ESTIMATING THE ENERGY AND EMISSION IMPACTS FROM THE IMPLEMENTATION OF TRANSPORT MEASURES

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Abstract

This paper presents the evaluation methodology and energy and emissions impacts of JUPITER (Joint Urban Project In Transport Energy Reduction). JUPITER is a transport project involving the implementation of a range of integrated transport management measures designed to increase the use of public transport, reduce the use of private cars, improve vehicle efficiency and use alternative fuel technologies in order to reduce the consumption of fossil fuels and harmful vehicle emissions. The measures were demonstrated in six European cities: Aalborg (Denmark), Bilbao (Spain), Florence (Italy), Gent (Belgium), Liverpool (United Kingdom) and Patra (Greece). The evaluation was based on the application of a spreadsheet model, which is a planning tool purposely developed in the context of JUPITER for the estimation of the energy and emission impacts from the implementation of transport measures.

INTRODUCTION

Transport is a major and ever-increasing pollutant of the environment. Road transport now contributes to most of the total carbon monoxide emitted in the UK, about half of all volatile organic .compounds, nitrogen oxides and black smoke, and nearly a quarter of the total carbon dioxide, the primary greenhouse gas (Department of Transport, 1997). In order to stabilise the emissions of carbon dioxide by the year 2000, as agreed at Rio in 1992, transport should have contributed a reduction of 2.5 million tonnes of carbon out of a total of 10 million tonnes. Instead, the best estimates are that it will increase its emissions by that same amount.

Transport is also a major and increasing user of energy in modern society. Energy consumption in the European transport sector has increased from 16.7 to 30.8 units between 1960 and 1994 (Eurostat, 1996). Currently, the transport sector consumes about a third of all energy in Europe. Road transport is responsible for about 85% of the energy consumed within the transport sector.

The continuous growth in transport demand, together with the expansion of the capacity of the transport infrastructure has led to increased pressure on the environment. Energy use and the emission of harmful pollutants have grown significantly in the past and are projected to continue growing in the future. Solutions for the environmental problem are urgently needed in order to enable a more sustainable development.

Governments and industries have begun the process of controlling transport emissions and reducing the consumption of fossil fuels. Emission controls and regulations have been introduced, technological improvements have been made in vehicle manufacturing, and various alternative fuel technologies have been introduced with successful results (Royal Commission on Environmental Pollution, 1994; Wemyss, 1996). In addition, a wide range of transport and demand management schemes, planning policies and control strategies have been introduced to promote a better use of transport facilities and mitigate the negative impacts on the environment (Hughes, 1992; Department of the Environment and Department of Transport, 1993; Chiquetto, 1995; Hall, 1995).

OBJECTIVES

This paper presents a method for the estimation of the impacts of transport measures on transport emissions and energy consumption. The method is based on the application of a spreadsheet model (Chiquetto and Blackledge, 1996). The estimates can be used to furnish planners, local authorities and transport operators with evidence about the likely energy and emission impacts from the implementation of proposed transport strategies and measures.

THE JUPITER PROJECT

JUPITER (Joint Urban Project In Transport Energy Reduction) was launched in 1993 as a major research and demonstration collaboration initiative, partially funded by the European Commission through its THERMIE energy-saving programme (Directorate General for Energy – DG XVII). JUPITER is a transport project involving the implementation of a range of integrated transport management measures designed to reduce energy and emissions.

The process of design, development, demonstration and evaluation took nearly four years. The total investment was 62 million ECUs, of which 21% was financed by the THERMIE programme. The project had the full support of the political administrations in the partner cities. JUPITER was co-ordinated by Merseytravel, the public transport authority for the Merseyside region in the UK, and managed by Transport & Travel Research Ltd., who also developed the evaluation methodology for the project.

The JUPITER measures were demonstrated in cities offering a range of sizes and structures and covering six different member states of the European Union: Aalborg (Denmark); Bilbao (Spain); Florence (Italy); Gent (Belgium); Liverpool (United Kingdom) and Patra (Greece). Figure 1 shows the location of the JUPITER cities.

Figure 1 - Location of the JUPITER cities

The main objective of JUPITER was to demonstrate the potential of a range of integrated transport measures for reducing the consumption of fossil fuels and harmful vehicle emissions, by:

- increasing the use of public transport;
- reducing the use of private cars;
- introducing new, fuel-efficient public transport vehicles;
- evaluating the use of alternative fuel technologies.

The systems implemented as part of JUPITER can be categorised within six main strategies:

- Improvement of public transport;
- Investment in new vehicles and fuels;
- Management and control of traffic;
- Provision for non-motorised modes;
- Parking policy;
- Intermodality.

It was intended that the integration of the various types of transport strategies would provide added value in terms of the overall impacts. The various integrated transport measures implemented in JUPITER are summarised in Table 1.

Table 1 - Measures implemented in JUPITER

MEASURES	JUPITER CITY					
	AALBORG	BILBAO	FLORENCE	GENT	LIVERPOOL	PATRA
IMPROVEMENT OF PUBLIC TRANSPORT						
Stops, stations and interchanges	∇	∇	o	∇	∇	
Automatic Vehicle Location systems		o	o	o	o	o
Trip planning information systems		o				o
Real-time information systems		o		o	∇	o
Advanced ticketing					o	
Image	o	o	o	o	o	o
INVESTMENT IN NEW VEHICLES AND FUELS						
Low-emission diesel buses		∇	∇		∇	o
CNG buses		∇	∇			
Hybrid buses	∇					
Electric battery buses			∇			
Lightweight buses	o					
Bio-diesel buses	o					
MANAGEMENT AND CONTROL OF TRAFFIC						
Traffic management and restraint	o	o	o	∇	o	
Priority lanes				∇	o	
Urban traffic control & associated systems		o		∇	o	o
Signal priority	o		o	∇	o	∇
Information systems						∇
PROVISION FOR NON-MOTORISED MODES						
Pedestrianisation		o				
PARKING POLICY						
Parking management systems		o		o		∇
Parking information and guidance systems	∇			o		∇
INTERMODALITY						
Park and Ride	o	o	o	∇		∇
Integrated payment system				∇		
UTC & PT integration		o	∇	o	o	o

o *Part of the JUPITER project in the city*
∇ *A major element of the JUPITER project in the city*

Although most of the individual measures implemented within JUPITER were not new, the project was innovative in the sense that it involved the introduction of packages of complementary measures in a range of different city environments, and provided the opportunity for a comprehensive evaluation of their impacts.

The inter-relationships between the implemented JUPITER measures and their potential energy and environmental impacts are summarised in Figure 2. The main focus of the project evaluation was on measuring, modelling and assessing these impacts.

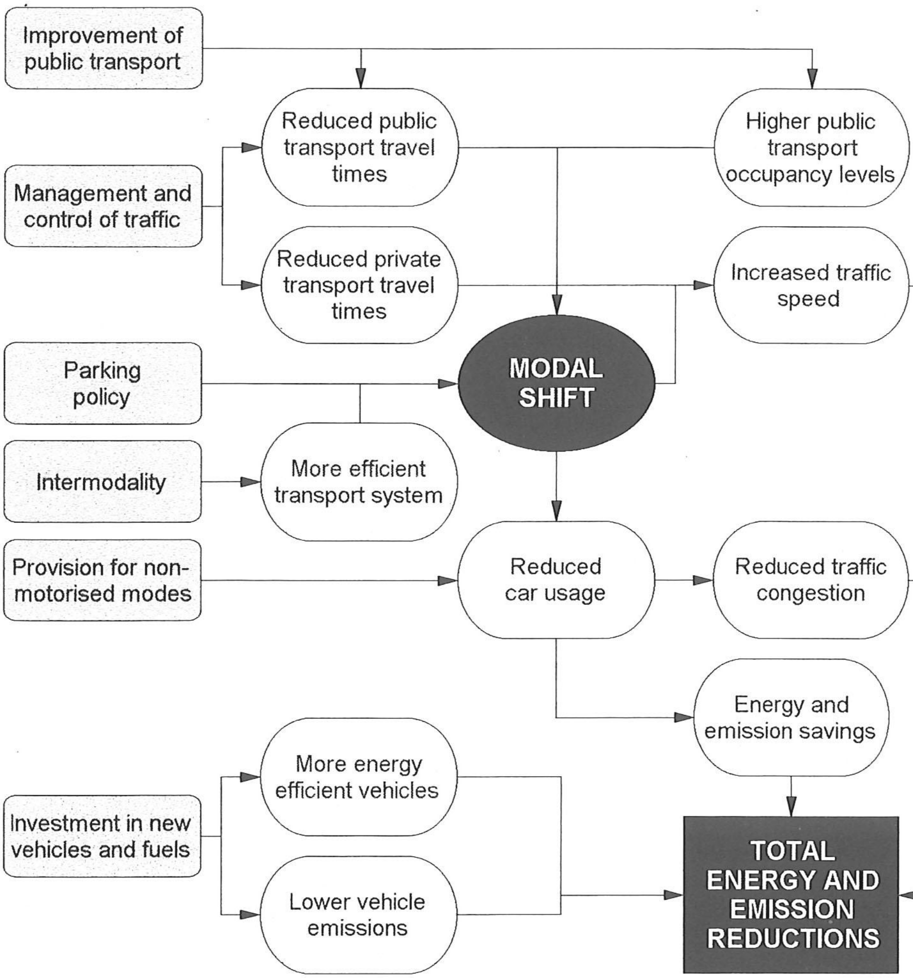

Figure 2 - The relationship between JUPITER measures and energy/emission impacts

The JUPITER project is now completed, and the measures implemented can be seen to have had a considerable effect on travel patterns, accessibility, energy use and environmental conditions. These impacts have enabled the individual cites to meet the JUPITER project goals.

JUPITER EVALUATION

The primary objective of the JUPITER evaluation was to determine the energy and environmental impacts of the integrated urban transport management and fuel efficiency measures implemented in the city demonstration projects. This included not only the immediate impacts measured in the field trial areas, but also the potential impacts on whole cities and on the global environment. Ultimately, the benefits from the reduction in energy and emission impacts, along with other benefits for users and operators, were considered against the costs associated with these measures.

The JUPITER Evaluation Working Group was established during the formative stages of the project consortium. This group was created to develop a common evaluation methodology, which would ensure the application of consistent methods to measure and model the impacts of the JUPITER measures within each partner city. The focus of the development of the methodology had been to ensure that the approaches adopted by the individual partner cities were sufficiently similar to allow comparative results to be obtained, even though the techniques adopted may not have been the same. These were selected to be the most appropriate for each individual partner city.

The estimation of the energy and environmental impacts was a major focus of the project evaluation. The evaluation methodology embraced not only the variety of measures being implemented and the different ways in which energy and emission savings were achieved, but also the different environments of the cities. In addition, the possibility of extending the measures to other areas of the cities, and to other cities willing to adopt energy-saving transport policies, were also considered as part of the overall assessment. The JUPITER evaluation was carried out in three levels:

- *City project evaluation* – This evaluation level was applied to the measurement of the local impacts of the city demonstration projects. Each JUPITER city was responsible for carrying out its own demonstration evaluation within the common framework. These required some monitoring and data collection in all cities in order to measure key variables in each evaluation category, plus the use of existing data from research studies and other projects. The precise activities adopted in any particular city depended on the nature of the project and the resources available to the city.
- *Strategic level evaluation* – Strategic level evaluation was undertaken in each city in order to assess the potential impacts of extending each of the city projects to cover a wider area (e.g. the whole city or conurbation). This involved extrapolating the results of the city project evaluation to the wider area, which has enabled comparisons across the demonstration projects in different JUPITER cities.
- *European level evaluation* – The final stage in the evaluation was the comparative European evaluation. The objective was to consider whether the lessons learnt in one city could be applied to other cities of comparable size and demography. Unfortunately, limitations on data availability and comparability meant that it was impossible to complete this work.

THE JET MODEL

The evaluation was based on the application of a method purposely developed by Transport & Travel Research Ltd. in the context of JUPITER, for the estimation of the energy and emission impacts from the implementation of various transport measures. JET (JUPITER Energetics in

Transport) is a spreadsheet model originally developed in 1994. In 1996, significant improvements led to Version 2 and Version 3 is currently under way.

Input data

JET provides a way of predicting energy and emissions impacts from a set of input data which were either directly available or could be estimated for any city. The data for both the current and predicted situations following implementation of the measures in question comprise:

- Vehicle-kilometre data by mode and vehicle type;
- Network average speeds, trip lengths and vehicle occupancies;
- Average annual air temperature;
- City characteristics data (used for the European evaluation only).

Factors taken into consideration

Energy and emissions from traffic sources are influenced by a large number of factors, particularly in the urban transport environment. It is extremely difficult to incorporate all such factors into a single estimation procedure. Nevertheless, the JET model uses a set of factors and equations which reflect the best practice within the current state-of-the-art, taking into consideration the most relevant factors influencing traffic emissions, namely:

- *Road traffic composition* – This is an essential consideration, since different vehicles produce different pollutant emissions at different rates and consume different amounts of fuel. The road vehicle categories included in JET are: cars, buses, heavy goods vehicles, motorcycles and vans.
- *Type of fuel* – Because emission rates from petrol vehicles are very different from those produced by diesel vehicles for the various air pollutants, private cars are classified in JET into petrol and diesel. The potential contribution of new technology public transport vehicles in JET was particularly relevant for the JUPITER project, since many cities have introduced state-of-the-art diesel buses and buses powered by alternative fuels. The types of fuel for buses included in JET are: diesel, compressed natural gas (CNG), electricity (batteries) and petrol / electric hybrid.
- *Average traffic speed* – Traffic emission studies at the local level commonly consider the variation in emission factors with changing traffic conditions as a function of traffic speed (ETSU, 1995). The basic speed-emission functions for private cars in JET are based upon the CORINAIR study (Eggleston *et al*, 1993). This represents the most comprehensive effort to compile common sets of speed-related equations from different categories of European vehicles, according to engine size, technology and type of fuel. The functions for bus emissions according to speed are taken from TÜV Rheinland (ETSU, 1995). The emissions from other road transport vehicles (such as vans and heavy goods vehicles) are not calculated as a function of traffic speed.
- *Car engine size* – This factor is only taken into account in JET for private cars, as other vehicles (for example, heavy goods vehicles and vans) have a small range of engine sizes and their contribution to total traffic level is usually limited. The classification for car engine sizes in JET is: < 1.4 cm^3, between 1.4 and 2.0 cm^3, and > 2.0 cm^3.

- *Type of buses* – Different sizes and types of bus produce different energy and emission factors. There is a huge variety of buses in Europe, and these were classified in JET into three main categories: large conventional diesel, EURO-2 type (which produce reduced emission levels) and mini.
- *Fitting of catalytic converters* – In the UK, the fitting of catalytic devices in petrol cars has become compulsory and such devices alter significantly the patterns of traffic emissions. Petrol cars are sub-classified into those fitted and not fitted with catalytic converters.
- *Cold emission* – A great deal of traffic pollutants is emitted when the engine is not operating at its most efficient level. In addition, the performance of catalytic converters in petrol cars is drastically reduced under such conditions. Thus, because the speed related equations represent hot running conditions, the emission estimates for private cars have to be corrected for cold running conditions. It is assumed that all public transport vehicles operate constantly under hot conditions, as their cold cycle is normally completed before they enter service.

Further discussions about the factors, equations and the assumptions used in the JET model can be found in Chiquetto and Blackledge (1996).

Further features

The JET model provides further capabilities which enhance the attractiveness of the tool, the main one being a cost-benefit module incorporating:

- *Monetary valuation of the externalities in transport* – The externalities of traffic represent costs to society, which can be significant within evaluation procedures. The JET model produces estimates of the monetary valuation for the externalities of traffic, based on recent research and a set of assumptions contained in Banister (1997). The estimates include the costs incurred from greenhouse gases, local air pollution, noise, road damage, accidents and congestion.

Output format

For each city, the JET model produces estimates of:

- Emissions of carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (HC), total particulate matter (PM) and carbon dioxide (CO_2) (in tonnes per year);
- Fuel consumption (in litres per year);
- Energy consumption (in megajoules per year);
- Energy efficiency (in megajoules per passenger-kilometre).

The estimates are provided in terms of the absolute and percentage changes due to the implementation of the transport measures, both overall and by mode of transport. The results of emission changes across the JUPITER cities are presented in table and graph formats. Results and graphs are automatically produced when traffic and city characteristics data are input for the 'before' and 'after' situations.

Advantages and constraints

The main advantages of the JET model are that it is simple to use, is very flexible, takes into consideration some of the most important factors of urban traffic conditions and yet requires relatively little input data. The model can be applied to any other area or city as long as the required traffic and city characteristics input data can be provided.

The main difficulty with using JET is that the traffic conditions and city characteristics for the 'before' and 'after' situations must be pre-defined by the application of transport models, measurements, surveys or estimates. The quality of the input data has a considerable effect on the quality of the results.

Despite the potential constraints in the accuracy of predictive procedures, the JET model is considered to be accurate and reliable enough to represent changes in energy and emissions from transport measures with a sufficient level of detail that it can help planners to draw meaningful conclusions.

EVALUATION RESULTS

The potential for environmental improvements varies between city projects, mainly because of the wide range of objectives and investment levels for the measures implemented in different JUPITER cities (Blackledge, 1994 and 1995). The evaluation of the impacts of the various city projects was based upon the set of data required from each city for the application of the JET model, which have been derived from the application of transport models, traffic surveys, measurements and estimates. The accuracy of the evaluation relies on the accuracy of the estimation procedure, which in turn relies heavily on the quality of the input data.

Figure 3 presents the estimated savings in emissions and energy consumption for each JUPITER city. The left hand side bar indicates the actual savings achieved in the city demonstration projects, whereas the right hand side bar indicates the estimated potential benefits which could be achieved if these projects were to be implemented at a wider scale (from the strategic evaluation).

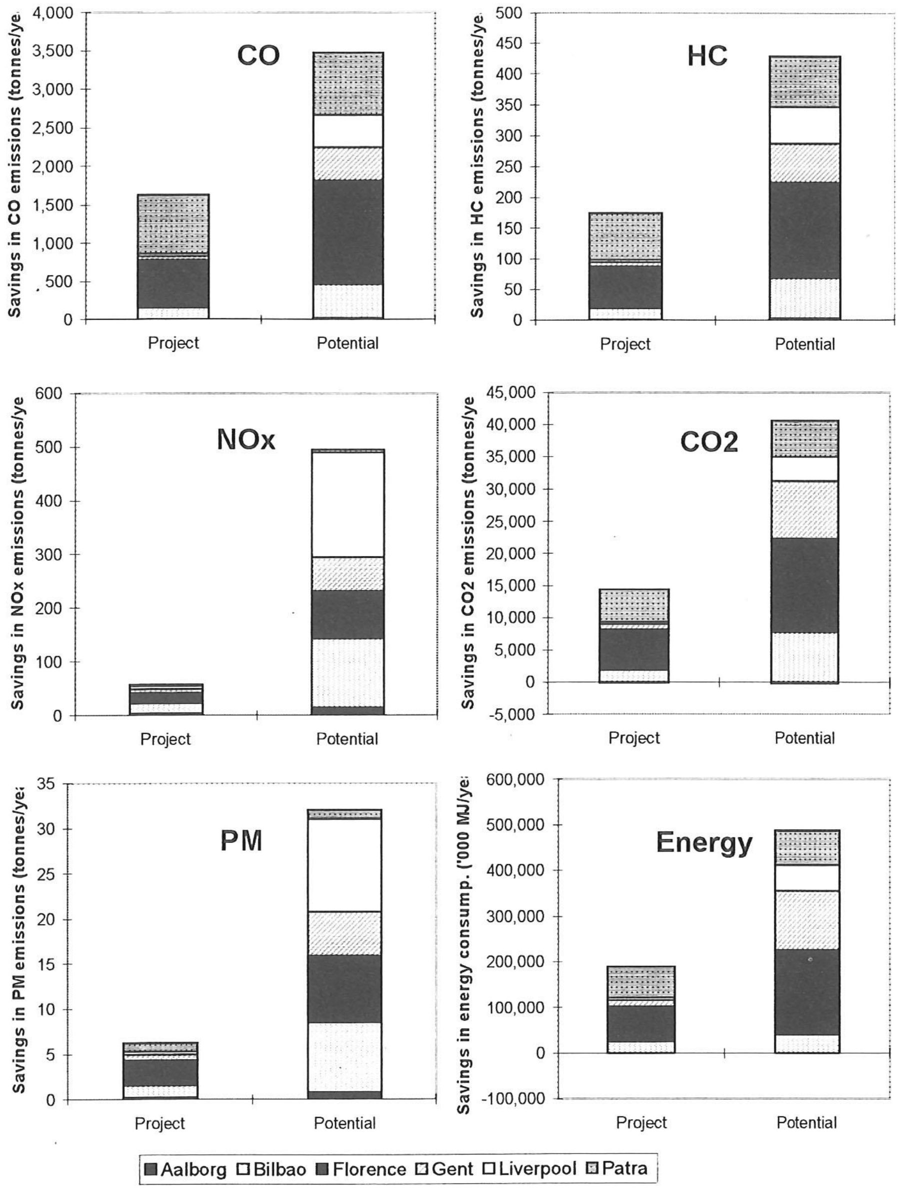

Figure 3 - Estimated emission savings in the JUPITER cities

Based on the application of the JET model, these figures indicate that emission were reduced significantly in all JUPITER city projects. The total reductions in the emission level of CO, NO_x, HC, PM and CO_2 from the JUPITER project as a whole have been estimated at approximately: 1628, 58, 175, 6 and 14276 tonnes per year, respectively. Considerable reductions in the consumption of fuel and energy were also achieved. The modal shift, together with other influences including the use of alternative fuels, promoted a reduction in fuel consumption by 5.7 million litres per annum in all JUPITER cities. On the other hand, 286,000 m^3 of CNG are now consumed by the new CNG buses. Overall, energy consumption has been reduced by about 189 million megajoules per annum.

The potential benefits of emission reductions at the strategic level would be much more substantial than at the project level. At the strategic level, the overall reductions in the emission levels of CO, NO_x, HC, PM and CO_2, have been estimated at about 3473, 495, 429, 32 and 40280 tonnes per year, respectively. The potential savings in energy consumption have been estimated at 486 million megajoules per annum.

Estimates have also been produced for the percentage changes between the 'before' and 'after' scenarios. Figure 4 shows the estimates of the percentage reduction in the total emissions for each air pollutant under consideration and in energy consumption, from the package of measures implemented in each JUPITER city. The left hand side set of bars indicates the actual percentage reductions achieved in the city demonstration projects, whereas the right hand side bars indicate the estimated potential reductions, which could be achieved if these projects were implemented at a wider scale.

The figures indicate that the magnitude of percentage reductions varies considerably according to the city and pollutant, because different measures implemented in each city produce different environmental impacts.

In general, the measures within JUPITER are estimated to provide substantial benefits in terms of emission and energy reductions. Such benefits are mostly due to the introduction of lower emission public transport vehicles and reduction in car travel from the modal shift promoted. For the project level, emission and energy reductions ranged from an increase of 0.14% for CO_2 in Aalborg to a reduction of nearly 10% for CO in Patra. For the strategic level, estimated reductions could vary from a small increase of 0.44% for CO_2 in Aalborg to a reduction of about 23% for PM in Bilbao. The increases in fuel consumption and CO_2 emissions in Aalborg are due to the introduction of the new technology petrol/electric hybrid buses.

It may seem that the percentage reductions are low, but this is due to the fact that the various measures implemented only affect a limited number of vehicles in the project area. Such overall reductions are, therefore, realistic and the packages of measures implemented in each city can be considered successful. Moreover, it has been shown that benefits could increase significantly if the measures implemented were to be expanded to a wider scale.

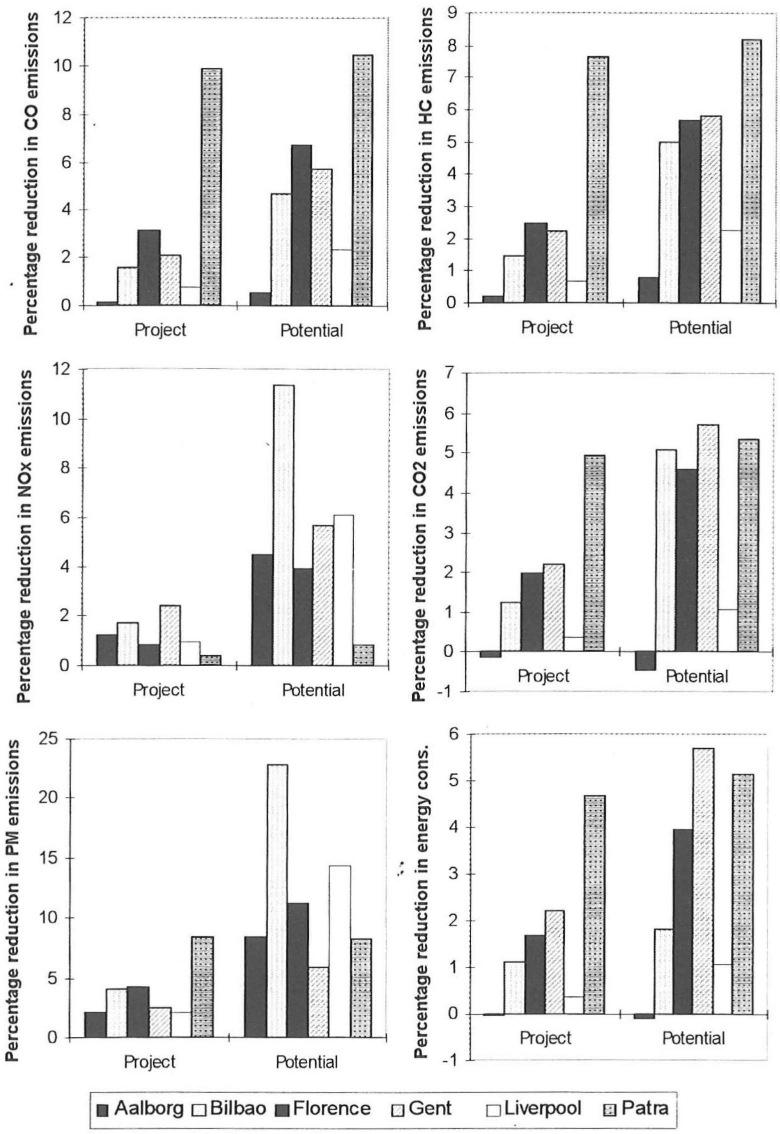

Figure 4 - Estimated percentage reduction in emissions and energy consumption

CONCLUSIONS

The JUPITER project successfully achieved its main aim of implementing integrated transport demonstration projects in six European cities and promoting energy and emission savings.

The JET model developed within JUPITER can be used as a planning tool to estimate the changes in energy and emissions for a wide range of transport strategies and measures applied to virtually any city situation. The estimates provided by the model can be used to furnish planners, local authorities and transport operators with evidence about the likely energy and emission impacts from the implementation of proposed transport schemes. Ultimately, the outputs can be used to indicate the most environmentally effective measures and investments.

Applied in JUPITER, estimates by the JET model have shown that emission levels were reduced significantly in all cities. The total reductions in the emission level of CO, NO_X, HC, PM and CO_2 from the JUPITER project as a whole have been estimated at approximately 1628, 58, 175, 6 and 14276 tonnes per year, respectively. Overall, fuel consumption has been reduced by 5.7 million litres per annum in all JUPITER cities. This represents yearly energy consumption savings of about 189 million megajoules. At the strategic level, the reductions in the emission levels of CO, NO_X, HC, PM and CO_2, have been estimated at about 3473, 495, 429, 32 and 40280 tonnes per year, respectively. The potential savings in energy consumption have been estimated at 486 million megajoules per annum.

The results of the JUPITER project have shown that significant reductions in energy and emissions can be achieved if appropriate transport measures are introduced. The introduction of an integrated package of measures can produce even more significant improvements than if they had been introduced singly. As a consequence of JUPITER, all six cities are now extending the demonstration measures to other areas.

The measures introduced within JUPITER are applicable to other European cities and similar benefits to those realised in JUPITER can be expected. Many other cities can increase the use of cleaner technology vehicles, as well as further promote the use of the public transport system available, in order to incorporate energy efficiency criteria within the city planning schemes.

During the course of the JUPITER project, much interest has been shown by other European cities in the types of integrated measures introduced. There has also been a strong interest in the evaluation techniques, which to a large extent enables the improvement in the quality of life in urban areas to be measured on a consistent basis. Leading on from this, is the possibility of predicting what improvements in fuel usage and reduction in pollutants might be had as a result of the introduction of measures to assist a shift in modal split in favour of public transport.

The work carried out in JUPITER is a starting point for the development of policies for sustainable mobility in cities. The work is now being extended and further developed in JUPITER-2, a new THERMIE targeted transport project also funded by the European Commission, which will run until December 1999. JUPITER-2 includes five of the six original JUPITER cities (all except Patra), two new demonstration cities, namely Heidelberg (Germany) and Nantes (France), and a follower city (Riga). It will use the same method for the evaluation as in JUPITER.

The JET model will continue to undergo further development, such as the inclusion of additional vehicle fuel types and technologies, and more updated energy and emission functions and factors. JET Version 3 is predicted to be released in the near future.

ACKNOWLEDGEMENTS

JUPITER serves as an excellent example of what can be achieved by collaborative action between cities in different EU member states. The project would not have been possible without the strong commitment shown by senior political representatives of the city administrations and the financial support provided by the THERMIE programme. The authors would like to thank in particular all

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