that rail freight activity will have a 100% growth by 2050, as compared to baseline scenario (*E*0), which will pass from a 5.3% share in 2010 to an 11% share in 2050.
- *Scenario E*3: In this scenario, we doubled the rate of hybrid vehicle penetration starting at 2020, compared to *E*0, as per equation (4) and Table 1. These vehicles will replace other vehicles in the rest of the market share (gasoline, diesel and NCG).
- *Scenario E*4: In this scenario, we combined all the other scenarios, but with an additional 50% decrease of gasoline-powered private vehicles.

2.8 Monte Carlo sensitivity analysis

A Monte Carlo simulation was conducted in order to test the sensitivity of the results against the uncertainties related to the model parameters. The model was tested in 150 runs where each coefficient varied according to a normal deviation from the average value set for baseline *E*0. The amplitude of the coefficient variation increased linearly from 2010 to 2050, considering a higher uncertainty as the simulations departed from present year: $a_i(y) = gaus\_ran(\bar{a}, \Delta a \times (y / \Delta y))$; where $a(y)$ is the actual coefficient value at year y; $\bar{a}$ is the average coefficient used at scenario *E*0; Δa is the maximum deviation at year 2050; $\Delta y = (2050 - y)$; $gaus\_ran(x, \sigma)$ is a normal Gaussian random function with mean x and σ deviation. All a_i coefficients had a maximum deviation at

2050 of 20% with respect to 2010. The range of possible outputs also gives a better understanding of the range of possible mitigation alternatives.

3 Results

The basic data sources for Argentina which were relevant to this study are shown in Appendix 1 and summarised in Table 5 for the period 1960 to 2010. The model is set to run from year 1960 to 2050. Activity coefficients for PKT and TKT were estimated using data from 1990 to 2010 (Table 6). Table 7 shows the data for fuel and energy consumption in Argentina for the TS used to calibrate consumption for each fuel type. The last two columns show the energy efficiency (MJ/km) of private vehicles based on 20,000 annual travelled kilometres and the freight sector efficiency (MJ/ton-km) based on Table 6. Table 8 summarises the basic results for all scenarios. Figure 9 shows the evolution of carbon emissions produced by the TS in Argentina. The first column describes the variables; the four consecutive columns show the results for 1980 through 2010. The last five columns represent the baseline scenario *E*0 and scenarios *E*1 through *E*4 at year 2050. This table is organised in several sub-tables: Table 8(a): basic data (population and GDP), transport activities and energy data; Table 8(b): emissions, energy intensities and emissions efficiencies; Table 8(c): transport cost and other transport indicators.

- *Baseline scenario E*0. In the baseline scenario, the motorisation will jump from 10 million vehicles in 2010 to 22 million in 2050, which entails a rate of motorisation of 235 vehicles per 1,000 inhabitants in 2010 to 310 veh./inhab. in 2050. Public transport is expected to grow from 53 to 123 billion pass-km for the same period 2010 to 2050, while freight activity will increase from 269 to 769 billion ton-km (2.8 times the value of 2010) especially due to an expected increase in cultivated areas of export crops. Given these basic data, the energy consumption in 2050 will almost double the reference value in 2010 (1297 PJ in 2050 as compared to 681 PJ in 2010), as shown in Table 8(a). The highest increases are expected in the use of CNG for private vehicles (2.8 times: 140 PJ in 2010 to 389 PJ in 2050), and the freight subsector (twice as high: 186 PJ in 2010 to 388 PJ in 2050), mainly provided by gas-oil powered trucks. Fuel efficiencies are expected to improve in all sectors for the period 2010 to 2050: from 3.7 to 2.9 MJ/km for private vehicles; from 0.7 to 0.5 MJ/pass.-km for public transportation; and from 0.8 to 0.5 MJ/ton-km for freight trucks. With regard to carbon emissions, they will rise from 47 Tg (2010) to 86 Tg (2050) [Table 8(b) and Figure 9]. The model assumes an improvement in average emissions factors for private vehicles from 246 g/km (2010) to 185 g/km (2050) mainly due to the adoption of hybrid vehicles (Figure 7).
- *Scenario E*1: In this scenario we consider a 100% growth of public transport activity by 2050 as compared to *E*0. This condition implies a PKT increase from 53 billion pas-km in 2010 to 246 billion pas-km in *E*1 compared to123 billion pas-km in *E*0 in 2050. The PKT increase produces a proportional reduction in the private active fleet from 22.5 (*E*0, 2050) to 15.5 million vehicles (*E*1, 2050), where most of the reduction is applied to gasoline vehicles. This combined effect produces an 8.6% energy decrease (112 PJ), from 1,297 (*E*0, 2050) to 1,185 (*E*1, 2050) PJ, while emissions reach an 8.1% (7Tg) reduction: 86 (*E*0, 2050) to 79 (*E*1, 2050) PJ. The

overall transport cost (*E*1, 2050) would be a 4.1% of the GDP, which is less than that for *E*0, i.e., about 4.5% of the GDP. Reductions in fuel and private vehicles are obtained in exchange for 17% higher costs in public transport activity.

- *Scenario E*2: In this scenario, we consider that rail freight activity will have a 100% increase by 2050 as compared to baseline scenario (*E*0). This condition implies a TKT-Rail increase from 13 billion ton-km in 2010 to 76 ton-km in 2050 for scenario *E*1, as compared to 38 ton-km in *E*0 in 2050. Rail freight increase is achieved by taking share from the road freight truck activity, passing from 5.3% to 11%. This condition produces a 0.4% reduction in energy and a 0.5% reduction in emissions as compared to the baseline scenario. More investment in new infrastructure and equipment is needed to achieve a higher modal share.
- *Scenario E*3: In Scenario *E*3, we include a higher rate of NCG vehicle conversion and new HEV starting in 2020. These vehicles will replace other vehicles in the rest of the market share (mainly gasoline and diesel). This scenario implies a strong replacement of old internal combustion cars with NCG or hybrid vehicles, reaching more than 14 million GNC vehicles and 1.4 million HEV units in 2050. Should this assumption be achieved, emissions will drop by 2.7% to 83.9 Tg (as compared to 86.2 in *E*0). Transport cost will be reduced from 4.5% (*E*0, 2050) to 4.3% (*E*3, 2050). The technology conversion cost is compensated with lower fuel consumption. Vehicle conversion to NCG or HEV slightly improves energy consumption (–0.8%) but reduces carbon emissions. Therefore, it is less energy efficient than public transport use.
- *Scenario E*4: Combining scenarios *E*1, *E*2 and *E*3 with a 50% higher private vehicle conversion to NCG and HEV, it is possible to achieve an 8.6% reduction in energy consumption and an 8.9% reduction in emissions as compared to *E*0 in 2050. Transport cost could reach a low value of 4.0% of GDP (Table 8).

Table 5 Average 5-year annual values of Argentina's main socio-economic indicators

Year	*Pop. per million inhabitants*	*GDP billons USD*	*GDP/cap USD/inhab*	*Energy (*) thousand TJ*	*Emissions (*) Tg*	*Veh. per 100 inhab*	*Active fleet thousand units*
1960	20.65	59.96	2,903	793	45.20	13	270
1965	22.31	74.25	3,326	1,055	60.09	45	1,011
1970	24.22	95.09	3,924	1,342	76.46	81	1,964
1975	26.48	105.25	3,974	1,514	86.22	112	2,968
1980	28.77	111.27	3,870	1,688	96.17	129	3,709
1985	30.92	109.23	3,534	1,950	104.63	128	3,951
1990	32.96	124.56	3,773	2,101	110.83	124	4,075
1995	34.73	153.41	4,414	2,468	130.25	156	5,414
2000	36.66	149.58	4,082	2,639	131.84	184	6,748
2005	38.72	201.70	5,203	3,030	161.74	204	7,894
2010	39.85	230.69	5,788	3,148	168.09	226	9,023

Notes: Pop.: population; GDP: gross domestic product; Veh.: vehicles; inh.: inhabitants.
(*) Corresponding to all sectors: industrial, energy production, residential, transportation and agriculture.

Table 6 Annual values of TKT Freight and PKT in Argentina

Year	*Railroad million tons*	*TKT-railroad billion ton-km*	*Truck million tons*	*TKT-truck billion ton-km*	*Public transport billion pass-km*
1994	12,000	5.90	306,116	104.29	36.64
1995	13,850	6.60	338,833	111.89	36.73
1996	15,450	7.20	394,146	127.28	38.88
1997	17,250	8.30	470,298	156.80	40.13
1998	17,000	8.30	475,966	161.03	41.71
1999	16,150	7.90	432,141	146.48	42.02
2000	15,650	8.70	411,106	158.36	40.61
2001	17,000	8.99	422,603	154.86	39.38
2002	17,500	9.45	383,924	143.66	37.78
2003	20,500	11.00	484,906	180.30	39.10
2004	21,700	11.60	554,271	205.31	42.21
2005	23,500	12.25	630,227	227.64	45.90
2006	23,900	12.65	657,580	241.18	48.92
2007	24,950	12.85	679,741	242.59	49.55
2008	26,100	13.00	747,934	258.14	51.32
2009	20,735	10.65	626,421	212.98	52.28
2010	23,551	12.11	712,467	242.24	53.30

Note: TKT: Freight activity in travelled tons-kilometre.

Table 7 Fuel consumption for the TS in Argentina

Year	*Gasoline TJ*	*NCG TJ*	*Diesel oil TJ*	*FO+EE+AK TJ*	*PV EF MJ/km*	*FT EF MJ/ton-km*
1960	86,723		74,359	21,982	26.3	2.22
1965	139,395		91,443	27,033	11.9	2.19
1970	171,156		97,876	41,491	6.6	2.16
1975	166,061		135,043	43,223	3.7	2.20
1980	234,205		159,833	35,285	4.0	2.24
1985	190,931	156	163,899	28,791	2.7	2.07
1990	187,874	8,487	171,211	29,837	2.6	2.04
1995	211,278	39,203	244,047	21,821	2.5	2.04
2000	148,516	65,286	299,620	22,801	1.6	1.75
2005	134,019	123,324	278,820	18,052	1.5	1.12
2010	210,766	103,716	265,509	51,249	2.3	1.14

Notes: NCG: natural compressed gas; FO: fuel-oil; EE: electricity generation; AK: kerosene for air fuel; PV: EF: private vehicles energy efficiency based on Gasoline consumption and 15,000 annual kilometre per vehicle; FT EF: freight transport energy efficiency based on activity presented in Table 7.

Table 8(a) Comparative annual values for the TS calculated for each scenario for year 2050: activity data and energy consumptions

Variable	*Scenario*				*E0*	*E1*	*E2*	*E3*	*E4*
Year	*1980*	*1990*	*2000*	*2010*	*2050*	*2050*	*2050*	*2050*	*2050*
Population (million inhabitants)	27.6	31.7	36.4	41.8	72.5	72.5	72.5	72.5	72.5
GDP (billions USD)	172.6	221.0	283.0	362.4	974.2	974.2	974.2	974.2	974.2
Activity									
Active vehicular fleet (million vehicles)	4.9	6.6	8.0	9.8	22.5	15.5	22.5	22.5	15.7
Rate of motorisation (vehicles/1,000 inhab.)	179.2	208.2	221.3	235.3	309.7	213.1	309.7	309.7	216.3
VKT gasoline (billion veh.-km)	39.2	47.3	50.2	47.5	44.1	11.2	44.1	30.1	9.5
VKT CNG (billion veh.-km)	1.3	5.5	17.8	40.3	154.6	136.3	154.6	188.2	151.2
VKT gas oil (billion veh.-km)	14.6	20.9	27.5	34.6	87.9	62.2	87.9	59.7	49.2
VKT Hybrid (billion veh.-km)					34.9	34.9	34.9	42.6	38.3
PKT (billion passenger-km)	25.7	33.1	42.0	52.7	123.2	246.4	123.2	123.2	246.4
Freight TKT (billion ton-km)	67.7	110.6	175.8	268.3	768.4	768.4	768.4	768.4	768.4
Freight TKT rail (billion ton-km)	3.4	5.5	8.8	13.4	38.4	38.4	76.8	38.4	76.8
Freight TKT truck (billion ton-km)	64.3	105.1	167.0	254.9	730.0	730.0	691.5	730.0	691.5
Freight TKT rail/truck (%)	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%	11.1%	5.3%	11.1%
Energy consumption									
Total energy consumption (1,000 TJ = 1 PJ)	366.2	441.7	550.7	681.6	1297.2	1185.3	1291.4	1287.0	1185.6
Freight rail (PJ)	2.6	3.7	5.4	7.6	15.9	15.9	31.8	15.9	31.8
Freight truck (PJ)	60.0	86.7	126.9	178.7	371.7	371.7	352.1	371.7	352.1
Public transportation (PJ)	25.0	28.5	33.3	38.5	65.4	153.4	65.4	65.4	153.1
Private transportation (PJ)	278.7	322.8	385.1	456.8	844.2	644.3	842.1	834.0	648.5
Gasoline (PJ)	200.5	211.6	210.8	191.2	155.4	68.7	153.3	118.7	62.3
CNG (PJ)	6.1	22.5	66.8	139.8	389.1	342.9	389.1	473.6	380.5
Gas-oil (diesel oil, fuel oil, kerosene) (PJ)	159.5	207.4	272.6	349.5	682.6	703.5	678.9	608.9	665.7
Hybrid (PJ)					70.2	70.2	70.2	85.8	77.2

Notes: GDP: gross domestic product, NCG: natural, compressed gas; TKT: ton-kilometre-travelled; PKT: passenger-kilometre travelled; 1 ton = 10^6 g, 1 PJ = 10^{15} J.

Table 8(b) Comparative annual values for the TS calculated for each scenario for year 2050: emissions and emissions efficiencies

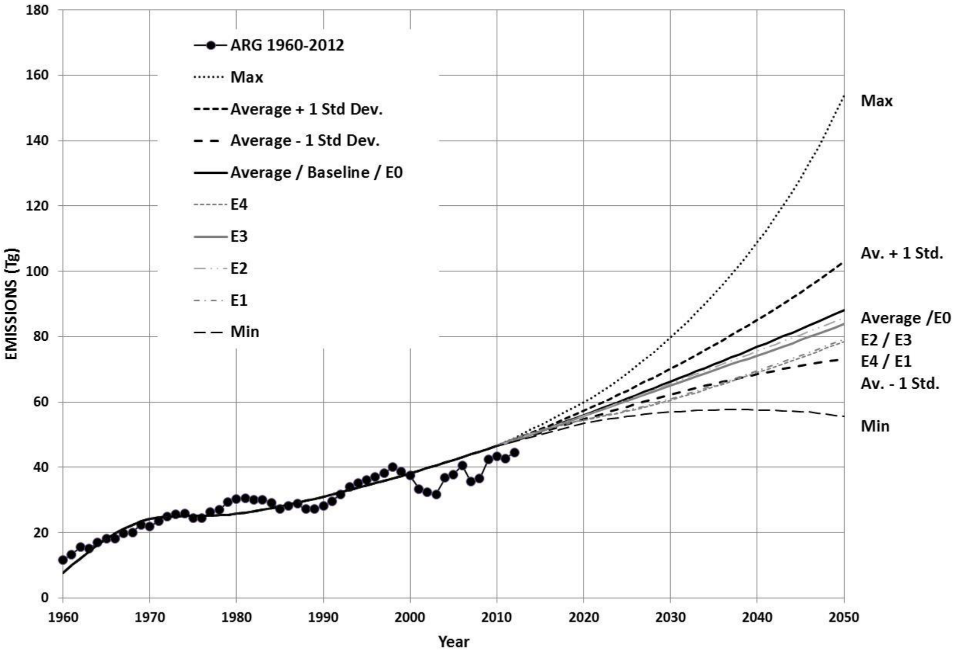
Variable	*Scenario*				*E0*	*E1*	*E2*	*E3*	*E4*
	Year *1980*	*1990*	*2000*	*2010*	*2050*	*2050*	*2050*	*2050*	*2050*
Emissions									
Total emissions (Tg)	25.8	31.0	38.2	46.6	86.2	79.2	85.8	83.9	78.5
Freight rail (Tg)	0.2	0.3	0.4	0.6	1.2	1.2	2.3	1.2	2.3
Freight truck (Tg)	4.4	6.4	9.3	13.1	27.3	27.3	25.8	27.3	25.8
Public (passenger) transportation (Tg)	1.8	2.1	2.4	2.8	4.8	11.2	4.8	4.8	11.2
Private (passenger) transportation (Tg)	19.4	22.3	26.0	30.1	53.0	39.6	52.9	50.6	39.1
Gasoline (Tg)	13.8	14.5	14.5	13.1	10.7	4.7	10.5	8.1	4.3
CNG (Tg)	0.3	1.2	3.7	7.8	21.6	19.0	21.6	26.3	21.1
Diesel (private transp.) (Tg)	5.3	6.5	7.8	9.1	16.8	11.9	16.8	11.4	9.4
Gas oil, fuel oil, kerosene (Tg)	6.4	8.7	12.1	16.5	33.2	39.7	32.9	33.2	39.4
Hybrid (Tg)					3.9	3.9	3.9	4.8	4.3
Energy intensity and emissions efficiency									
Private vehicles (MJ/vehicle-km)	5.1	4.4	4.0	3.7	2.9	3.1	2.9	3.0	3.1
Public transportation (MJ/passenger-km)	1.0	0.9	0.8	0.7	0.5	0.6	0.5	0.5	0.6
Freight rail (MJ/ton-km)	0.8	0.7	0.6	0.6	0.4	0.4	0.4	0.4	0.4
Freight truck (MJ/ton-km)	0.9	0.8	0.8	0.7	0.5	0.5	0.5	0.5	0.5
Public transportation (g/pass-km)	71.2	63.1	58.1	53.6	38.9	45.6	38.9	38.9	45.6
Freight rail (g/ton-km)	2.9	2.6	2.4	2.2	1.6	1.6	3.4	1.6	3.4
Freight truck (g/ton-km)	68.3	60.5	55.7	51.4	37.3	37.3	37.3	37.3	37.3
Private cars (g/veh-km)	351.7	302.0	272.9	245.7	185.0	188.8	184.5	182.2	186.3
Gasoline (g/km)	351.3	306.7	288.1	276.2	241.9	421.7	238.7	270.1	448.5
CNG (g/km)	263.0	226.8	208.6	192.5	139.8	139.8	139.8	139.8	139.8
Diesel (g/km)	360.4	310.9	285.8	263.8	191.5	191.5	191.5	191.5	191.5
Hybrid (g/km)					111.8	111.8	111.8	111.8	111.8

Table 8(c) Comparative annual values for the TS calculated for each scenario for year 2050: transport costs

Variable	*Scenario*				*E0*	*E1*	*E2*	*E3*	*E4*
	Year 1980	*1990*	*2000*	*2010*	*2050*	*2050*	*2050*	*2050*	*2050*
Transport cost									
Transport cost (billions USD)	11.8	14.5	17.9	21.7	44.2	39.7	44.0	42.3	39.3
Public transport cost (billions USD)	0.38	0.46	0.57	0.70	1.50	3.52	1.50	1.50	3.51
Freight truck (billions USD)	1.80	2.67	3.96	5.68	13.06	13.06	12.37	13.06	12.37
Freight railroad (billions USD)	0.08	0.12	0.18	0.25	0.53	0.53	1.06	0.53	1.06
Private car users cost (billions USD)	9.5	11.3	13.2	15.1	29.1	22.6	29.1	27.2	22.3
Transport cost/GDP (%)	6.8%	6.6%	6.3%	6.0%	4.5%	4.1%	4.5%	4.3%	4.0%
Freight (Rail + Truck)/GDP (%)	1.1%	1.3%	1.5%	1.6%	1.4%	1.4%	1.4%	1.4%	1.4%
Private car users cost/GDP (%)	5.5%	5.1%	4.7%	4.2%	3.0%	2.3%	3.0%	2.8%	2.3%
Freight cost (USD/100 ton-km)	2.80	2.54	2.37	2.23	1.79	1.79	1.79	1.79	1.79
Public transport cost (USD/100 pass.-km)	1.47	1.38	1.35	1.32	1.22	1.43	1.22	1.22	1.42
Private transport cost (USD/veh-km)	0.17	0.15	0.14	0.12	0.10	0.11	0.10	0.10	0.11
Average fuel cost (USD/m^3)	907	963	1022	1085	1379	1379	1379	1379	1379
Other indicators									
Transp. cost/emission (USD/Mg)	2.19	2.13	2.13	2.15	1.95	1.99	1.95	1.98	2.00
Emissions/GDP (g/USD)	149.5	140.2	134.9	128.5	88.5	81.3	88.1	86.1	80.6
Emissions/pop. (Mg/inhab.)	0.94	0.98	1.05	1.12	1.19	1.09	1.18	1.16	1.08
Energy/GDP (MJ/USD)	2.12	2.00	1.95	1.88	1.33	1.22	1.33	1.32	1.22
Emissions/energy (Mg/TJ)	70.4	70.2	69.3	68.3	66.5	66.9	66.4	65.2	66.2

Note: 1 Mg = 10^6 g

Figure 9 Emissions from the TS (Tg) in Argentina



Notes: Data (1970 to 2008): black circles. Scenarios: baseline E0: black dash-dotted line; E3 black line; E4: grey line. Monte Carlo analysis: average (grey line – with black diamonds –; average + 3 standard deviations: dotted grey line with open white triangles; average – 3 standard deviations: black line with open white squares (coincident with E0). Maximum value: dotted black line; minimum value: short discontinuous black line).

4 Discussion of the proposed scenarios

This study for Argentina reveals that private vehicles are the major emitters of GHGs in the TS, producing 30.1 Tg (or 64.6% of the total emissions of TS in 2010), and could reach 53 Tg in 2050. The emission factor for public transportation is 53 g/pass.-km in 2010 but could reach 39 g/pass.-km in 2050. Given the age of the vehicular fleet, the average rate of emission is 245 g/veh.-km in 2010 and could be reduced to 185 g/veh.-km in 2050 with technological improvements and car replacements. Considering the average vehicle occupancy of 1.5 people, the emission rate is 164 g/pass.-km (2010) or 123 g/pass.-km in 2050, thus demonstrating that the private car emission factor is three times higher than mass transit.

Freight transport is another important activity (230 billion ton-km in 2010) producing high carbon emissions (14 Tg or 29.3% of total TS emissions in 2010). In Argentina, the rail freight takes 5% of the load demand, mainly for grains and minerals transportation, with an average emission factor of 2.2 g/ton-km versus 51.4 g/ton-km for trucks. The grain producing areas in the country are relatively near the fluvial ports of grain, so distances are short (between 300 and 500 km). This relative short distance (considering the geographical extension of Argentina) favours an emission balance and makes trucks very competitive as compared to railroad. Given the fact that the rail system is organised in a radial manner towards the grain fluvial ports, it has great potential to increase its cargo movement several times, but it requires substantial investment in order to upgrade the rolling material and the signalling system. Therefore, a significant mitigation of CO_2 emissions in the freight sector could be reached in the medium term in the freight sub-sector.

5 Conclusions

Most countries around the world are facing an increasing demand for mobility and accessibility, which is currently being met by available urban means of transportation, mostly private cars. The challenge is to propose environmentally friendly options to switch to low carbon/non-motorised modes and higher quality transit modes to compete with the use of private cars (Poudenx, 2008; Tiwari et al., 2011). For developing countries, this purpose implies an additional burden, which does not necessarily imply following the same 'carbon path' that developed countries have taken since the mid-20th century. This model shows that, for the baseline scenario, stabilisation of GHG emissions with technological improvements in terms of expected fuel efficiencies and better integrated transport efficiencies will not be achieved within the next 40 years, under the assumption of an average 2.5% annual GDP growth rate and even a decreasing population growth rate of 0.9%. Therefore, more active policies have to be implemented in order to reach a stabilised emission target in the TS under 80 Tg by 2050, which represents approximately twice the current values, as shown in the alternative scenarios. Public transport has the greatest potential for carbon emissions reduction, but its implementation can be complex given the large number of actors involved and the inherent inertia in new transport systems development. This development may take decades and its influence may last for many years. A change in transport user behaviour will also take many years to meet new environmental requirements. Latin American cities still have some potential to capture a significant share of private car journeys, especially by improving underutilised mass transit systems, routes, and service quality. Any increase in capacity is related to changes in land use patterns and availability of convenient and affordable transportation means. However, political inaction and/or different conceptions result in loss of opportunities as new residential areas are built away from work/educational/commercial centres along expanded highways following the examples of suburban development of high-income countries.

Other available options in the short and mid-terms include a higher rate of vehicle replacement with lower carbon levels through the use of smaller cars with lower energy consumption and emissions, such as HEV or NCGs as a transition alternative. Fleet in Argentina nowadays has a 20% NCG share and on average, it is composed of small (1.4–1.6 dm^3 engine) but relatively old cars (> 12 years). Private vehicle replacement with NCG or HEV is less effective in energy consumption and carbon emissions terms as compared to public transport. Nevertheless, such replacement is more likely to be applied since car industry is being promoted (i.e., in Argentina and other developing countries) to increase employment through small supplier industries for automotive factories.

The adoption of low carbon transport media for short distances is slowly taking place as municipalities allocate public space for biking and walking. However, the implementation of more radical measures to discourage the use of private vehicles, such as high parking fees and tolls or the conversion of main streets into pedestrian areas, does not find much support from downtown business owners as they fear a loss in sales and employment to the benefit of large shopping centres with ample parking areas and fast access. At national level, policy makers fear that these measures could slow down the urgently needed economic growth to step out of poverty.

Acknowledgements

This work has been supported by the National Scientific and Technical Research Council (CONICET), the National Technological University of Argentina (UTN), under Grant Project # PID IFI 1487 and 1799 and CONICET PIP 112 201101 00673.

References

Argentina (2007) *Second National Report to IPCC* [online] http://www.ambiente.gov.ar/archivos/web/File/home_documentos/Informe_Final_2CN.pdf (accessed 29 January 2015).

Bass, F. (1969) 'A new product growth model for consumer durables', *Management Science*, Vol. 15, No. 5, pp.215–227.

Bastani, P., Heywood, J. and Hope, C. (2012) 'The effect of uncertainty on US transport-related GHG emissions and fuel consumption out to 2050', *Transportation Research Part A*, Vol. 46, No. 3, pp.517–548.

Bouf, D. and Hensher, D. (2007) 'The dark side of making transit irresistible: the example of France', *Transport Policy*, Vol. 14, No. 6, pp.523–532.

EIA, *International Energy Outlook* [online] http://www.eia.gov/forecasts/ieo/ (accessed 29 January 2015).

EPA (2009) *Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 through 2009*, Office of Transportation and Air Quality, US Environmental Protection Agency, Report EPA 420-R-09-014

Hao, H., Wang, H. and Ouyang, M. (2011) 'Fuel conservation and GHG (greenhouse gas) emissions mitigation scenarios for China's passenger vehicle fleet', *Energy*, Vol. 36, No. 11, pp.6520–6528.

Hao, H., Wang, H. and Ouyang, M. (2012) 'Fuel consumption and life cycle GHG emissions by China's on-road trucks: future trends trough 2050 and evaluation of mitigation measures', *Energy Policy*, Vol. 43, pp.244–251.

Hensher, D. (2007) 'Sustainable public transport systems: moving towards a value for money and network-based approach and away from blind commitment', *Transport Policy*, Vol. 14, No. 1, pp.98–102.

IPCC (2007) 'Climate change 2007: synthesis report', in Pachauri, R.K. and Reisinger, A. (Eds.): *Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC, Geneva, Switzerland.

Litman, T. (2007) 'Evaluating rail transit benefits: a comment', *Transport Policy*, Vol. 14, No. 1, pp.94–97.

Mobile6 (2001) *Fleet Characterization Data for MOBILE6*, EPA 420-R-01-047 [online] http://www.epa.gov/oms/models/mobile6/r01047.pdf (accessed 29 January 2015).

National Highway Traffic Safety Administration (NHTSA) (2014) *Summary of Fuel Economy Performance*, NHTSA, NVS-220 June.

O'Toole, R. (2004) *Great Rail Disasters; The Impact of Rail Transit on Urban Livability*, Transportation Policy Center [online] http://transportation.i2i.org/2004/02/01/great-rail-disasters/ (accessed 29 January 2015).

Poudenx, P. (2008) 'The effect of transportation policies on energy consumption and greenhouse gas emission from urban passenger transportation', *Transportation Research Part A*, Vol. 42, No. 8, pp.901–909.

Schipper, L., Marie-Lilliu, C. and Gorham, R. (2000) *Flexing the Link between Transport and Greenhouse Gas Emissions: A Path for the World Bank*, International Energy Agency, Paris.

Stopher, P.R. (2004) 'Reducing traffic congestion: a reality check', *Transport Policy*, Vol. 11, No. 2, pp.117–131.

Taylor, B.D. (2004) 'The politics of congestion mitigation', *Transport Policy*, Vol. 11, No. 3, pp.299–302.

Tiwari, R., Cervero, R. and Schipper, L. (2011) 'Driving CO_2 reduction by integrating transport and urban design strategies', *Cities*, Vol. 28, No. 5, pp.394–405.

Winston, C. and Maheshri, V. (2007) 'On the social desirability of urban rail transit systems', *Journal of Urban Economics*, Vol. 62, No. 2, pp.362–382.

World Bank (WB) *World Development Indicators* [online] http://data.worldbank.org/data-catalog/world-development-indicators (accessed 29 January 2015).

Yan, X. and Crookes, R. (2009) 'Reduction potentials of energy demand and GHG emissions in China's road transport sector', *Energy Policy*, Vol. 37, No. 2, pp.658–668.

Appendix

Sources of information

The basic information used in this study was gathered from several Argentine Agencies and Public Offices, yearbooks and independent reports. Population and GDP data were obtained from the National Statistics Office (INDEC), and such data have been reproduced in several world yearbooks such as the World Bank (WB, http://www.worldbank.org) and the International Energy Outlook (EIA, http://www.eia.gov/ieo). Records of vehicle production, sales and registration from 1960 to 2010 were made available by the National Property Registry of Motor Vehicles (DNRPA) and the Automotive Manufacturers Association (ADEFA). Energy sales and consumption data were made available by the Secretary of Energy (SEN). Transportation activity was obtained from the Secretary of Transportation (STN), and from several reports by Universidad Tecnológica Nacional (UTN/C3T), and PTUMA. Some studies such as IPCC 1994, 1997 and 2000 Argentina Country Report (Argentina, 2007) were also consulted.

Acronyms and websites of Argentine National Agencies and Public Offices

- ADEFA. Asociación de Fábricas de Automotores (Automotive Manufacturers Association) http://www.adefa.org.ar.
- DNRPA. Dirección Nacional del Registro de la Propiedad Automotor (National Property Registry of Motor Vehicles) http://www.dnrpa.gov.ar.
- SEN. Secretaría de Energía de la Nación (Secretary of Energy) http://www.energia3.mecon.gov.ar.

- BEN. Balance Energético Nacional (National Energy Balance) http://www.energia3.mecon.gov.ar.
- STN. Secretaría de Transporte de la Nación (Secretary of Transportation) http://www.transporte.gov.ar.
- PTUMA. Proyecto de Transporte de Áreas Metropolitanas de Argentina (Urban Metropolitan Area Transportation Project) http://www.ptuba.org.
- UTN/C3T. Centro Tecnológico de Transporte y Tránsito. Universidad Tecnológica Nacional (National Technological University –Transportation Research Center) http://www.utn.edu.ar/secretarias/extension/c3t.utn.
- INDEC. Instituto Nacional de Estadísticas y Censos (National Institute for Statistics and Census) http://www.indec.mecon.ar.