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Economic Evaluation of Future Carbon Dioxide Impacts from Italian Highways

Silvio Nocera[a,*], Federico Cavallaro[b]

a IUAV University of Venice - Research Unit “Traffic, Territory and Logistics”, Dorsoduro 2206, I-30123 Venice, Italy
b EURAC European Academy of Bozen/Bolzano - Institute for Regional Development and Location Management, Viale Druso 1, I-39100 Bolzano, Italy

Abstract

In recent years, a large body of literature has been published on the management of CO_2 emissions. Despite the proposal of several methods for their monetisation, a definitive method remains to be found. This paper reviews some of the commonly adopted techniques and evaluates their pros and cons. The most reliable values for the years 2010-2020 have been determined with the Avoidance Cost technique. Three different scenarios are analysed, each of them representing a different political strategy regarding the reduction of CO_2 emissions. The values obtained are then applied to the case study of Italian highways, demonstrating that the application of an aggressive emissions reduction policy would require an investment of about €17,000 million more than a conservative policy.

Keywords: CO_2 Economic Value, Avoidance Cost, Transportation, Italian highways

1. Introduction

Global warming is one of the main externalities in the transportation sector and the literature generally concurs that greenhouse gases (GHGs) are the main cause of increasing temperatures (Sinha & Labi, 2007; Black, 2010). Among all GHGs, CO_2 accounts for more than 75% of total emissions (IPCC, 2007), making it the most relevant of the global warming gases.

Corresponding author: Tel.: +390412571370; fax: +390412571392
E-mail address: nocera@iuav.it

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Atmospheric CO_2 concentrations currently stand at 390 million by volume (ppmv), which is above the harmfulness threshold of 350 ppmv. At this concentration, CO_2 contributes to the consequences of climate change, including droughts, floods, increase in sea levels, and loss of biodiversity (Hansen et al., 2008; TRB, 2008). The transportation sector plays a significant role, since emissions have grown by about 30% in the last twenty years, the only sector to fail to provide a reduction in comparison to 1990 (EC, 2009).

To reduce these emissions, global warming consequences have to be internalised in overall transportation costs by monetising their impact on the environment. This approach can also be included into a more comprehensive assessment about the economical evaluation of all the external impacts of an infrastructure through a Cost Benefit Analysis or a Multi Criteria Evaluation (IUAV TTL, 2010).

Section 2 of this paper describes several methods to determine a reliable unitary economic value for CO_2 emissions and chooses reference values with respect to European shared targets. Section 3 applies these values to the case study of transport on Italian highways. Some concluding remarks, including pros and cons of the method, are in the final section of the paper.

2. Unitary economic value of CO_2 emissions

CO_2 emission costs can be internalised by adopting a monetisation technique. In this process, the gases emitted are first quantified in terms of tonnes of carbon dioxide (tCO_2). This value is then converted into a monetary figure ($, £ or €) by multiplying the quantity of emissions by a unitary price.

The main problem of this process is to determine a fair unitary price. The techniques adopted to this aim are normally placed into two categories: market-based prices (section 2.1) and prices that take into account future expected variations (section 2.2). Each of these methods has several pros and cons, making it difficult to choose the most reliable one. The following subchapters deal specifically with this aspect.

2.1. CO_2 Market-based prices

The traditional methods to determine the current market value of CO_2 are Carbon-trading Price and Tax Price. The former is based on the "Cap-and-Trade" law. “Cap” is the maximum amount of CO_2 that can be emitted without paying a fine; within this cap, companies receive emission allowances that they can sell to or buy from one another if needed (“trade”). The second method is a fee on the carbon content of fuels or on the estimated CO_2 emitted in the fuel combustion process. These two methods are conceptually very different (Weitzman, 1974), since the variable taken into account to obtain the expected results are either ‘quantities’ in the Cap-and-Trade method or ‘prices’ in the Tax method. Theoretically speaking (i.e., in a perfect-information system), the results obtained by the two techniques are the same: if the regulator distributes the optimal number of permits, their price will correspond to the optimum tax level, ending in no difference for the polluter (Baumol and Oates, 1988).

In practice, however, the results can be very different, due to the imperfect information and laws that regulate the economy. On the one hand, Carbon Tax can generate significant revenues for the government, which it can then use to reduce distortionary taxes in the economy (Aldy et al., 2008). However, Carbon Tax suffers from an important political handicap: it is an unpopular measure among citizens, and most times its introduction is considered as an attempt to garner popularity in the electorate, rather than to determine a fair price. It follows then that the risk of rejection of the tax is significant. Moreover, even if introduced, there is a significant risk to underestimate the tax rate, thus producing very disparate and incomparable values (up to four orders of magnitude). For example, Sumner et al. (2009) cite the \$105.00/t CO_2 and \$0.045/t CO_2 reference prices in Sweden and California, respectively. Countries in which the tax has been rigorously introduced have great economic disadvantages compared with countries where the tax has not either been introduced or introduced at lower levels (Pearce, 1991). In the former case, production costs are obviously greater, thus contributing to higher, less competitive consumer prices. Finally, social factors must also be considered: carbon taxes mostly impact lower income households, since they tend to spend more proportionally on carbon intensive activities (Santos, 2010).

On the other hand, the application of Cap-and-Trade is largely limited by the technology; it can only be adopted for stable sectors, such as industry and power plants, in which the quantification of emissions is technically feasible. For other fields, such as transportation, buildings and agriculture, it is difficult to implement. Moreover, due to the economic nature of the price, this system may lead to significant price fluctuations, which increase the intrinsic uncertainty of the reference price. This price is particularly influenced by the pressure of industry sector, which contributes to make it noticeably underestimated. Finally, the cap for a given future temporal horizon is determined at some point during the current period and is usually valid for five years, thus facilitating the initial decision to implement the system, but making it inherently unsuitable for long-term forecasts (Ellerman et al., 2008).

As far as a strategic CO_2 economic evaluation is concerned, the focus on current emission values and the lack of a long-term temporal horizon are insurmountable issues through these methods. These prices are thus unsuitable unless very short temporal horizons are considered. It follows then that other prices should be found for future forecasts.

2.2. CO_2 prices based on future consequences

To determine current and future economic values of CO_2, more complex techniques have been adopted since the 1990s: Damage Cost and Avoidance Cost can be considered as the two methods most employed (Maibach et al., 2008).

Damage Cost assesses the future physical impacts of climate change and links them with the consequences on the economy and society. It is based on a Cost Benefit Analysis (CBA) that determines the optimal policies to adopt on the basis of the environmental, social and economic consequences expected, and then evaluates whether the benefits are expected to exceed the costs. The aim is to establish the so-called Marginal Social Cost of Carbon (MSCC), defined as the Net Present Value of climate change impacts over the next 100 years of one additional tonne of CO_2 emitted in the atmosphere today (Watkiss et al., 2005). Damage Cost is quantified by adopting specific Integrated Assessment Models (IAMs), such as DICE (Nordhaus, 1992), FUND (Kuik et al., 2008) and PAGE (Hope, 2006).

Even if theoretically rigorous, this method suffers from several uncertainties that are endemic to all forecasts and estimations. The process goes as follows: first, future CO_2 emission levels are estimated; secondly, a link between emissions and atmospheric concentration is determined; thirdly, the GHG consequences to climate change are assessed; and fourthly, the physical impacts of climate change are measured. On this basis, Clarkson and Deyes (2002) highlight the two main aspects of uncertainty: scientific and economic. The former consists of evaluating future CO_2 emission levels, determining a link between emissions and atmospheric concentration, assessing the GHG consequences on climate change and finally measuring the physical impacts of climate change. The latter is based on the quantification of a parameter called 'Equity Weighting' and the choice of the discount rate used to monetise future emissions. It follows that uncertainty can be minimised, but not eliminated.

As a result of these uncertainties, studies that adopt the Damage Cost technique range from \$19.00 to about \$900.00/t CO_2 (Litman, 2011). This obviously vast range does not help to define a singular reliable value.

Avoidance Cost (also known as Mitigation or Control Cost) quantifies the funds required to avoid an increase of CO_2 levels, to reduce their emission, and to remove them from the atmosphere. Scientific uncertainty is much lower in this case, since environmental effects are not directly included in the analysis. The method is strictly related to the development of policy targets that aim at lowering emissions to a given percentage in a fixed temporal horizon. In this sense, the determination of the CO_2 emission price is in large part a political issue, related to the targets that a society wishes to attain. Therefore, in attributing a unitary CO_2 price, it is of the utmost importance to state clearly the goals expected in terms of environmental results, in terms of relative variation from current level (%), absolute CO_2 concentrations (ppmv) or temperature changes (°C).

Operatively, Avoidance Cost is based on a cost-effectiveness analysis focussed on expressing the optimum price to achieve the targets. Since it compares the costs of alternative ways of producing the same or similar outputs, it can be considered a relative measure. In economic terms, the value represents the least expensive option to achieve a required reduction level of greenhouse gas emissions. The optimum emission level is determined as the intersection of the curves of Marginal Avoidance Cost (MAC) and Marginal Social Damage (MSC). Emissions are at their optimum level when the incremental social costs of additional abatement (i.e. reducing emissions by one tonne) are equal to the additional social benefits of avoided damage.

As with Damage Cost, the range of unitary values is broad, varying from €15.00/t CO_2 (CEC, 2007) to €381.00/t CO_2 (Kuik et al., 2008). However, these differences can be explained in terms of the target and temporal horizon chosen; Kuik et al. (2008) state that a targeted reduction of CO_2 concentration to 450 ppmv by 2025 would imply an aggressive policy, due to the shorter temporal horizon. The European Commission fixes the same target for 2050, with a constant linear yearly increase of values. Also this trend is influenced by some uncertainty (e.g., the future energy costs used in the technical and non-technical options to reduce CO_2 emissions cannot be determined with certain knowledge), but the overall incidence is noticeable lower than in Damage Cost (Litman, 2011).

2.3. Discussion of the chosen method

Given the previous analysis, Avoidance Cost method would seem to be a more effective in determining a fair CO_2 unitary price, provided that targets, measures and policies are clearly stated. Therefore it is adopted as the reference method in this paper. The temporal horizon is a ten-year period (up to 2020), according to the case study presented in the following section 3. Rather than a single value, a range has been introduced, characterised by the targets of different environmental policies. Three values are determined, namely, the lower, the medium and the upper values.

The lower value is the product of a very conservative carbon policy: CO_2 emissions in 2020 would stabilise at the level forecast by the 'Kyoto Protocol' (UN, 1998), which is an international environmental agreement ratified by most of the world's nations between 1997 and 2005. The original goal was to reduce the overall CO_2 emissions of a nation by 5%, compared to 1990, but in Europe this reduction was increased to 8% from 2008 to 2012. The values range between €7.00/t CO_2 for the year 2010 (Maibach et al., 2008) and €20.00/t CO_2 for the year 2020 (Nash, 2003; EC, 2005), growing proportionally in this range in this 10-year period.

The medium value is the result of a long-term policy suggested by EU up to the year 2050, which aims to stabilise the Earth's temperature at 2°C above pre-industrial age levels. To this end, the achievement of the 'Europe 20-20-20' targets (EU, 2012a) can be considered a medium-term goal. This policy implies a reduction in CO_2 emissions of 20% below 1990 levels and the adoption of 20% of renewable energies by 2020. The values are based on a European project (CEC, 2007), which has been developed under the direct supervision of EU. In the year 2010, the central value is fixed at €19.00/t CO_2, a cost that rises to €38.00/t CO_2 by the year 2020.

Finally, the upper value is part of a more ambitious policy, which aims at a 30% reduction of CO_2 by 2020 compared to 1990 levels. The values here proposed are €38.00/t CO_2 in the year 2010 and €93.00/t CO_2 in the year 2020, based respectively on studies developed by Capros and Mantzos (2000) and Elzen et al. (2007). These values are also coherent to those expressed by van Vuuren et al. (2006).

Table 1 summarises the CO_2 unitary values previously described.

These values are taken from different European studies and are limited to continental Europe only. If compared to other absolute parameters, such as CO_2 concentrations or temperature increases, the reduction of relative CO_2 emissions seems a more robust target, since it is neither affected by nor dependent upon the decision of other states. In other words, Europe can achieve its goals independently from the decisions of non-European countries. Hence, the complexity deriving from the global cooperation/competition strategies to obtain a common goal can be avoided (Forgó et al., 2005).

In next section these values are used to determine the economic impact of CO_2 emissions in transportation field by evaluating the case study of road traffic on Italian highways.

Table 1: CO_2 prices (€/tCO_2) adopted here in the period 2010-2020: lower, median and upper values.

CO_2 prices (€/tCO_2): years 2010-2020			
YEAR	CO_2 LOWER UNITARY PRICE €/tCO_2	CO_2 MEDIAN UNITARY PRICE €/tCO_2	CO_2 UPPER UNITARY PRICE €/tCO_2
2010	7.00	19.00	38.00
2011	8.30	20.90	43.50
2012	9.60	22.80	49.00
2013	10.90	24.70	54.50
2014	12.20	26.60	60.00
2015	13.50	28.50	65.50
2016	14.80	30.40	71.00
2017	16.10	32.30	76.50
2018	17.40	34.20	82.00
2019	18.70	36.10	87.50
2020	20.00	38.00	93.00

3. Case-study: the costs of CO_2 emissions deriving from Italian highways in the period 2010-2020

As far as the evolution of CO_2 emissions is concerned, transportation is undoubtedly one of the most critical sectors internationally. Emissions have been constantly increasing over the past 20 years (EU, 2009) and forecasts seem to confirm this trend. Hence, the EU encourages a better balance of transport modes by limiting the growth of the most pollution-causing and encouraging the development of the most sustainable, including the rail and the maritime ones (EC, 2011). However some of the oligopoly and market problems that bound their development make these systems not attractive enough (Fornasiero and Libardo, 2011).

On the contrary, road transport is very used and belongs to the more polluting systems (van Essen et al., 2003). Among European countries, Italy has one of the highest percentages of road transport (about 70% for goods and 90% for passengers; Cicerchia, 2004). According to the Italian Association of Motorway and Tunnel Concessionaire Companies (Aiscat), the highway network in Italy is constantly expanding. Currently it is 6,650 km long, but a further 150 km are under construction and further 500 km have already been planned in the coming years (Aiscat, 2010). This section attempts to provide a reliable measure of the damages related to climate change that are produced by road vehicles by determining the cost of CO_2 emission deriving from the Italian highways between 2010 and 2020.

From a theoretical perspective, the first step is to determine the annual national CO_2 emissions for the transportation mode *i.* This value can be calculated as the product of the distance covered, the average consumption of a standard vehicle and the overall amount of the vehicles considered (Nocera and Cavallaro, 2011). Then, the value obtained must be multiplied by the unitary economic price of CO_2, as shown in formula (1):

$$p_{ij} = (d_{ij} \cdot c_{ij} \cdot n_{ij}) \cdot u_j \qquad (1)$$

Where: p_{ij} stands for the cost of CO_2 emissions for the transportation mode *i* in the year *j;*

d_{ij} is the distance covered from the transportation mode *i* in the year *j*;
c_{ij} is the average fuel consumption of the standard vehicle of the transportation mode *i* in the year *j*;
n_{ij} is the overall amount of vehicles in the transportation mode *i* in the year *j*;
u_j is the unitary economic price of CO_2 emissions in the year *j*.

Operatively, AISCAT provides information about annual traffic circulation on the entire highway network. Data are expressed as total amount of cars and heavy goods vehicles (HGVs) and as vehicle kilometres travelled (VKT), that is, the sum of all kilometres travelled in a year on a highway by a given class of vehicles. Recalling formula (1), VKT can be thought as the product of d_{ij} by n_{ij}. Data are available from 1980 to 2010. By the adoption of a trend series, it is possible to extrapolate values and determine the amount of vehicles circulating along Italian highway network up to 2020. Overall data thus obtained, expressed as billion VKT, are reported in Table 2.

Table 2: Traffic on the Italian highway network between 1980-2020. Source: AISCAT, Annual Reports 1980-2010

TRAFFIC ALONG ITALIAN HIGHWAYS 1980-2020					
Year	**Cars** ***Billion VKT***	**HGVs** ***Billion VKT***	**Year**	**Cars** ***Billion VKT***	**HGVs** ***Billion VKT***
1980	22.99	9.91	2001	55.82	17.23
1981	23.76	10.24	2002	57.32	17.81
1982	24.91	10.29	2003	59.01	18.33
1983	25.26	10.23	2004	59.93	19.03
1984	26.79	10.56	2005	60.20	19.16
1985	28.34	8.10	2006	62.12	19.76
1986	30.68	8.44	2007	63.56	20.23
1987	33.42	9.12	2008	62.27	19.81
1988	36.48	9.96	2009	64.55	18.36
1989	38.88	10.82	2010	64.50	18.77
1990	40.48	11.31	**2011**	**69.50**	**20.67**
1991	41.23	11.92	**2012**	**70.98**	**21.23**
1992	42.77	12.30	**2013**	**72.41**	**21.81**
1993	43.76	12.31	**2014**	**73.80**	**22.39**
1994	45.16	12.93	**2015**	**75.09**	**22.98**
1995	46.47	13.51	**2016**	**76.34**	**23.58**
1996	47.07	13.73	**2017**	**77.55**	**24.01**
1997	48.77	14.43	**2018**	**78.77**	**24.42**
1998	50.82	15.16	**2019**	**80.04**	**24.83**
1999	52.13	15.97	**2020**	**81.40**	**25.25**
2000	53.62	16.77			

Note: normal type = historical data; bold type = forecast data

The specific annual emissions (c_{ij}) of a vehicle must then be determined. To this end, several tools have been developed in recent years (Nocera et al., 2012). The "Handbook Emissions Factors for Road Transport" (Infras, 2004) is known to be one of the most suitable. In this book, the evaluation of the specific emissions is based on vehicle type. For goods, the standard vehicle is a 14-20 tonne HGV powered by diesel (Euro 4), with an average speed of 85 km/h. The emissions are the average of a journey with a full and empty load. The standard vehicle for passengers is a 1.4-2 l car powered by gasoline (Euro 4), with an average speed of about 110 km/h. No slope on the highways is considered. Results are expressed in g/km (Table 3).

Table 3: CO_2 unitary emissions (g/km) of cars and HGVs on highways. Source: Infras, 2004

CO_2 SPECIFIC EMISSIONS		
YEAR	**CAR g/km**	**HGV g/km**
2010	207.41	656.12
2011	205.69	658.24
2012	203.99	660.24
2013	202.18	662.14
2014	200.66	663.75
2015	199.26	665.16
2016	197.96	666.56
2017	196.77	667.83
2018	195.67	668.97
2019	194.66	669.96
2020	193.74	670.80

Referring to formula (1) and recalling that u_j values were determined in Table 1, it is now possible to quantify the economic values of CO_2 emissions adopting the lower, medium and upper values as the product of data expressed in Tables 1, 2 and 3.

The external costs deriving from CO_2 emissions of cars alone in decade 2010-2020 are €2,238M, €4,706M and €10,840M, if lower, medium or upper unitary CO_2 prices are considered. The costs deriving from HGVs alone are €2,304M, €4,824M and €11,140M (Table 4).

Table 4: CO_2 economic value of car and HGV emissions on Italian highways for the period 2010 to 2020.

CO_2 ECONOMIC VALUE OF EMISSIONS ON ITALIAN HIGHWAYS						
	CARS			**HGVs**		
YEARS	**LOWER € M**	**MEDIAN € M**	**UPPER € M**	**LOWER € M**	**MEDIAN € M**	**UPPER € M**
2010	93.65	254.19	508.37	86.21	233.99	467.98
2011	118.65	298.77	621.84	112.93	284.36	591.85
2012	139.00	330.13	709.50	134.56	319.59	686.83
2013	159.57	361.60	797.87	157.41	356.70	787.05
2014	180.67	393.92	888.54	181.31	395.31	891.69
2015	201.99	426.43	980.03	206.35	435.63	1,001.19
2016	223.67	459.42	1,073.00	232.62	477.81	1,115.94
2017	245.68	492.88	1,167.35	258.16	517.92	1,226.65
2018	268.18	527.12	1,263.85	284.25	558.70	1,339.56
2019	291.36	562.47	1,363.32	311.08	600.53	1,455.58
2020	315.41	599.28	1,466.66	338.75	643.63	1,575.21
Total	**2,237.84**	**4,706.22**	**10,840.35**	**2,303.63**	**4,824.17**	**11,139.53**

The overall economic value of CO_2 emissions is then determined by summing of the outcomes of the method above described for each vehicle and for each year belonging to the period of time considered, as expressed in Table 5:

Table 5: CO_2 economic value of emissions on Italian highways in the period 2010 to 2020. Overall data

CO_2 ECONOMIC VALUE OF EMISSIONS ON ITALIAN HIGHWAYS FROM 2010 TO 2020			
TYPE	**LOWER**	**MEDIAN**	**UPPER**
	€ M	**€ M**	**€ M**
Cars	2,237.84	4,706.22	10,840.35
HGVs	2,303.63	4,824.17	11,139.53
Total	**4,541.47**	**9,530.39**	**21,979.88**

Table 5 summarises the economic impact deriving from CO_2 emissions on Italian highways in the period 2010 to 2020. As far as the lower value is considered, the overall costs of CO_2 emission are quantified at about €4,500M. The value rises to about €9,500M for the median value and about €22,000M for the upper value. This vast range (about Mio 17,500 €) is the economic difference in road transportation sector between a strongly sustainable policy and a policy that aims only at limiting the more detrimental consequences of global warming, but without facing them in a resolute way.

4. Conclusions

If the historical trend of road traffic use continues unabated, CO_2 emissions from the transport sector are likely to grow substantially in the coming years. On the other hand, widespread use of alternative fuels, electric batteries or fuel cells could lead to their reduction. These technical solutions seem however to demand substantive economic costs and technology changes.

Possible alternatives to lower overall costs depend on the implementation of new carbon policies: European governments wishing to achieve substantial CO_2 mitigation in the transport sector have at least three options: the first would be the conservative option of adopting the Kyoto Protocol, that is, reducing emissions by 8% compared with 1990 levels and taking the risk that the hazards of climate change become so apparent that technological and political costs to achieve more substantial greenhouse gas emission reductions cannot be avoided by society. The second would be to achieve the Europe 20-20-20 targets, that is, reducing CO_2 emissions by at least 20% compared to 1990 values by shifting 20% of energy needs to renewable sources by 2020. Under this policy, the most feasible opportunities for greenhouse gas mitigation in the transport sector are likely to lie in efforts to achieve other policy objectives– including reducing automobile dependence, traffic congestion, energy consumption and air pollution (Nocera, 2011), as well as reducing net subsidies to road users. These objectives may best be addressed through combinations of measures, including regulations and user fees to internalise social and environmental costs, and changes in access to public funding and infrastructure to shift priorities away from cars and trucks, towards buses, rail and non-motorised transport. The third and final alternative is linked to a radical 30% reduction with respect to 1990 CO_2 emissions. More stringent measures would be needed to achieve a greater reduction: huge fuel taxes would likely lead to less traffic and some vehicle downsizing, but should be accompanied by a reduction in speed limits and other fiscal and regulatory measures, along with the development of new technologies or the re-examination of transport needs and society's road use.

This paper has developed a method for the monetisation of carbon emissions on Italian highways in these three hypothetical scenarios. The method is based on forecasts of future CO_2 emissions, derived from the multiplication of future traffic demand, emissions, and total distance covered. The value obtained is further multiplied by the unitary CO_2 cost, determined with the Avoidance Cost method, which seems to be the most reliable technique if policy targets and measures are stated clearly.

Further refinements of the method described here could focus on three main areas: (i) a more complete survey on the composition of the car and HGV fleet, which should lead to a more detailed quantification of overall emissions; (ii) the determination of future traffic demand using different travel forecasting models: for instance, in a previous paper Libardo and Nocera (2008) have found a strong correlation between GDP and road passenger/km; (iii) the further refinement of economic CO_2 unitary values from deeper analysis that takes into account longer temporal horizons.

Our analysis has led to several interesting considerations. Firstly, the costs to mitigate carbon impacts in the three scenarios described above are radically different: the economic impact of CO_2 highway emissions if the Kyoto Protocol targets are embraced is approximately €4,540M; the figure is €9,530M if Europe assumes the 20-20-20 targets; and, finally, adopting a more sustainable policy aiming at reducing CO_2 emissions by 30% would incur a cost €21,980M (Table 5). As expected, the increased costs are not proportionally linear with CO_2 reduction. Indeed, the achievement of ambitious objectives (30% CO_2 reduction) carries much higher costs. According to EU (2012b), it must be considered that also the ‘Europe 20-20-20’ policy makes the achievement of the goal fixed by the IPCC scenario n° 1 possible: an increase of temperature in comparison with pre-industrial age of only 2°C and a stabilisation of CO_2 at 350-400 ppmv (Barker, 2007).

Secondly, major emissions, and consequently major climate change costs, are expected from HGVs (+€65.79M, +€117.96M and +€299.19M, if the lower, medium or upper unitary price are considered), even though the overall amount of cars is considerable higher in comparison with HGVs (Table 3). Independent of the aims of the policy adopted, these figures could be strongly reduced through appropriate measures for the reduction of road traffic demand, including discouraging road transport use and shifting towards railways without worsening the overall quality of transport. Preliminary forecasts would suggest that significant behavioral changes would be needed to complement the gains achieved by future technological improvements and that future carbon policies need to be globally-based with a strategic and coordinated framework of action prepared by local planners based on the core principles of sustainable development.

5. References

Aiscat (1980-2010). Annual Traffic Reports. Rome, Italy

Aiscat (2010). Aiscat informazioni. Quarterly Report. Online at .http://www.aiscat.it/pubblicazioni/downloads/trim-3-4_2010.pdf [07.02.2012].

Aldy J.E., E. Ley, I.W.H. Parry (2008). A tax-based approach to slowing global climate change. National Tax Journal, 61(3), pp. 493–517.

Barker T., I. Bashmakov, L. Bernstein, J. E. Bogner, P. R. Bosch, R. Dave, O. R. Davidson, B. S. Fisher, S. Gupta, K. Halsnæs, G.J. Heij, S. Kahn Ribeiro, S. Kobayashi, M. D. Levine, D. L. Martino, O. Masera, B. Metz, L. A. Meyer, G.-J. Nabuurs, A. Najam, N. Nakicenovic, H. -H. Rogner, J. Roy, J. Sathaye, R. Schock, P. Shukla, R. E. H. Sims, P. Smith, D. A. Tirpak, D. Urge-Vorsatz, D. Zhou (2007). Technical Summary. In: Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, L. A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Baumol W., W. Oates (1988). The theory of environmental policy. Cambridge: Cambridge University Press.

Black W.R. (2010). Sustainable Transportation: Issues and Solutions. New York and London: The Guilford Press.

Capros P., L. Mantzos (2000). Kyoto and technology at the European Union: costs of emission reduction under flexibility mechanisms and technology progress’, *Int. J. Global Energy Issues,* Vol. 14, Nos. 1-4, pp. 169-183.

Cicerchia A., 2004. Leggeri sulla Terra. L’impronta ecologica della vita quotidiana. Franco Angeli, Milano.

Clarkson R., K. Deyes (2002). Estimating the Social Cost of Carbon Emissions. Department of Environment, Food and Rural Affairs: London.

Commission of the European Communities (CEC) (2007). Limiting Global Climate Change to 2 degrees Celsius. The way ahead for 2020 and beyond. Online at: http://eur-lex.europa.eu/LexUriServ/site/en/com/2007/com2007_0002en01.pdf [07.02.2012].

Ellerman A. D., M. D. Webster, J. Parsons, H. D. Jacoby, M. McGuinness (2008). Cap and Trade: Contributions to the Design of a U.S. Greenhouse gas Program. MIT Center for Energy and Environmental Policy Research, Massachussets.

Elzen M.G.J.D., P.L. Lucas, A. Gijsen (2007). Exploring European Countries’ Emission Reduction Targets, Abatement Costs and Measures Needed Under the 2007 EU Reduction Objectives. Netherlands Environmental Assessment Agency (MNP), Bilthoven.

European Commission (EC) (2005). ExternE. Externalities of Energy, Methodology 2005 update. P. Bickel, R. Friedrich (eds.). Luxembourg: European Commission.

European Commission (EC), Directorate-general for energy and transport (2009). EU Energy and Transport in Figures. Statistical Pocketbook 2009. European Communities.

European Commission (EC) (2011). White Paper. Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system. Online at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0144:FIN:EN:PDF [07.02.2012].

European Union (EU) (2012a). Analysis of options to move beyond 20% greenhouse gas emission reductions and assessing the risk of carbon leakage. Online at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:0265:FIN:EN:PDF [14-02-2012].

European Union (EU) (2012b). EU action against climate change.
Online at:http://ec.europa.eu/climateaction/eu_action/index_en.htm [14-02-2012].
Forgó F., J. Fülöp, M. Prill (2005). Game theoretic models for climate change negotiations European Journal of Operational Research, Volume 160, Issue 1, 1 January 2005, pp. 252-267.
Fornasiero E., A. Libardo (2011). Market economy and sustainability: role of italian ports. Ingegneria Ferroviaria 66-5, pp. 449-470
Hansen J., Mki. Sato, P. Kharecha, D. Beerling, R. Berner, V. Masson-Delmotte, M. Pagani, M. Raymo, D.L. Royer, and J.C. Zachos (2008): Target atmospheric CO_2: Where should humanity aim? Open Atmos. Sci. J., 2, pp. 217-231.
Hope C. (2006). The marginal impact of CO_2 from PAGE2002: An integrated assessment model incorporating the IPCC's five reasons for concern, Integrated Assessment.
Infras (2004). The Handbook Emission Factors for Road Transport (HBEFA). Online at: http://www.hbefa.net. [07-05-2012].
Intergovernmental Panel on Climate Change (IPCC) (2007). Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Climate Change 2007: Synthesis Report. Geneva.
IUAV TTL (2010). Feasibility Decisions in Transportation Engineering. McGraw-Hill, Milan, Italy.
Kuik O., L. Brander, R.S.J. Tol (2008). Marginal Abatement Costs of Carbon-Dioxide Emissions: A Meta-Analysis. Energy Policy, 37, (4), pp. 1395-1403.
Libardo A., S. Nocera (2008). Transportation Elasticity for the Analysis of Italian Transportation Demand on a Regional Scale. Traffic Engineering and Control 49-5, pp. 187-192.
Litman T. (2011). Climate change emission valuation for transportation economic analysis. Research for Victoria transport policy Institute. Online at: http://www.vtpi.org/ghg_valuation.pdf [07.02.2012].
Maibach M., C. Schreyer, D. Sutter, H.P. van Essen, B.H. Boon, R. Smokers, A. Schroten, C. Doll, B. Pawlowska, M. Bak (2008). Handbook on estimation of external costs in the transport sector Internalisation. Measures and Policies for All external Cost of Transport (IMPACT) Version 1.1 Delft, CE.
Nash C. (2003). Unification of accounts and marginal costs for transport efficiency (UNITE), Final report for publication. Leeds : ITS, University of Leeds, 2003.
Nocera S. (2011). The key role of quality assessment in public transport policy. Traffic Engineering & Control 52-9, pp. 394-398.
Nocera S., F. Cavallaro (2011). Policy effectiveness for containing CO2 emissions in transportation. Proced Soc Behav Sci 20, pp. 703–713.
Nocera S., F. Maino, F. Cavallaro (2012). A heuristic method for determining CO2 efficiency in transportation planning. Eur. Transp. Res. Rev. DOI 10.1007/s12544-012-0073-x.
Nordhaus W.D. (1992). An optimal transition path for controlling greenhouse gases. Science 258, pp. 1315-1319.
Pearce D. (1991). The role of carbon taxes in adjusting to global warming. The Economic Journal, 101(407), pp. 938–948.
Santos G., H. Behrendt, L. Maconi, T. Shirvani, A. Teytelboym (2010). Externalities and economic policies in road transport. Research in Transportation Economics 28 (2010) pp. 2–45.
Sinha K. C., S. Labi (2007). Transportation Decision Making - Principles of Project Evaluation and Programming. John Wiley and Sons, New York, USA.
Sumner J., L. Bird, H. Smith (2009). Carbon Taxes: A Review of Experience and Policy Design Considerations. Technical Report NREL/TP-6A2-47312. Online at: http://www.nrel.gov/docs/fy10osti/47312.pdf [14-02-2012].
Transportation Research Board (TRB) (2008). Potential Impacts of Climate Change on U.S. Transportation. Special Report 290. Washington, DC: National Research Council, Transportation Research Board.
United Nations (UN) (1998). Kyoto protocol to the United Nations framework convention on climate change. Online at: http://unfccc.int/resource/docs/convkp/kpeng.pdf [01-02-2011].
van Essen H., O. Bello, J. Dings (2003). To shift or not to shift, that's the question. The environmental performance of freight and passenger transport modes in the light of policy making. Delft.
van Vuuren, D., M.G.J. Den Elzen, P. Lucas, B. Eickhout, B.J. Strengers, M.M. Berk, H.J.M. De Vries, M. Hoogwijk, M. Meinshausen, S.J. Wonink, R. Van den Houdt, R. Oostenrijk (2006). Stabilising Greenhouse Gas Concentrations at Low Levels: An Assessment of Options and Costs. Netherlands Environmental Assessment Agency, Bilthoven.
Watkiss P., D. Anthoff, T. Downing, C. Hepburn, C. Hope, A. Hunt, R. Tol (2005). The Social Costs of Carbon (SCC) Review: Methodological Approaches for Using SCC Estimates in Policy Assessment, Final Report. Department for Environment, Food and Rural Affairs (Defra), London.
Weitzman M. (1974). Prices vs. quantities. Review of Economic Studies, 41(4), pp. 477–491.