The role of town energy planning in reducing urban transport emissions

F. Asdrubali, G. Baldinelli
Department of Industrial Engineering
University of Perugia, Italy

Abstract

The paper presents the main results obtained in the Energy Plan of the town of Perugia (Italy), which prominently features traffic aspects. For each possible action in this field, a very detailed technical analysis has been carried out. The actions have been divided into five groups:

- traffic planning (infrastructures, traffic restrictions, mobility management);
- alternative mobility (lifts, escalators, surface undergrounds and other kinds of public transport);
- alternative fuels (biodiesel, bioethanol, “white” gas oil);
- alternative vehicles (electric, hybrid, fuel cells);
- shared mobility (car pooling, car sharing and others).

For each group, technical, environmental, social and economic aspects have been taken into account; particular emphasis has been put on energy saving aspects and on the evaluation of greenhouse gases emissions reduction.

The paper gives useful indications to municipalities to choose the best solutions to reduce traffic consumptions and impact on a local scale, according to current technologies.

1 Introduction

Transport represents one of the main sources of energy consumption all over Europe (and Italy, as well), constituting one third of the entire energy demand, as shown in fig 1 e 2 [1, 2].
More than 75% of the population of the European Union lives in urban areas. Therefore urban transport accounts for a significant part of total mobility, and an even greater proportion of damage to the health of citizens and to buildings. One-fifth of all EU kilometres travelled are urban trips of under 15 km; between 1995 and 2030, total kilometres travelled in EU urban areas are expected to increase by 40%.

More than 10% of all carbon-dioxide emissions in the EU come from road traffic in urban areas which is also the main source of carbon-monoxide and fine particulates in European cities. These emissions pollute the immediate area and pose serious health hazards. The Kyoto protocol calls for an 8% cut in total EU carbon dioxide by 2008–2012 with respect to 1990 levels, but if current trends continue, CO₂ emissions from transport will be around 40% higher in 2010 than they were in 1990 [1].
Energy town planning and, more in general, local energy planning are very useful tools to verify energy consumption of an urban area in order to evaluate the resulting impact and therefore to improve energy savings and the use of alternative sources on a local scale. This work deals with the possible and feasible interventions in urban transport, from traffic planning, to alternative fuels, vehicles and mobility, focusing on energetic and environmental points of view.

2 Town energy planning

Italian law n° 10/1991 on rational use of energy, energy saving and renewable sources development has introduced a town energy plan: those municipalities with more than 50,000 inhabitants have to set up a specific section on energy planning in their general territorial plan.

2.1 Contents

The structure of an energy-environmental plan reflects the shape of the territorial-environmental-energy system from different points of view (such as final uses, energy sources, sectors and territorial areas) and supplies a complete frame, as far as possible, of the temporal evolution of the energy and environmental situation. Besides, the plan foresees the possible future scenarios that aim at indicating the potential interventions (on both sides: supply and demand). Finally, it identifies instruments that could be useful in different sectors and defines an action plan, characterizing factors suitable to contribute to the success of the plan actuation and others that, on the other hand, represent obstacles.

2.2 Methodologies

The first step towards energy planning consists in describing the situation of the municipal territory under all aspects of interest for energy-environmental analysis. Afterwards, the possible and feasible interventions in the municipality have to be examined to optimize the energy consumption and minimize the environmental effects on the territory. In the Energy plan of the town of Perugia, four groups were chosen and, for each of them, a series of technical files have been elaborated, to describe in detail every single possible intervention:
1. development of renewable energy sources;
2. interventions on urban transport;
3. energy saving;
4. management and administrative aspects;

The files are uniformly structured and contain a technical description of the particular interventions according to the following points:
- state of the art: description of the current technologies, together with the machinery available, their performances and their possible use in various sectors;
- development perspectives: the expectations on short, medium and long period of the examined technology, taking into account the development of the national market;
- energetic, environmental and economic implications: energy saving linked to each intervention is evaluated together with its advantages from an economic and environmental point of view;
- municipal territory feasibility: the possibilities on local areas are studied.

3 Possible actions in the field of transport

Focusing on the transport sector, five action areas worthy of an in-depth analysis were considered: traffic planning, alternative mobility, alternative fuels, alternative vehicles and shared mobility.

3.1 Traffic planning

The different levels of traffic planning (strategic, tactical and operative) with instruments such as general transport plan and urban traffic plan represent the most important and effective action that the administration could undertake. An urban traffic plan basically consists of the adjustment of the viability facilities such as main roads, roundabouts, traffic lights and exchange parkings. The final aim is to organize the traffic flow in a more rational way [3].

Focusing attention on the historical centre of the town, an integrated urban traffic system has been realized: it registers information and statistical data of the traffic flow, access to restricted areas and places available in parks, informing the drivers, in real time, the easiest way to reach different points in the city and car parks with free spaces.

The theme of proposing days with “city without cars” has also been object of evaluation, considering that in many Italian cities this initiative is common and considering that mayors of the most polluted cities have to adopt this kind of strategy each time pollution exceeds the air quality level limit.

The latest proposal on traffic planning is linked to mobility management, an integrated approach towards the mobility demand, in particular for a workplace-home movement plan.

3.2 Alternative mobility

In this group the state of the art of innovative collective transport systems has been presented.

The mini-metro, a sort of surface, electrical underground, represents a valid alternative to the traditional means of transport. Belonging to this category are systems derived from the underground which are characterized by new technologies that allow: total automatism, use of small vehicles, possibility of driving on tyres or on air cushions. This solution presents various advantages: zero local emissions, independent route, short building time, comfortable track, access without architectonic barriers, short wait and low noise pollution.
Two other systems of alternative mobility are already active in the city: lifts and escalators; they are useful as short-track transport means, completely automatic and particularly suitable for urban links in towns with complex orographic profiles.

Particular emphasis has finally been given to the promotion of public tyre transport; this objective can be reached by higher efficiency in terms of fuel consumption, improvement of communication with final users, economic competitiveness, adoption of new high environmental quality technologies, higher comfort inside the vehicles, expansion of the urban network and intermodality of public transport. Being successful in carrying more passengers means less energy consumption and lower toxic emissions.

### 3.3 Alternative fuels [4]

Biodiesel is derived from rapes, sunflowers, soybeans and coconuts; tests have been made by mixing various percentages of biodiesel with normal diesel oil, starting from 5%, to 100%. Mixtures with 30% biodiesel by volume may be used in engines without any particular changes, except for verifying the compatibility of the materials that constitute the injection plant.

Bioethanol is produced through biological treatment of some agricultural biomass such as sugarcane, sugar beet, wood, corn and other cereals. The process is based on biochemical transformation of carbohydrates to alcohol operated by microorganisms (yeasts) with successive distillation. Replacing conventional gasoline with ethanol implies a net advantage in terms of emissions because of the elimination of NOx and aromatic compounds, together with the reduction of carbon-monoxide and unburned hydrocarbons.

The use of methane as fuel for internal combustion engines is spreading; high performance, low consumption, reduced emission, almost zero carbotic residual inside the engine, low noise level and high capacity of mixing with air in the combustion chamber. The Italian Government provides some incentives for the transformation of gasoline-fed vehicles into methane-fed vehicles and for the purchase of new cars, built for methane feeding.

“White” oil is an emulsion composed by 88.0% of diesel oil, 10.3% of demineralised water and 1.7% of a specific additive with the task of guaranteeing stability of the mixture. Each vehicle with the engine designed for diesel oil can employ “white diesel oil” without any modification. The environmental advantage is reduction in NOx and in particulates, though there is no negligible reduction in the lower heating value of the fuel.

### 3.4 Alternative vehicles

The state of the art of electric cars shows that the expansion of this technology is blocked by high costs and poor performance (autonomy of 60/100 km today, 150/200 km in the next future). However, this solution could be adopted especially by public institutions, employing these vehicles to give an emission-reduction-oriented action as a model for private citizens.
Vehicles with hybrid engine propulsion are characterized by the presence on board of two (or more) energy sources: a primary energy converter (internal combustion engine, electric engine, turbo gas or fuel cell) and one (or more) store systems. The function of this accumulation is to recover energy from downhill roads and from energy wasted in braking phases, especially on urban tracks where acceleration and deceleration are very frequent. Because of the absence of a European network for hybrid vehicles marketing, as well as lack of economic incentives, the diffusion of this solution could be possible only at medium-long term.

The fuel cells employ hydrogen to produce electricity through a simple oxidation-reduction reaction, moving the vehicle by means of an electric engine. The efficiencies depend on the ways of hydrogen production: on an average, considering urban runs, the values range around 30%. The local emissions of a fuel cell vehicle are practically absent or dramatically lower than those of any fossil fuel vehicle and extremely below the limits imposed on exhaust gases emissions by worldwide standards. Nevertheless, it is clear that this technology is still at an experimental stage and, at the moment, the distribution system and technical assistance is lacking. For these reasons, a forecast on short-term period results are premature but concrete applications are easily predictable, assuming the feasibility and scientific relevance of the solution [5].

3.5 Shared mobility

Given the aim of reducing traffic, a possibility is represented by the use of the same vehicle by as many people as possible. In many cases, the so called car pooling is organised by workers of the same company or companies situated close to each other: only one car is used, with some (more than one) people travelling, to cover the same route. People who take part in car pooling have advantages, such as reserved car parks, access to restricted traffic areas or special fares on public transport.

Car sharing is collective use of a fleet of cars among people thereby creating an association for this purpose: the members dispose of a certain number of vehicles that can be taken from special car parks. The main push for car sharing development comes from lack of parking space and from the desire of rationalizing costs and investments. Data collected from past experience shows that this system is competitive for annual runs lower than 10,000 km. The typical car sharing configuration is made of a headquarter, a fleet of cars available for users and a series of parking spaces from where vehicles are withdrawn and redelivered.

Road pricing consists in fixing a payment for vehicles running on certain streets or even in entire cities. It is a radical measure and its set up leads to an adequate assessment of the citizens’ reactions, the right price and the evaluation of alternative services.

Another administrative intervention deals with the differentiation of timetables of some city services, aiming at traffic decongestion, especially in rush hours. For instance, students may use public transport in different hours with respect to
adults, reducing the number of circulating vehicles and obtaining a more rational employment of public vehicles. The system can be extended to factories and offices.

“Park and ride” plan stands for an interchange parking system, generally positioned in suburbs, between private vehicles and the public transport network. The efficiency of this solution is linked to the correct location of parking in relation to the prevalent traffic flows and to regular public transport offer near the parkings.

4 Energy saving aspects

Transport energy consumption may represent more than 50% of the total energy needs of an urban area. For this reason every possible action which implies a reduction in traffic flow or use of low-impact technologies is extremely important. In this section, energy saving aspects related to various interventions in the field of urban transport are presented.

4.1 Traffic planning

At present, the mean speed of vehicles on municipal territory is about 28 km/h; With the intervention of traffic planning, and especially with the realization of new infrastructures, it is reasonable to assume that the speed will increase to 35 km/h. At these speed levels fuel consumption is inversely proportional to speed itself.

Banning the circulation of all vehicles in the centre of Perugia, 300,000 km each day are saved (5,000 cars running for 6 km, the average route in the urban streets).

Concerning mobility management, the main advantages derived from the effectiveness of this policy find expression in lower transport and parking costs, reduction in movement times, possibility of cash prizes, stress reduction, reduction in air and noise pollution, reduction in energy consumption. Focusing on the advantages for the companies, easier accessibility to workplace could be mentioned, better relations with the site inhabitants, reduction in mobility refunds, creation of an environmentally-oriented image of the company.

4.2 Alternative mobility

All the energy consumption of the mini-metro system derives from electric source: on an average, 0.031 kWh per passenger per km represents the efficiency of the system.

As reported for the mini-metro, the energy consumption of lifts and escalators comes from electric source: on an average, 0.033 kWh per passenger per km represents the efficiency of these systems.
At present, users of public transport on tyres are about 13,000,000 per year. The goal of the administration is to double this number; considering that the average distance covered by a passenger is 4.5 km long, each year 58,500,000 km are saved.

### 4.3 Alternative fuels

The biodiesel lower calorific value is about 13% lower than that of diesel oil (32.8 MJ/dm³ versus 35.6 MJ/dm³), but this is partially compensated by its higher density (0.88-0.89 kg/m³ versus 0.83-0.85 kg/m³ at 15°C): total loss of energy, with the same volume, amounts to 7%.

However, the consumption increase is hardly perceptible because of its high oscillation in relation to the way of driving and to the kind of run.

Since ethanol’s lower heating value results lower than the gasoline one, the mix of the two fuels determines higher consumption by volumetric base (km per litre). The addition of oxygen, completely absent in gasoline, gives an improvement to combustion because of a higher air/fuel ratio: the result is a positive effect, although marginal, to volumetric consumption.

Methane is a valid fuel for spark ignition engines; its capacity of easily mixing with air in the combustion chamber brings various benefits:

- good distribution of the air/fuel mix;
- good control of the air/fuel ratio in dynamic and thermal transients, thanks to the absence of fuel thin film in the inlet ducts;
- strict maintenance of the stechiometric ratio in the whole engine operative range.

Besides, methane’s molecular structure permits a good detonation resistance (more than 120 octanes) that allows to reach high compression ratio, over 12 to 1, without additives, necessary for gasoline.

The presence of water leads to a reduction of the energetic content of “white” gas oil with respect to diesel oil; nevertheless, this loss, thanks to better combustion, is limited to 5%, therefore hardly perceptible by users, especially in urban streets.

### 4.4 Alternative vehicles

The wide diffusion of electric vehicles could create anxiety considering electric energy consumption of the nation. The truth is that, even if there were one million electric cars circulating in Italy (an optimistic hypothesis), no repowering of electric generation plants would be needed. The average consumption of electric vehicles is about 30 kWh per 100 km.

The direct comparison of propulsion technology shows that, with the same conditions, hybrid engines consumption is lower than the gasoline engines one: for a 1660 cc engine, 6 l per 100 km against 8.6 l per 100 km.

The efficiency of fuel cell engines depends on the hydrogen production methods; on an urban track, on an average, the efficiency value is around 30%.
4.5 Shared mobility

The advantages of energy derived from car pooling diffusion can be easily evaluated: hypothesizing a group of four people, immediately two or three vehicles disappear from the road. Besides, the convenience for people consists in economic savings because of lower car use or even because of avoiding its purchase. At a social level, the diffusion of this system contributes to the rooting of more mental awareness regarding sustainable mobility and environment protection.

Car sharing users enjoy various advantages:
- car maintenance is always at its best because it is the association’s manager’s responsibility;
- time saving as far as bureaucratic paperwork (purchase and selling, insurances) is concerned and money saving as regards maintenance operations;
- reduction in transport costs with respect to car owning, especially for users with low annual runs;
- increase in personal mobility.

5 Greenhouse gases reduction

The effects of each single intervention on greenhouse gases reduction is brought back to a unitary mass (grams) saving of equivalent CO$_2$ (gCO$_2$-eq) and that value is normalized to each passenger and to each km covered (tab. 1). It has to be considered that, on average, the CO$_2$-eq production of a vehicle is about 215 gCO$_2$-eq/kmp [6].

Table 1: Saving of CO$_2$-eq for each intervention

<table>
<thead>
<tr>
<th>Transport mean</th>
<th>UNITARY CO$_2$ SAVING</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRANSPORT INFRASTRUCTURES</td>
<td>45 gCO$_2$-eq/kmp (1)</td>
</tr>
<tr>
<td>MOBILITY MANAGEMENT</td>
<td>50 gCO$_2$-eq/kmp</td>
</tr>
<tr>
<td>BIODIESEL</td>
<td>49 gCO$_2$-eq/kmp</td>
</tr>
<tr>
<td>BIOETHANOL</td>
<td>25 gCO$_2$-eq/kmp</td>
</tr>
<tr>
<td>WHITE GASOLINE</td>
<td>8 gCO$_2$-eq/kmp</td>
</tr>
<tr>
<td>METHANE</td>
<td>49 gCO$_2$-eq/kmp</td>
</tr>
<tr>
<td>ELECTRIC ENGINES</td>
<td>75 gCO$_2$-eq/kmp</td>
</tr>
<tr>
<td>HYBRID ENGINES</td>
<td>105 gCO$_2$-eq/kmp</td>
</tr>
<tr>
<td>FUEL CELLS</td>
<td>111 gCO$_2$-eq/kmp</td>
</tr>
<tr>
<td>COMPRESSED AIR ENGINES</td>
<td>104 gCO$_2$-eq/kmp</td>
</tr>
<tr>
<td>CAR SHARING</td>
<td>86 gCO$_2$-eq/kmp</td>
</tr>
<tr>
<td>CAR POOLING</td>
<td>100 gCO$_2$-eq/kmp</td>
</tr>
<tr>
<td>TELEWORKING</td>
<td>164 gCO$_2$-eq/kmp</td>
</tr>
</tbody>
</table>

(1) assuming that new transport infrastructures can guarantee the increase of the average speed of vehicles in the town streets from 28 to 35 km/h.
5.1 Traffic planning

Nowadays, the average speed of vehicles in the municipal territory has reached 28 km/h. With the development of infrastructures, the value could rise to 35 km/h, with an emission reduction of 45 gCO$_2$-eq per km per passenger. The cut involves all vehicles, therefore, this solution represents the most effective action in terms of greenhouse gases reduction; finally, traffic decentralization allows better dilution of pollutants. This intervention bans transit of 3,900 vehicles in the historical centre, where each car covers a distance of 6 km; the total emission saving is evaluated through unitary emissions of vehicles in urban streets (215 gCO$_2$-eq per km per passenger), and the number of passenger per vehicle (1.17). The check of the results attained has been conducted after three years. In air quality control stations the following data have been recorded:
- a mean CO reduction of 19%;
- a variable effect on NOx concentration: rising in some stations, reducing in others; this situation is explainable with the fact that vehicles ran faster with engines working at higher loads.

As far as mobility management is concerned, it has to be pointed out that at present, in the municipality, in order to cover the workplace-home route (15 km on an average), 85% of people use private vehicles, 10% public tyre transport and 5% railways. The goal is to reach 50% of public transport users, at least for the workers of companies that are obliged to use mobility management (15,000 people involved in the municipality); each person that changes means of transport leads to a reduction of 49.7 gCO$_2$-eq per km per passenger.

5.2 Alternative mobility

As far as mini-metro is concerned, in Italy, the production of one electric kWh in thermoelectric power stations produces an emission of 700 gCO$_2$-eq; from the data of mini-metro energy consumption, the greenhouse gases emission results 133 gCO$_2$-eq per km per passenger, saving 17.6 gCO$_2$-eq per km per passenger, a relevant amount, taking into account that each year 7,000,000 passengers could potentially use this means of transport, for the track of 6 km. Furthermore, electric energy is produced far from urban conglomeration with advanced pollution abatement systems and constant monitoring. The same considerations reported for the mini-metro are valid for lifts and escalators; the unitary emission saving is 127.5 gCO$_2$-eq per km per passenger and the potential users amount to 1,000,000 people per year that will not run 6 km with vehicles.

At present, the users of public transport on tyres are about 13,000,000 per year, the goal of the administration is to double this number; considering that the unitary reduction of emissions is equal to 128 gCO$_2$-eq per km per passenger, the environmental saving is obtained through the length of the medium track covered by a passenger (4.5 km).
5.3 Alternative fuels

The use of pure biodiesel leads to the following results:
SO\textsubscript{2}: although biodiesel is practically free from sulphur, SO\textsubscript{2} emissions remain significant because of the presence of the lubricating oil;
CO: a considerable reduction (5-8\%) has undergone, thanks to the oxygen in the fuel;
HC: unburned hydrocarbons mass emissions show substantially equivalent to standard diesel oil but, looking at the composition, the content of aromatic polycyclic compounds has dramatically reduced;
NO\textsubscript{x}: the growth of NO\textsubscript{x} is calculable as 15\%.
Particulate matter: result of these substantial emissions are equivalent to standard diesel oil but the average granulometry is ten times higher, limiting its danger.
CO\textsubscript{2}: since biodiesel is derived from biomass, the net carbon-monoxide emission in the atmosphere is null: the CO\textsubscript{2} produced by combustion is absorbed by the oleaginous vegetative cycle.

If impure biodiesel is used, the impact reduction will be proportional to the percentage of the mix with diesel oil. Considering a 30\% biodiesel mix, emission saving is about 10.8 gCO\textsubscript{2}-eq per km per passenger.

As for biodiesel, bioethanol does not present net CO\textsubscript{2} emissions because of the capture of carbon by the photosynthesis process that occurs in biomasses. Dealing with the other emissions, ethanol reduces SO\textsubscript{x}, aromatic compounds (in particular benzene), carbon-monoxide and unburned hydrocarbons with respect to gasoline. If impure ethanol is used, the impact reduction will be proportional to the percentage of the mix with gasoline. Considering a 15\% ethanol mix, emission saving is about 24.6 gCO\textsubscript{2}-eq per km per passenger.

The adoption of methane by motorization leads to the reduction of the production of the most dangerous hydrocarbons of a percentage close to 95\% as well as the CO\textsubscript{2} formation to 25-30\%, NO\textsubscript{x} to 85-90\% and CO to 85-95\%.

Besides, sulphur and lead do not appear in the exhaust gases, nor does particulate matter. The unitary greenhouse gases saving is around 49.2 gCO\textsubscript{2}-eq per km per passenger.

Considering that an engine fed with “white” gas oil produces CO\textsubscript{2} emissions 5\% lower than a pure diesel oil fed one, the unitary saving is 8.2 gCO\textsubscript{2}-eq per km per passenger.

5.4 Alternative vehicles

Taking into account the emissions of electric energy production (700 gCO\textsubscript{2}-eq per kWh) and the efficiency of electric cars, the CO\textsubscript{2} production saving is 24 gCO\textsubscript{2}-eq per km per passenger, compared to the average emissions of the total circulating car park.

Examining a standard engine working cycle and comparing the emission performance of a traditional vehicle with a hybrid equipped one, a unitary greenhouse gas saving of 105 gCO\textsubscript{2}-eq per km per passenger is had.
As far as fuel cell vehicles are concerned, the emission of pollutants has to be brought back to the hydrogen production process; considering the complete cycle, it leads to a CO$_2$ production saving of 111 gCO$_2$-eq per km per passenger.

5.5 Shared mobility

The simple reduction of circulating vehicles brings to a unitary greenhouse gas saving of 100 gCO$_2$-eq per km per passenger. The objective of the sensitization campaign conducted by the administration is to involve 10% of the circulating vehicles (2,500 a day) on a car pooling policy, running the average city track (15 km) with vehicles accommodating three or four people.

From the environmental point of view, the improvements could be summarized as follows:
- significant traffic reduction: each car sharing vehicle may lead to a replacement from six to three private vehicles;
- the vehicles travel a lot, this means that investment return is short and the car park is frequently renewed, following technological evolution, also in the pollution reduction field;
- in many cases the vehicles of a car sharing service belong to the alternative kind (electric cars, methane fed cars…) [7].

The unitary saving is 86.5 gCO$_2$-eq per km per passenger; the global effect on the municipality is obtained hypothesizing four car sharing services provided by three cars, each of them covering 45 km a day with only one person inside.

Finally, the setting up of firms for the management of dial buses or collective taxis could have positive effects on the employment side, in addition to the fact that an important social service (e.g. mobility for underprivileged categories) is covered.

6 Conclusions

Urban transport contributes to global warming. More than 10% of all carbon-dioxide emissions in the EU come from road traffic in urban areas which is also the main source of carbon-monoxide and fine particulates in European cities. These emissions pollute the immediate area and pose serious health hazards. The Kyoto protocol calls for an 8% cut in total EU carbon-dioxide emission by 2008–2012 with respect to 1990 levels, but if current trends continue, CO$_2$ from transport will be some 40% higher in 2010 than it was in 1990.

The challenge for future urban transport systems will be to meet the demand for accessibility for people, including people with limited mobility and goods, while at the same time minimising impact on the environment and safeguarding the quality of life.

In this contest, energy town planning can give a significant contribution to the spreading of sustainable mobility policies. The paper presents the possible and feasible interventions in urban transport, from traffic planning, to alternative fuels, vehicles and mobility, focusing on energetic and environmental points of view.
7 References