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Multidisciplinary study on reducing air pollution from transport—methodology and emission results

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Abstract

Within the national programme 'Sustainable Mobility' (1999-2001) Vito is working on the project 'measures in transport to reduce CO_2 and tropospheric ozone'. Measures are evaluated on their effectivity to reduce CO_2, ozone precursors (NO_x and VOC) and ozone concentrations, their techno-economic and social feasibility and their subsidiarity.

A methodology for multidisciplinary studies has been set up and tools have been chosen. Beside a description of the methodology, the first results concerning the effectivity to reduce CO_2, NO_x and VOC are discussed.

CO_2 emissions increase steadily from 1990 to 2012 for all scenarios. Thus, none of the defined scenarios could individually meet the Kyoto Protocol. For Business-As-Usual (BAU) scenario the CO_2 emissions increase by 62% in 2012 in comparison with 1990. The scenario involving car-pooling and Tele-working shows a clear curb in increase of CO_2 in comparison with the BAU scenario. Reducing passenger cars through more public transport and reducing freight road traffic through rail transport or inland shipping also seem appropriate options.

By 2012 NO_x and VOC decrease respectively by 61 and 85% under BAU scenario. For VOC the emission limits of the Göteborg Protocol are fulfilled for all scenarios, for NO_x only four scenarios are satisfactory. To reduce NO_x and VOC advanced introduction of environment-friendly vehicles and enhanced inspection and maintenance seem the most appropriate options.

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1 Introduction

In many countries growing traffic has raised concern about air pollution. Greenhouse effect, transgression of ozone limits, smog, etc. are highly topical problems requiring urgent attention. The pursuit of environmental quality and public health on one hand and constant economic growth on the other demands commitments and a policy that focuses on sustainable development. Therefore international agreements on reducing the discharge of various harmful substances are formulated. Well-known international agreements are the Kyoto Protocol on reducing greenhouse gases and the Göteborg Protocol setting emission limits on SO_2 (sulphur dioxide), NO_x (nitrogen oxides) and VOC (volatile organic compounds).

As in many countries, traffic in Belgium, especially road traffic, remains an important source of pollution. Road traffic is responsible for about 20% of the total CO_2 emission, 50% of the total NO_x emission and 35% of the NMVOC emission. Strategies to reduce emission from transport and fulfil international commitments have to be drawn up and implemented.

Within the national programme 'Sustainable Mobility' Vito is working on the evaluation of measures in transport to reduce CO_2 and tropospheric ozone. The feasibility to fulfil international commitments is also checked. A methodology for multidisciplinary studies has been set up and made operational. In the following, this methodology is briefly described and results concerning the effectivity of measures to reduce CO_2, NO_x and VOC are discussed.

2 Methodology

Before going into detail on the tools being used in this project an overview of the different tasks is given, see in Figure 1.

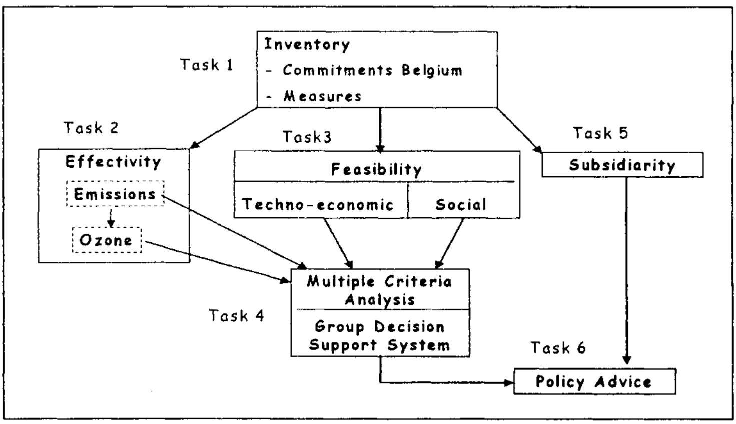

Figure 1: Global structure of the project.

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In task 1 a listing of commitments and obligations made in the international context in relation to the CO_2 and ozone problem is compiled. This task also involves the inventory of measures for the transport sector to manage above-mentioned commitments. For this purpose existing measures are further supplemented with approved but not yet introduced measures and new potential measures for Belgium.

Task 2 evaluates the effectivity of these measures for reducing emissions from transport and the ozone concentration in the air. Task 3 studies the techno-economic and social feasibility of the measures. Results of tasks 2 and 3 are the basis for a multiple criteria analysis, which is executed by several decision-makers. A Group Decision Support System exercise will aggregate the individual preferences into one group ranking of the measures.

Final policy advice will be given based on the group ranking taking into account the subsidiarity of the different measures and the feasibility to fulfil international commitments. Subsidiarity comprises a legal and policy expert examination of the execution modalities of the proposed measures.

2.1 Emission model TEMAT

To estimate future emissions from transport Vito has developed a model named 'TEMAT', *T*ransport *E*mission *M*odel to *A*nalyse (non-) *T*echnological measures. This model calculates emissions from road transport for non-technological as well as technological measures. For rail and ship traffic spread sheet models are used, based on the simplified MEET methodology [1].

Most of the TEMAT developing work was done within a project under contract to the Flemish Administration of the Environment, Nature, and Land Use (AMINAL) [2]. The development of such a model was very important because clear policy advice can only be given when the influence of different parameters is well known. Furthermore, a solid model for Belgium and the Flemish Region is developed, which could be extended and updated in future projects.

The basic formula for transport emissions consists of three main components, see eqn (1).

$$\text{Emission/year} = \text{emission factor} \times \text{activity/vehicle/year} \times \text{number of vehicles} \quad (1)$$

Emission factor is a constant or a speed dependant function [1,3]. In TEMAT this factor is function of: year, fuel type, age, technology, road type, traffic type, cylinder capacity or weight of vehicle, emission types. Furthermore a distinction is made in source of emission: warm, cold, evaporation, and distribution and production of fuels.

The activity is the mileage driven by a vehicle, historically this is known from statistics and inquiries. For the future, results from traffic models are integrated [4]. Within TEMAT activity is a function of year, fuel type, age, technology, road type, traffic type, cylinder capacity or weight of vehicle.

The number of vehicles comes from statistics or is calculated for the future given the total mobility demand by traffic experts or own scenario definition. The vehicle number is a function of year, fuel type, age, technology, cylinder capacity or weight of vehicle.

Road transport consists of six main vehicle categories: passenger cars, mini buses, light duty freight vehicles, buses, heavy-duty freight vehicles and motorised two-wheelers. Besides, the conventional fuel types petrol, diesel and LPG (Liquefied Petrol Gas) also alternative fuels are integrated i.e.: CNG (compressed natural gas), electric, hybrid, fuel cell methanol, fuel cell hydrogen and biodiesel.

Emissions can be calculated for CO (carbon monoxide), CO_2, NO_x, VOC, PM (particulate matter), SO_2 and Pb (lead). Three road types are distinguished: urban, rural and highway. Furthermore we distinguish normal and peak traffic. All these parameters can be extended in future studies.

TEMAT can be used at regional or national scale for annual emission estimations from transport. It is also a database in which input and output data are shown in an extensive way. An English version has been developed and made operational for Belgium and the Flemish Region.

2.2 OZON94 model

Although still in discussion, the most important ozone evaluation parameters seem to expand over longer periods (e.g. a whole summer). Models taking into account the hourly ozone concentrations for such a long periods lead to high computation time. Since many scenarios has to be evaluated to determine their effect on ozone concentration, Vito decided to design a simplified and fast model for policy support named 'OZON94'. The model uses the long-term meteorological conditions for the period May-August 1994 and varies the precursor emissions of VOC and NO_x. An extensive model (LOTOS) calculation sets the basis for this assessment [5]. The construction of the "OZON94" model is further based on a multiple linear regression technique, a method that is used and accepted internationally, e.g. in the RAINS model [6]. The RAINS model was applied to investigate the possible EC reduction strategies for ozone abatement and its results formed the basis for the negotiations leading to the Göteborg Protocol. Given the international character of the ozone problem, the effect of a measure on the ozone situation in Belgium can differ depending on the region in which the measure is carried out. We assume that each measure is implemented in the whole of the EU.

OZON94 estimates values for 13 ozone criteria. The selected ozone evaluation parameters for the multiple criteria analysis are: Accumulated exposure Over a Threshold of 60 ppb (parts per billion) or 120 $\mu g/m^3$ (AOT60), Accumulated exposure Over a Threshold of 40 ppb (AOT40ppb) and Number of Exceedances of a Threshold of 60 ppb (NET60ppb).

The AOT60 is a cumulative index related to long-term health effects. The AOT40 is a cumulative index estimating the long-term damage of ozone on

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ecosystems. The last parameter is linked to the future European directive on ozone and expresses a threshold related to instruments of legal actions [7].

For the three evaluation parameters mentioned above, the results of "OZON94" for 1994 were compared with measured values and showed a very satisfying agreement [8].

To avoid many long model runs, we compiled working tables In each table the NO_x and VOC emissions are reduced simultaneously with steps of 5% and the effect on the ozone evaluation parameters is calculated for each case using the same regression algorithm. This requires only a limited number of calculations and results in an universal working table from which ozone evaluation parameters and effectivity values can rapidly and simply be derived for a given measure. This makes such a working table an extremely handy tool for policy support with respect to ozone abatement.

2.3 Techno-economic and social feasibility

The techno-economic feasibility aims the cost-effectivity of measures within the transport sector. An international accepted approach based on private and national costs are used [9]. These costs are estimated on the base of literature and contacts with experts.

Beside CO_2, NO_x and VOC, two other pollutants are taken into account - CO and particulate matter - are taken into account within the cost-effectivity estimation of the different measures.

Unit reduction costs for different pollutants are derived from cost and emission figures. A measure is called cost-effective if the unit-reduction cost for one or more pollutants falls within the range set by alternative measures in other sectors. As most measures have effects on different pollutants simultaneously, cost effectiveness might be granted if unit reduction costs for more then one pollutant are close to the upper limits set by alternative measures in other sectors.

The general social feasibility of government measures, to a great extent, goes hand in hand with the perceptions and attitudes of those who have to carry out the measures (group 1) and those who will be subjected to them (group 2). This also applies to measures for limiting environmental problems caused by transport. Since almost the entire Belgian population belongs to these two groups, an investigation into the social feasibility must also be directed at the entire population.

A general questioning of the Belgian population, however, falls outside the scope and means of this project. Therefore an expert-opinion investigation is opted for. At first a social chart is compiled, charting the most important target groups and users, together with the actors (interest groups and policy makers), including their mutual interrelationships. On the basis of dynamic understanding of the social context in which the proposed measures will have to be executed, a selection is made of the most significant groups, institutions and their representatives. Opinions are asked on the feasibility of the proposed measures – in various different time perspectives (now, 2005 and 2010) – and on the presumed effects of these measures. These opinions are processed into quantitative data and inserted as criteria in the multiple criteria analysis.

2.4 ARGUS multiple criteria analysis

As a model for the multiple criteria analysis 'ARGUS' was chosen (Achieving Respect for Grades by Using Ordinal Scales only). ARGUS has been developed at the Free University of Brussels that is subcontracted to carry out this multiple criteria analysis [10]. This model has been chosen, because it allows to evaluate quantitative and qualitative values in an integrated way and solutions are stable - e.g. even when a measures is left out the model results in the same ranking. Furthermore, considerable input is needed from decision-makers by having them express their preference for the different criteria.

The ranking of the measures will be done such that the emission effectivity (CO_2, NO_x and VOC), ozone effectivity and social feasibility are maximal. The costs, in contrast, must be minimised.

Nine criteria well-balanced over the different disciplines were defined: cumulated (2001-2012) emission reduction of CO_2, NO_x and VOC, AOT60, AOT40, NET60, national cost, social desirability and political feasibility.

2.5 Group decision support system

A Group Decision Support System (GDSS) exercise will process the rankings of the individual decision-makers to one single ranking of the measures [11]. A group decision problem with e.g. m decision-makers can be seen as m multiple criteria problems: a multiple criteria method is selected (see §2.4) and applied – by ***a/o*** modelling the preferences of each decision-maker – to the problem. This results in m rankings of the alternatives. Since all decision-makers have used the same multiple criteria method, the GDSS will aggregate the individual preference models into one group preference model. This results in one group ranking of the alternatives.

First a measurement of how well a group ranking fits compared to the m individual rankings of the decision makers is worked out using the rank correlation coefficient of Kendall [12]. Then a multiple criteria method was selected. For this problem, the ARGUS-method was chosen.

Two methods will be used to find the 'best' group ranking according to the defined measurement. The first method will aggregate the individual preference models, which is in the ARGUS-method reflected in the balances, of the m different decision-makers into one group preference model. The second method is independent of the used multiple criteria method. It looks for the 'best' group ranking. In other words, it looks for a ranking that maximises the median of the m rank correlation coefficients of Kendall between that ranking and each individual ranking. The technique to find this 'best' group ranking will be simulated annealing, a combinatorial optimisation heuristic [13]. A heuristic method has been chosen because this optimisation problem can not be

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formulated in such a way that an existing algorithm can be used. The number of possible rankings –there can be ties! - is combinatorial determined.
The final group ranking will be the 'best' ranking of the two group rankings obtained by these two methods.

3 Emission results

3.1 Description of scenarios

3.1.1 Business-As-Usual scenario

A reference scenario assuming policy is left unmodified, i.e. Business-As-Usual or BAU scenario, has been designed. Hereby, account is taken of the expected developments in technology, economics and mobility. Technological measures been taken until mid 2000 – even when the implementation starts after this date - are taken into account. The agreement of the European Commission and the automotive industries to reduce average CO_2 emission from new cars is also integrated in BAU scenario.

CO_2, NO_x and VOC emissions from transport are analysed for the period 1990-2012. Those emissions include exhaust emissions and VOC evaporative losses of petrol-fuelled vehicles. Emissions related to production and transport of electricity used for electrical traction in rail traffic or electrical cars are also taken into account.

3.1.2 Alternative scenarios

On the base of the inventory of measures 12 options or scenarios were defined, see Table 1. These scenarios are related to a package of measures. It was decided to work on a higher abstraction level, packages in stead of individual measures, because this approach makes it easier to calculate the effectivity of measures enhancing or overlapping one another. This makes the use of the ARGUS methodology for the multiple criteria analysis more practicable.

Table 1: Overview of the 12 defined alternative scenarios.

N°	Description of alternative scenarios
1	Advanced introduction of environment-friendly conventional vehicles
2	Advanced introduction of environment-friendly alternative vehicles
3	Enhanced replacement of old vehicles
4	Conversion of vehicles to more environment friendly alternatives: retrofit
5	Introduction of electrical vehicles
6	Enhanced inspection and maintenance
7	More environment-friendly driving style
8	Reduce passenger car use through more car pooling and Tele-working
9	Reduce passenger car use through more public transport
10	Reduce passenger car use through more cycling and walking
11	Reduce road freight traffic through rail transport
12	Reduce road freight traffic through inland shipping

For the alternative scenarios it was aimed for to perform model runs for a realistic implementation level of the measures. Therefore, input data and boundaries for realistic scenarios were selected based on a questionnaire on the assessments of the economical and social acceptation for each objective. First an internal Vito working group came to a consensus. These results were discussed during a workshop with external experts [14].

3.2 Discussion

Figure 2 shows the evolution of the CO_2, NO_x and VOC emissions from transport in Belgium. Scenarios 4 and 7 are not plotted in the figure because model runs are not yet executed. The upper curve shows the evolution under the BAU scenario. The CO_2 emissions increase steadily over the given time horizon for all scenarios. In comparison to 1990 emissions in 2012 increased by 62% under BAU. For NO_x and VOC, emissions decrease respectively after 1992 and 1991. In comparison with 1990 the emissions decrease respectively by 61 and 85% in 2012 under BAU.

Analyses of the results of the different transport modes showed that rail and inland shipping traffic only have a marginal contribution to the total CO_2, NO_x and VOC emissions from transport. Passenger cars remain to have the main contribution in the near future. However for NO_x and VOC, heavy-duty freight vehicles are becoming as important as cars when approaching 2012.

Figure 2 shows that the agreement on new cars emitting less CO_2 is not sufficient to decrease or even stagnate CO_2 emission from transport. Although the agreement has slow down the increase of CO_2 from transport: an increase of 62% instead of 78% 'without' agreement in 2012 in comparison to 1990.

Although Figure 2 seems somewhat fuzzy, it clearly shows that he emission trends set by the BAU scenario are only affected in a small degree by the alternative scenarios.

To better visualise the differences between the scenarios, cumulative emission reductions for the period 1990-2012 are plotted in Figure 3. Most appropriate options to reduce CO_2 seem car-pooling and Tele-working, public transport and reducing freight road traffic through rail transport or inland shipping.

Concerning the reduction of NO_x and VOC, advanced introduction of environment-friendly vehicles and enhanced inspection and maintenance seem the most appropriate options. Also advanced replacement of old vehicles could result in a significant decrease of VOC emissions.

The scenario introducing electrical cars results in a small decrease of emissions. This can be explained by the low degree of acceptance of these cars. With exception of VOC, also enhanced replacement of old cars gives low emission reductions, especially for CO_2. Incentives for replacement were only given for 2 years: 2002 and 2003. Furthermore CO_2 emissions of new cars further decrease after 2003.

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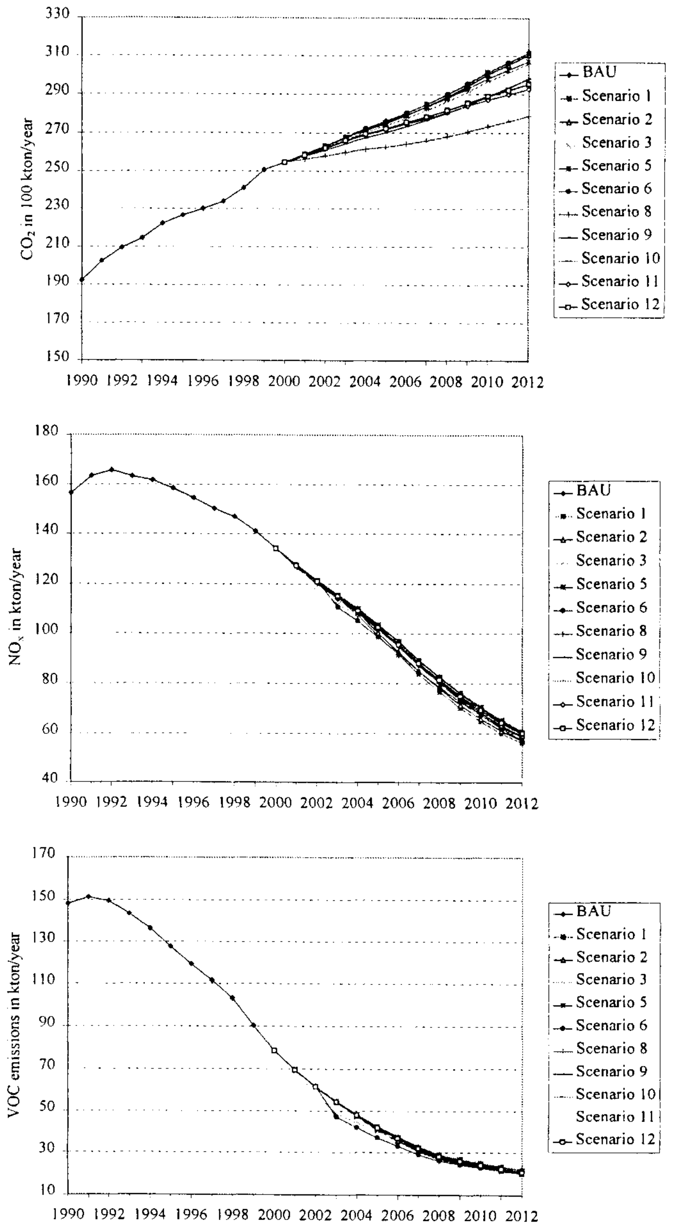

Figure 2: Evolution of CO_2, NO_x and VOC emissions from transport in Belgium for BAU and alternative (see Table 1 for description) scenario.

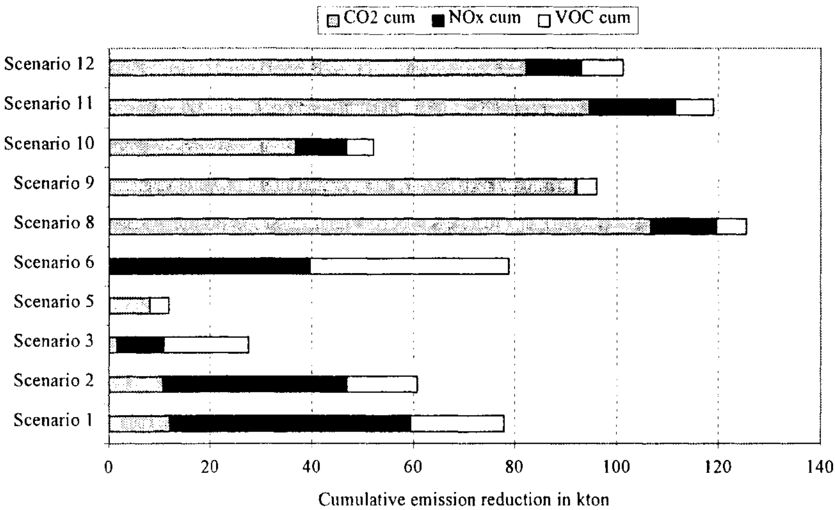

Figure 3: Cumulative CO_2, NO_x and VOC emission reduction (2001-2012) for the different scenarios (description in Table 1), in 100 kton CO_2 and kton NO_x and VOC .

3.3 Feasibility of international commitments

For each scenario the feasibility to comply with international commitments concerning CO_2 and ozone precursors - NO_x and VOC - is evaluated. For Belgium, the Kyoto Protocol attempts to reduce greenhouse gases by 7.5% averaged over 2008-2012 and 1990 taken as year of reference. Contributions of the different sectors have not been defined, so we assumed equal reduction goals for all sectors. The Göteborg Protocol sets emission limits in 2010 for ozone precursors. For the Belgian transport sector these limits are 68 kton NO_x and 35.6 kton VOC.

Table 2 gives an overview of the feasibility of the different scenarios to comply with above Protocols. Non of the scenarios could individually fulfil the Kyoto Protocol, but all of them - even BAU – fulfil for the VOC. For NO_x only the scenarios involving advanced introduction of environment-friendly vehicles comply with the limit. Enhanced inspection and maintenance, and car-pooling and tele-working resulted in emission in 2010 of 67.5 kton, so limits are only narrowly met.

Table 2: Feasibility of scenarios to meet international commitments.

Scenario	Kyoto Protocol	Göteborg Protocol	
	CO_2	NO_x	VOC
BAU	Not OK*	not OK	OK
1	Not OK	OK	OK
2	Not OK	OK	OK
3	Not OK	not OK	OK
5	Not OK	not OK	OK
6	Not OK	OK	OK
8	Not OK	OK	OK
9	Not OK	not OK	OK
10	Not OK	not OK	OK
11	Not OK	not OK	OK
12	Not OK	not OK	OK

* OK = okay, limits are met

4 Conclusions

Within the national programme 'Sustainable Mobility' Vito has set up a methodology for multidisciplinary evaluation of measures in transport. Tools have been selected and made operational. Measures are evaluated on their effectivity to reduce emissions and ozone concentrations, their techno-economic and social feasibility and their subsidiarity.

This methodology is applied in the project 'measures in transport to reduce CO_2 and troposferic ozone'. Interim results on the effectivity of measures to reduce CO_2, and ozone precursors (NO_x and VOC) are discussed.

CO_2 emissions increase steadily from 1990 to 2012 for all scenarios. Thus, none of the defined scenarios could individually meet the Kyoto Climate Protocol. For Business-As-Usual (BAU) scenario the CO_2 emissions increase by 62% in 2012 in comparison with 1990. Most appropriate options to reduce CO_2 seem car-pooling and Tele-working, public transport and reducing freight road traffic through rail transport or inland shipping.

Under BAU scenario NO_x and VOC emissions decrease respectively by 61 and 85% by 2012. For VOC the emission limit of the Göteborg Protocol is fulfilled for all scenarios. For NO_x on the other hand only four scenarios meet the requirement. Advanced introduction of environment-friendly vehicles and enhanced inspection and maintenance seem the most appropriate options to reduce NO_x and VOC.

The scenario introducing electrical cars results in a small decrease of emissions, because of the low degree of acceptance of these cars.

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