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Transport policy and climate change: How to decide when experts disagree

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ABSTRACT

Transport is the sector with the fastest growth of greenhouse gases emissions in many countries. Accumulation of these emissions may cause uncertain and irreversible adverse climate change impacts. In this context, we use the analytic hierarchy process (AHP) to face the question on how to select the best transport policy if the experts have different opinions and beliefs on the occurrence of these impacts. Thus, both the treatment of uncertainty and dissent are examined for the ranking of transport policies. The opinions of experts have been investigated by a means of a survey questionnaire. A sensitivity analysis of the experts' weights and the criteria' weights confirms the robustness of the results.

1. Introduction

The transport system has mutual interactions and multi-dimensional effects on environment (i.e. in terms of urban air pollution, climate change and land use), economic development (i.e. in terms of GDP) and social equity (i.e. in terms of accessibility, human health, life quality of cities and metropolitan areas).

Amongst the industries, transport is the sector with the fastest growth of greenhouse gases emissions, both in developed and in developing countries. In developed countries this problem is intensified with substantial growth in transport volumes. For example, in Italy, passenger and freight traffic have risen, respectively, by 29.5% and 22.75%, in the period 1990–2000. These traffic flows are expected to grow in the next years and, if no environmental policy action is applied by the government, the greenhouse gas emissions will increase (Mazzarino, 2000). The Italian government has developed the new Master Plan, which deals with the Kyoto Protocol on Climate Change of 1997. On the basis of this Protocol, the transport sector is committed to contribute to 15% reduction (with respect to the 1990 levels) of its CO_2 emissions. This is equivalent to reduce the CO_2 emissions by about 30 millions tons per year (t/year). On the other hand, developing countries strongly rely on energy consumption for their daily mobility. For example, in Singapore the rapid economic development has led to increase the demand for land transportation, which is strongly dependent on oil. Various measures and recommendations were announced and documented in the Singapore Green Plan to reduce the greenhouse gas emissions Poh and Ang (1999).

The aim of the different plans to reduce the greenhouse gas emissions and, hence, the adverse climate change impacts, can usually be achieved by different transport policies, each characterized quantitatively and qualitatively by different effects on the transportation system itself, as well as on

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environment, economic growth and social context. But as there is uncertainty on the occurrence of those impacts, a problem on how to select the best transport policy arises. The expected utility theory (EUT) is not appropriate as a general theory of decision-making under pure uncertainty, which prevails when the space of outcomes is well defined, but the decision maker has no basis for assigning probabilities to the different outcomes, such as in the case of climate change impacts. By construction, von Neumann-Mongersten utilities are insensitive to low probability events and, hence, this makes the expected utility approach inadequate for evaluating events under pure uncertainty. Furthermore, a second reason is that decision makers have different attitudes to gains and losses. Kahneman and Tversky (1979) found that disutility that people experienced from a loss of some magnitude often outweighed the utility from a gain of the same magnitude.

In this context, we have faced the problem by collecting the opinions of experts. However, the choice may become difficult if the experts have different beliefs and opinions. Thus, the problem to take into account is that of a decision-maker that faces a panel of experts with differing beliefs about alternative transport policies to reduce climate change impacts.

To our knowledge this paper is the first which concerns with the evaluation of the transport policies at global level. In facts, although various studies have been carried out on the design and evaluation of transport strategies (Colorni et al., 1999; May et al., 2000; Vold, 2005), essentially, all these works analyse the optimal transport strategy in urban areas or at local level. Furthermore, as there is uncertainty on the occurrence of the climate change impacts and there is lack of consensus among experts about them, the paper addresses the question on how to form transport policies when the experts disagree.

The opinions of experts have been surveyed by a means of a questionnaire. The experts were chosen as individuals with an in-depth understanding of the transport policies and their effects on climate change. Experts did not have to agree on the relative importance of the criteria or the rankings of the alternatives, but each expert entered his judgements giving a distinct, identifiable contribution to the issue. The experts had to compare six policy options: (i) voluntary agreements amongst industries to improve the ecological efficiency of new vehicles; (ii) incentives for turnover of car fleet renewal; (iii) tax schemes aiming at promoting environmental-friendly transport modes; (iv) better integration between transport planning and land uses; (v) new and better transport infrastructures; (vi) development of intelligent transport system (ITS) technologies.

We have applied the analytic hierarchy process (AHP), developed by Saaty (1980), which decomposes the decisional process in a hierarchy of criteria, subcriteria, attributes and alternatives through a set of weights. The AHP has been widely applied to assess numerous complex environmental and economic problems (Alphonce, 1997; Ramanathan, 2001; Duke and Aull-hyde, 2002; Ferrari, 2003). Furthermore, we run the sensitivity analysis to test under which conditions the ranking of policies may change if some parameters change. The method has involved specifying a certain number of experiments, which set different possible combinations of two parameters: the criteria' weights and the experts' weights. The sensitivity analysis confirms the robustness of the policy ranking.

2. The methodology

The AHP is a method of measurement for formulating and analyzing decisions. Saaty (1980) provided a theoretical foundation for the AHP, which is a decision support tool appropriate to solve complex decision problems taking into account tangible and intangible aspects. Therefore, it supports decision makers to make decisions involving their experience, knowledge and intuition.

The AHP decomposes the decision problem into elements, according to their common characteristics, and levels, which correspond to the common characteristic of the elements. The topmost level is the ‘‘focus'' of the problem or ultimate goal; the intermediate levels correspond to criteria and sub-criteria, while the lowest level contains the ‘‘decision alternatives''. If each element of each level depends on all the elements of the upper level, then the hierarchy is complete; otherwise, it is considered incomplete. The elements of each level are compared pairwise with respect to a specific element in the immediate upper level.

Table 1 reports the pairwise comparison scale used in the AHP developed by Saaty (1977). It allows to convert the qualitative judgments into numerical values, also with intangible attributes.

For computing the priorities of the elements, a judgmental matrix is assumed as follows:

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \quad (1)$$

where a_{ij} represents the pairwise comparison rating between the element i and element j of a level with respect to the upper

Table 1 – The AHP pairwise comparison scale

Numerical values	Verbal scale	Explanation
1	Equal importance of both elements	Two elements contribute equally
3	Moderate importance of one element over another	Experience and judgment favour one element over another
5	Strong importance of one element over another	An element is strongly favoured
7	Very strong importance of one element over another	An element is very strongly dominant
9	Extreme importance of one element over another	An element is favoured by at least an order of magnitude
2, 4, 6, 8	Intermediate values	Used to compromise between two judgments

level. The entries a_{ij} are governed by the following rules: $a_{ij} > 0$; $a_{ij} = 1/a_{ji}$; $a_{ii} = 1 \forall i$.

Following Saaty (1980, 2000), the priorities of the elements can be estimated by finding the principal eigenvector w of the matrix A, that is

$$AW = \lambda_{max} W \quad (2)$$

If the vector W is normalized, it becomes the vector of priorities of elements of one level with respect to the upper level. λ_{max} is the largest eigenvalue of the matrix A.

In cases where the pairwise comparison matrix satisfies transitivity for all pairwise comparisons, it is said to be consistent and it verifies the following relation:

$$a_{ij} = a_{ik} a_{kj} \quad \forall i, j, k \quad (3)$$

Saaty (1980) has shown that to maintain reasonable consistency when deriving priorities from paired comparisons, the number of factors to be considered must be less or equal to nine. AHP allows inconsistency, but provides a measure of the inconsistency in each set of judgments. The consistency of the judgmental matrix can be determined by a measure called the consistency ratio (CR), defined as

$$CR = \frac{CI}{RI} \quad (4)$$

where CI is called the consistency index and RI is the random index.

Furthermore, Saaty (1980, 2000) provided average consistencies (RI values) of randomly generated matrices (Table 2). CI for a matrix of order n is defined as

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (5)$$

In general, a CR of 0.1 or less is considered acceptable, this threshold is 0.08 for matrices of size four and 0.05 for matrices of size three. If the value is higher, the judgments may not be reliable and should be elicited again.

Once the local priorities of elements of different levels are available, in order to obtain final priorities of the alternatives a_i, the priorities are aggregated as follows:

$$S(a_i) = \sum_k w_k S_k(a_i) \quad (6)$$

where w_k is the local priority of the element k and $S_k(a_i)$ is the priority of alternative a_i with respect to element k of the upper level.

3. Transport policies

In order to reduce the greenhouse gas emissions, the decision makers can take into account six policy actions.[1]

[1] Readers can find a rigorous discussion of the different transport policy options in Button and Hensher (2001).

Table 2 – The average consistencies of random matrices (RI values)

Size	RI
1	0.00
2	0.00
3	0.52
4	0.89
5	1.11
6	1.25
7	1.35
8	1.40
9	1.45
10	1.49

Firstly, *voluntary agreements among industries to improve the ecological efficiency of new vehicles*, which concern the agreements on standard of emissions produced by vehicles. Environmental agreements in the transport sector are difficult to take place; however, in 1998, a voluntary agreement between the European Union and European car industries has been signed to reduce CO_2 emissions by 25% (per vehicle/km) by 2008.

Secondly, implementation of *incentives for turnover of car fleet renewal*, which can produce two opposite effects on the environment. The positive effect regards the reduction of the pollution emissions caused by the substitution of the old polluting vehicles with the new ones, which are cleaner. The negative effect regards the shorter average car's life and, therefore, if the incentives are permanent or repeated over time, they increase the amount of energy and materials used, and emissions caused by all the steps involved in car construction, dismantling, scrapping and recycling. The positive effect is likely to prevail for most of the schemes implemented.

Thirdly, *tax schemes aiming at promoting environmental-friendly transport modes*, which use the price mechanism to reduce the road traffic congestion and the greenhouse gas emissions, mainly in urban areas. These would allow the achievement of economic efficiency (price equal to marginal social costs), because the external costs produced by the transport sector and traffic are taken into consideration. Furthermore, the introduction of pricing schemes influences the costs of transport for certain modes, networks and/or time periods by means of taxes or fares, and involve all dimensions of travel choices: generation (choosing to make a trip); distribution (destination choice); mode choice (choosing the mode of transport); choice of day for travel and route choice. The use of pricing, combined with regulation of parking spaces available, is applied quite widespread in urban areas. This combination is thought as a very powerful tool for influencing the number of vehicles attracted to an area, enhancing in the same time the public transport, with rapid effects on reducing traffic and, thus, environmental pressure, where it is desired (Paulley, 2002).

Fourthly, *better integration between transport planning and land uses*, which regards both the transport demand management and the control of development. The former has to address issues of meeting environmental standards, identifying pollution hotspots, and setting and achieving traffic reduction targets, but at the same time ensuring that all people have appropriate levels of accessibility to jobs, services and facilities. The latter has to control the development of activities within existing public transport corridors (mainly, with integrated public transport systems by time scheduling, space coordination and fare integration) and by making the city structure more easily accessible, improving living conditions and decentralizing business and services activities. (Banister, 2001).

Fifthly, implementation of *new and better transport infrastructures*. The transport systems depend on the capacity of the infrastructure. The rapid growth in transport demand and, hence, of the congestion in transport infrastructures (port, airport, highways and rail stations) requires either new constructions or transport demand management policies. Environmental and social costs involved in the construction of new infrastructures make this solution unacceptable and not good in the long period, because the expected growth demand will be able to cause still worse congestion levels. On the other hand, transport demand management policies can increase the capacity of infrastructures through information provision. Nevertheless, in all cities road construction is still seen as an important measure, as well as the construction of pedestrian areas. Construction of public transport infrastructure depends on the present public transport system and on the size of the city. Bus and/or tram lanes are used or planned and light rail systems are in use in many cities. Park and ride facilities are built in the larger cities and off street parking facilities in smaller cities. Traffic calming infrastructure and cycle paths have been planned in many cities (Lakshmanan and Anderson, 2001; May et al., 2003).

Finally, *development of intelligent transport systems (ITS) and information technologies* are now emerging as a set of key tools for improvement in the management of the transportation network. These must be considered in the context of travel demand management, because the new and emerging technologies allow to improve the modal split of travel. There is a number of possible ways to affect peoples' choices as to which mode of travel to select in space and in time, in broad terms. These are the following:

(i) reduce the reliance or attractiveness of private transport through measure, such as private vehicle access control;
(ii) increase the attractiveness of more environmental and sustainable forms of transport (such as public transport, car pooling);
(iii) use of new telematics means to reduce the reliance on travel to congested business areas and city centres by trip substitution in the form of teleworking/telecommuting.

In terms of integrated transport and demand management, a key requirement is to facilitate the interchange between the private and public transport. Whilst the information provision, both on trip and pre-trip, provides the mechanism by which the traveller make an informed decision on mode, time and route, public transport, dedicated bus lanes and other bus priority measures are the key to provide a service with more reliable travel times and a quicker route through the congested road network. The provision of information is a means for the success of transport integration and interchange. Intelligent transport systems offer many new routes for the provision of this information before the user begins his or her trip. These systems also dynamically provide information to users on trip through in-vehicle delivery of information, roadside mounted VMS, personal information devices (SMS mobile phone) as well as the internet, kiosks and information boards at interchange facilities (Taylor, 2001; Chowdhury and Sadek, 2003).

4. Assessment of alternative transport policies

In order to evaluate alternative transport policies to reduce the adverse climate change impacts, we have investigated the opinions of nine experts on transport policies and economics by a means of a survey questionnaire. The expert sample is formed by two associate professors and seven researchers coming from different academic institutions.[2] Their scientific research is mainly on transport policy and environment. Consulting more experts avoids bias that may be present when the judgements are considered from a single expert. Experts did not have to agree on the relative importance of the criteria or the rankings of the alternatives. Each expert entered his judgement and gave a distinct, identifiable contribution to the issue.

For the case study, a three-level AHP has been applied, as shown in Fig. 1. The first level is composed of the final goal one wishes to attain in carrying out the project: reduction of the adverse climate change impacts due to the transport sector.

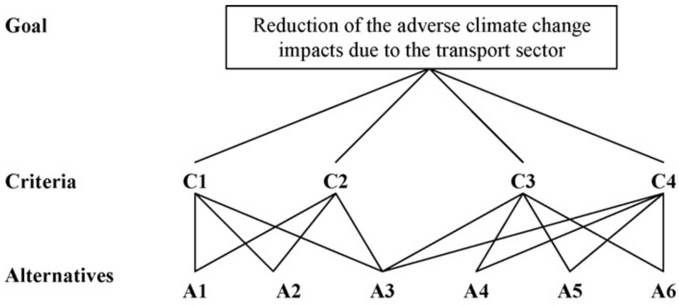
The second level represents the criteria on the basis of which the projects are to be evaluated:

- adoption of fuels with reduced carbon content (C1);
- technological improvements in the ecological efficiency of vehicles (C2);
- increase in the public and multi-modal transport market share (C3);
- improvements due to better mobility management systems (C4).

The third level presents the policy options, which are:

- voluntary agreements amongst industries to improve the ecological efficiency of new vehicles (A1);
- incentives for turnover of car fleet renewal (A2);
- tax schemes aiming at promoting environmental-friendly transport modes (A3);
- better integration between transport planning and land uses (A4);
- new and better transport infrastructures (A5);
- development of intelligent transport system (ITS) technologies (A6).

[2] The experts have been selected from Institute for Transport Studies (University of Leeds, Leeds, UK), Institute for Environment and Sustainability, Transport and Air Quality Unit (European Commission, Ispra, Italy), Danish Transport Research Institute (Denmark) and Centre for Transport Research (Roskilde University, Denmark).



C1 adoption of fuels with reduced carbon content
C2 technological improvements in the ecological efficiency of vehicles
C3 increase in the public and multi-modal transport market share
C4 improvements due to better mobility management systems

A1 voluntary agreements amongst industries to improve the ecological efficiency of new vehicles
A2 incentives for turnover of car fleet renewal
A3 tax schemes aiming at promoting environmental-friendly transport modes
A4 better integration between transport planning and land uses
A5 new and better transport infrastructures
A6 development of intelligent transport system (ITS) technologies

Fig. 1 – Analytic hierarchy structure.

The criteria C1 and C2 involve the alternatives A1, A2 and A3. Essentially, A1 and A2 regard the factors directly responsible of the vehicle emissions by fixed standards on fuels and vehicles. The alternative A3 indirectly produces environmental benefits through the disincentive of private car use, increasing the perceived costs of private transport, and promoting the public transport and non-motorized modes (by cycle and walking). Moreover, the criteria C3 and C4 involve the alternatives from A3 to A6, since their environmental benefits are correlated with the traffic reduction produced by transport demand management policies either transport demand side or transport supply side.

Experts were asked to compare pairwise the relative importance of the elements for each level on the basis of the Saaty scale (Table 1). The questionnaire submitted to the experts is reported in the Appendix A.1. From the pairwise comparisons, a judgmental matrix was formed for each expert. This matrix was used for computing the priorities and the consistency index was carried out. Appendix A.2 reports the matrix of criteria and alternative comparisons per each expert. Furthermore, the priorities expressed by experts have been combined using the geometric mean method (Ramanathan and Ganesh, 1994; Saaty, 2000).

5. Results

By applying the procedure previously outlined, the results indicate the highest importance to the criteria C2 "technological improvements in the ecological efficiency of vehicles" (35.1%); the other three criteria have almost equal priority (about 20%). Results from the eigenvector of the criteria comparison matrix, reported in Table 3, provide an estimate of the weights of the criteria. The principal eigenvalue of this matrix is $\lambda_{max} = 4.027$, with a $CR = 0.0098 < 0.08$. Thus, the results are consistent.

Table 4 reports the priorities of the policy options for each criteria. Tax schemes aiming at promoting environmental-friendly transport modes (A3) turn out to have the highest priority for any criteria. In particular, for the criteria C1 (adoption of fuels with reduced carbon content) and C2 (technological improvements in the ecological efficiency of vehicles), the priority of A3 is slightly higher than 60%. The remaining is shared almost equally by the other two alternatives: voluntary agreements amongst industries to improve the ecological efficiency of new vehicles (A1) and incentives for turnover of car fleet renewal (A2). For criteria C3 and C4 the priority of A3, respectively accounts for 40% and 36% and is lower than its weight for the other two criteria. The priority A4 (better integration between transport planning and land use) is the second-best policy option for both criteria. A5 (new and better transport infrastructures) is slightly more important than A6 (development of ITS technologies) for

Table 3 – Matrix of criteria comparison

Criteria	C1	C2	C3	C4	Weights' vector
C1	1	0.584	0.921	1.421	0.228
C2	1.712	1	1.408	1.825	0.351
C3	1.086	0.710	1	0.956	0.226
C4	0.704	0.548	1.046	1	0.195

Table 4 – Matrix of the priorities of the policy options per criteria

Policy options Criteria	A1	A2	A3	A4	A5	A6
C1	0.199	0.177	0.624	0	0	0
C2	0.217	0.178	0.605	0	0	0
C3	0	0	0.407	0.243	0.209	0.141
C4	0	0	0.361	0.302	0.169	0.167

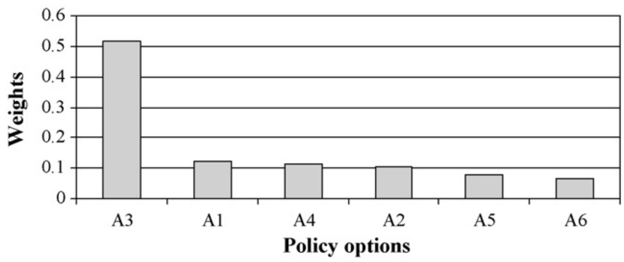


Fig. 2 – Analytical hierarchical process priorities for policy options.

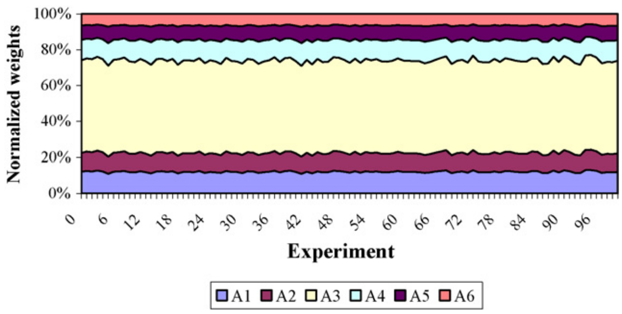


Fig. 3 – Sensitivity analysis of criteria' weights.

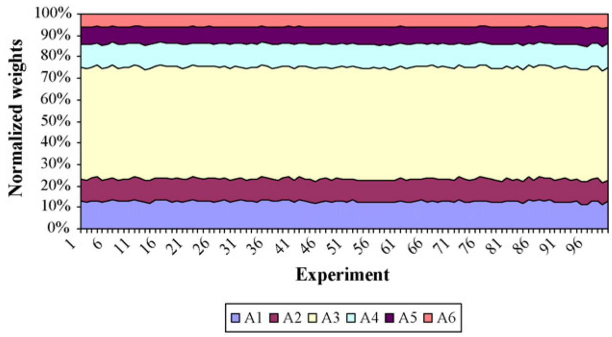


Fig. 4 – Sensitivity analysis of the experts' weights.

criteria C3; whereas, A5 and A6 are almost equally important for criteria C4.

The ranking of the policy options with respect to the ultimate goal, shown in Fig. 2, is obtained by multiplying the transpose matrix of priority of the alternative under each criteria (Table 4) by the weights of the matrix vector of compared criteria (Table 3). The policy option A3 receives the highest importance (more than 50%); A1 is the second-best option (12%), but it is slightly more important than A4 and A2.

6. Sensitivity analysis

We run the sensitivity analysis to test under which conditions the ranking of alternatives may change if some parameters change. The method has involved specification of certain number of experiments, which set different possible combinations of two parameters: the criteria' weights and the experts' weights.

The weight w_i has been supposed to evolve according to the stochastic differential equation:

$$dw_i = \mu w_i\, dt + \sigma w_i\, dz \quad \forall_i \tag{6}$$

This equation implies that w_i is changing according to a process of *geometric Brownian motion* (GBM). The term μ dt is the mean or expected percentage change in w_i for the increment dt, and μ is called the *mean drift rate*. The term σ dz introduces a random component to the drift, because $dz = \varepsilon(t)\sqrt{dt}$, where $\varepsilon(t)$ is a normally distributed random variable with 0 mean and standard deviation of 1. A discrete approximation of (6) is given by the stochastic difference equation:

$$w_{i,t+1} = (1+\mu)w_{i,t} + \sigma w_{i,t}\,\varepsilon_{t+1} \tag{7}$$

where the ε_{t+1} are the standard normal variates and the implied increment is dt = 1.

By giving the base weights to vector of the criteria in Table 3 and the values for μ and σ, selected from the standard normal distribution defined for the 95% confidence interval, we have generated sample paths of 100 random numbers for any criteria. The sensitivity results, reported in Fig. 3, confirm the ranking of the policy options in Fig. 2. Also Table 5, which reports the mean percentage change in each alternative and the standard deviation across the 100 random samples, suggests that the results are relatively robust to different combinations of the weights' values. In fact, the mean percentage change is very low, as well as the standard deviation tends to be quite small. Moreover, analysing the sample probability of the ranking of alternatives, we have found that A3 is always the best option, and the change in the ranking of alternatives is mainly due to the fact that A4 becomes slightly more important than A1 (26% of cases) or less important than A2 (9% of cases). Substantially more robust results follow from the sensitivity analysis of the experts' weights, as reported in Fig. 4 and Table 6.

Table 5 – Sensitivity analysis of criteria' weights

	Mean (%)	Standard deviation
A1	3.276	0.009
A2	3.362	0.007
A3	3.676	0.028
A4	4.430	0.007
A5	4.235	0.005
A6	4.408	0.004

Table 6 – Sensitivity analysis of experts' weights

	Mean (%)	Standard deviation
A1	0.003	0.005
A2	0.001	0.003
A3	−0.001	0.003
A4	0.002	0.003
A5	−0.005	0.003
A6	0.000	0.002

7. Discussion and conclusions

Amongst the alternative policies, the *tax schemes aiming at promoting environmental-friendly transport modes* have been identified as the best transport policy to reduce the adverse climate change impacts. Thus, the experts still now retain that only if people pay for the full costs due to their choices, then the reduction in traffic, and, hence, of emissions, is obtained, because pricing policies are able to affect the behaviour of road users, increasing their perceived costs of private transport. However, this policy action may fail if the willingness to pay by road users is high. Furthermore, as in any use of prices, there are problems of fairness and equity: a ban which applies equally to everybody is often perceived as fairer than using prices, which affect some people than others. It follows that a key role has to be played by the public transport system, which should be able to attract major shares of the transport demand by information diffusion (pre- and on-trip) and by improving the perceived quality of the service. Also, government should promote public and environmental-friendly transport modes, such as car sharing and car-pooling, or non-motorized modes. The efforts of planning should be addressed to modify the behaviour of users, rationalizing their trips (reducing number of kilometres run and eliminating unnecessary trips), and rebalancing their modal choices to reduce climate change impacts.

As the ranking of policies depends strongly on the sample of interviewed experts, to avoid bias in the results, a sensitivity analysis has been run, that confirms the robustness of the results. Of course, the results may change if other groups, such as stakeholders, policy makers and citizen groups, are involved. But the choice to select only experts finds reasons in the fact that experts, more than the other groups, are challenged to meet the needs of stakeholders and public. Finally, the methodology is striking. It integrates two relevant questions in the effectiveness of policy assessment: how uncertainty is managed and how opposing insights are dealt with.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.envsci.2008.01.008.

REFERENCES

Alphonce, C.B., 1997. Application of the analytic hierarchy process in agriculture in developing countries. Agric. Syst. 53, 97–112.

Banister, D., 2001. Transport planning. In: Button, K.J., Hensher, D.A. (Eds.), Handbook of Transport Systems and Traffic Control, Vol. 3. Pergamon, pp. 9–19.

Button, K.J., Hensher, D.A., 2001. Handbook of Transport Systems and Traffic Control. Pergamon, Oxford (UK).

Chowdhury, M.A., Sadek, A., 2003. Fundamentals of Intelligent Transportation Systems Planning. Artech House, Boston.

Colorni, A., Laniado, E., Muratori, S., 1999. Decision support systems for environmental impact assessment of transport infrastructures. Transport. Res. D 4, 1–11.

Duke, J.M., Aull-hyde, R., 2002. Identifying public preferences for land preservation using the analytic hierarchy process. Ecol. Eco. 42, 131–145.

Ferrari, P., 2003. A method for choosing from among alternative transportation projects. Eur. J. Oper. Res. 150, 194–203.

Kahneman, D., Tversky, A., 1979. Prospect theory: an analysis of decision making under risk. Econometrica 47, 263–291.

Lakshmanan, T.R., Anderson, W.P., 2001. Infrastructure capacity. In: Button, K.J., Hensher, D.A. (Eds.), Handbook of Transport Systems and Traffic Control. Pergamon, Oxford (UK).

May, A., Sheperd, S.P., Timms, P.M., 2000. Optimal transport strategies for European cities. Transportation 27, 285–315.

May, A.D., Jopson, A.F., Matthews, B., 2003. Research challenges in urban transport policy. Transport Policy 10, 157–164.

Mazzarino, M., 2000. The economics of the greenhouse effect: evaluating the climate change impact due to the transport sector in Italy. Energy Policy 28, 957–966.

Paulley, N., 2002. Recent studies on key issues in road pricing. Transport Policy 7, 175–177.

Poh, K.L., Ang, B.W., 1999. Transportation fuels and policy for Singapore: an AHP planning process. Comput. Ind. Eng. 37, 507–525.

Ramanathan, R., 2001. A note on the use of the analytic hierarchy process for environmental impact assessment. J. Environ. Manage. 63, 27–35.

Ramanathan, R., Ganesh, L.S., 1994. Group preference aggregation method employed in the AHP: an evaluation and an intrinsic process for deriving members' weightages. Eur. J. Oper. Res. 79, 249–265.

Saaty, T.L., 1977. A scaling method for priorities in hierarchial structures. J. Math. Psychol. 15, 234–281.

Saaty, T.L., 1980. The Analytic Hierarchy Process: Planning, Priority Setting and Resource Allocation. McGraw-Hill, New York.

Saaty, T.L., 2000. Fundamentals of Decision Making and Priority Theory with the Analytic Hierarchy Process. RWS Publication, Pittsburg.

Taylor, M.A.P., 2001. Intelligent transport systems. In: Button, K.J., Hensher, D.A. (Eds.), Handbook of Transport Systems and Traffic Control. Pergamon, Oxford (UK).

Vold, A., 2005. Optimal land use and transport planning for the Greater Oslo area. Transport. Res. A 39, 548–565.

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