

Sustainable road transport from the energy and modern society points of view: Perspectives for the automotive industry and production

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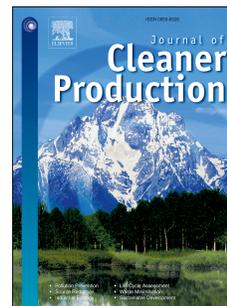
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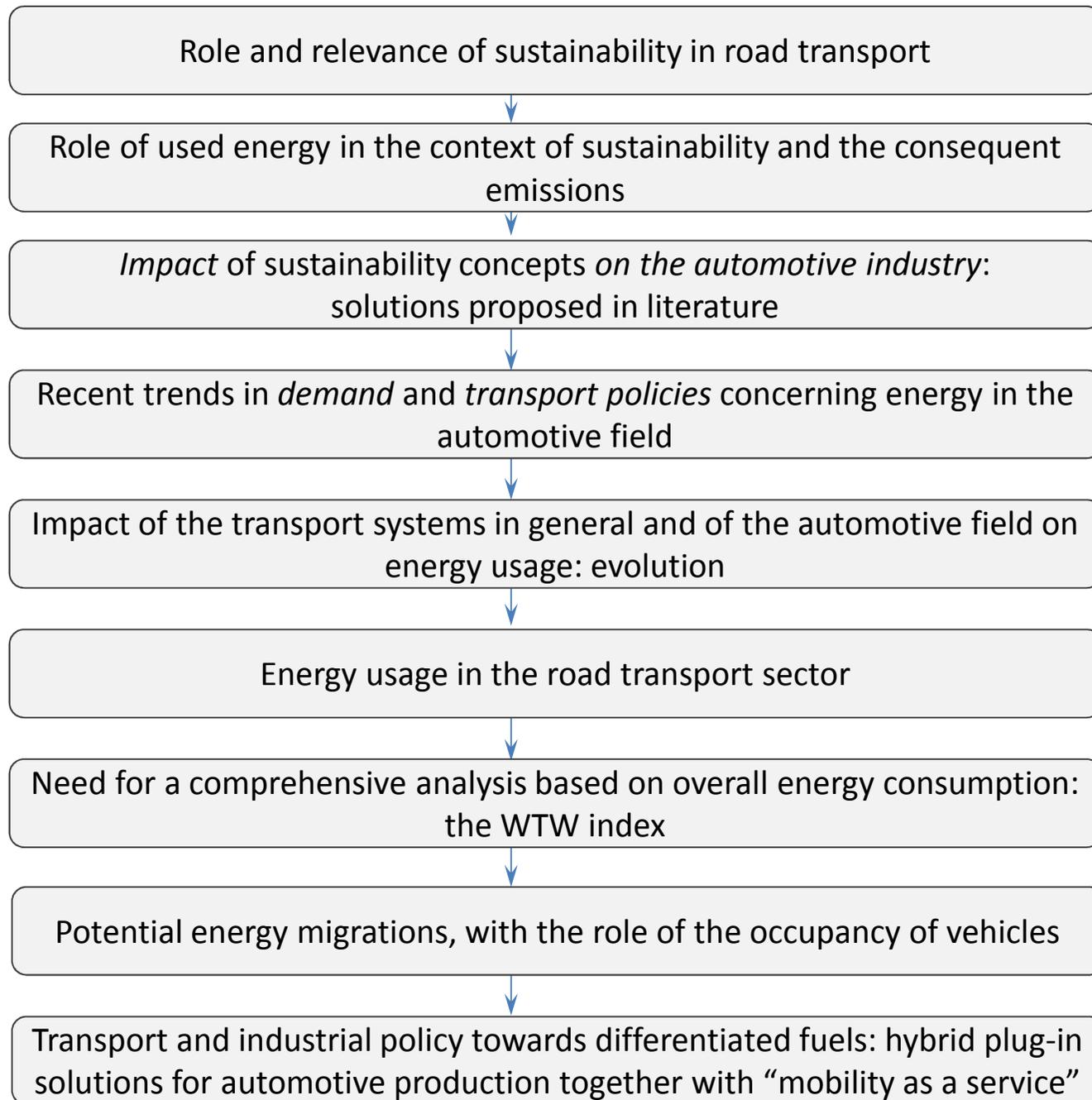
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# Sustainable road transport from the energy and modern society points of view: perspectives for the automotive industry and production

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## Abstract

This paper attempts to provide an overall analysis of the most recent, relevant and consolidated issues of sustainable transport with the aim of indicating a specific perspective in the automotive field for a defensible production of an acceptable product, which would be able to satisfy the modern aspirations of the industrialised society.

A broad framing of the role of sustainability in transport systems as well its impact on the automotive industry are presented first, focusing in particular on the energy consumption of road vehicles; the impact of transportation on energy use and the weight of energy consumption on the operational costs of the different transport modes are dealt with, together with the evolution of this consumption.

These elements are essential for a clearer understanding of where and how much *energy efficiency* and the related emerging technologies can have an impact on road transport, mainly in the automotive field; furthermore, they provide the grounds for some overall considerations on the energy demand for transport. The environmental impact is implicitly a consequence of choices in the use of energy.

Technical and economic solutions for a transport system that complies with the energy supply i.e. automotive production and the expected availability of the main used sources, and for its sustainability can thereafter be analysed: quantitative analyses, such as the well-to-wheel method, and the energy related to the actual occupancy of vehicles, are also taken into account, before some main technological perspectives are proposed for automobiles, which the authors consider to be winning, from a strategic viewpoint, and which should be closely coupled to industrial choices in the most technologically advanced countries in the world.

*Keywords:* Road transport systems; energy efficiency; sustainable motorised mobility; well-to-wheel analysis; automotive industry; production.

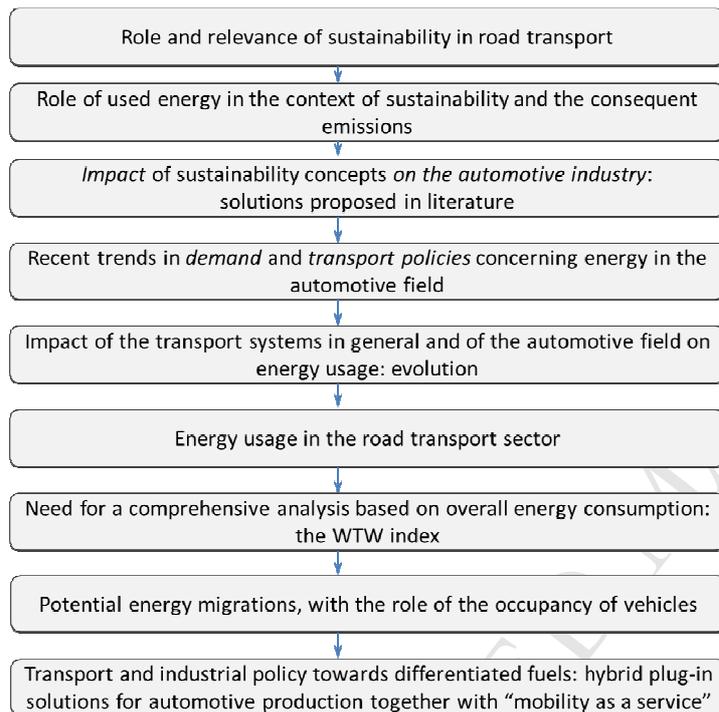
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## 1. The key factors of sustainability in the land-based transport system

For the last few years, road transport has become burdened by a number of issues related to sustainability, namely by the kind of energy that is used, the consequent emissions and connected points of view of modern society. With this paper the authors would like to provide some perspectives to the automotive industry and its related production by suggesting goals for transport policy makers and the public at large. This wide analysis has been faced according to the steps outlined in Fig. 1.



**Fig. 1. The main steps of this analysis: from sustainability of road transport to a policy concerning the automotive production, passing through the energy usage**

The almost continuous growth of road circulating vehicles, of infrastructures and of personal motorised mobility – which has significantly marked the second half of the last century in the United States, Japan and in Europe – has been showing some conditionings or constraints for a number of years; these have strengthened and made the concept of what is nowadays called “sustainable transport” or “sustainable motorised mobility” to be felt more by modern society, as not-motorised mobility is implicitly sustainable inasmuch as people have the ability to move. These conditioning elements can be summarised as follows:

- 1) *Saturation of the land*, in the meaning of both infrastructures constructed throughout the territory and of vehicles using these infrastructures; a profound awareness of such an issue already surfaced in the nineteen eighties with the consequent spreading of environmental impact assessments and similar analyses in the nineties.
- 2) Concerns arising from the impending and inevitable lack of *energy resource*, and of black oil in particular, at least at widely accessible prices, of which approximately *half* of the extraction is absorbed by transport systems throughout the world and on which they depend for at least 96% in European countries and nearly 93% in the US in terms of t.o.e. (tons of oil equivalent), to mention just some of the relevant industrial areas.
- 3) The release of gases and materials, derived from the combustion of combustibles obtained from black-oil, into the *environment*, with the subsequent atmospheric pollution, health issues and possible climate changes, which have resulted in global commitments being taken worldwide, and in particular in the aforementioned industrialised areas, together with continental standards on car-engine emissions.
- 4) The need to *physically and functionally maintain* as well as *technologically update* the existing transport infrastructures, here intended as their economic sustainability during their whole *life cycle* (their maintenance and technological upgrading): The property of a country increases with the development of new infrastructures as well as with the upgrading of the existing network; neglecting an infrastructure may imply its loss of attractiveness and of value, while it continues to be the responsibility of the State from the moment a decision was made concerning its realisation.
- 5) The increase in *safe mobility*, which is a binding road transport objective of the EU as well as of the USA and Japan and which – as intended as a reduction in road accidents in particular, in absolute terms and not as a rate - results to be incompliant with the growth of motorised mobility, even though the incidence of accidents due to additional road traffic was limited, possibly due to assisted driving and ITS, and in the future possibly to the use of autonomous automobiles.
- 6) A natural limit in the increase of long-range relationships between people, a possibly ethic objective with which the continuous *growth of motorised mobility* may become incompliant with local relationships, with one owns' family and with the regular development of on-site working activities. This increase in mobility was welcome in the past because of the growth in relationships beyond the reference housing context; since roughly the beginning of the new century, bidirectional communication without mobility has emerged and conquered a relevant part of modern society (internet, smart phones, teleconferences and the like, and possibly one day tele-presence), and has sometimes substituted communication associated with movement, i.e. effective and not virtual transport.

Given this entire recent burden on the automotive industry, it is reasonable to ask: how can today's industrial production still satisfy the transportation needs of modern society without

losing the market in favour of motionless communications and, at the same time, overcoming the modern constraints related to sustainability? An attempt will first be made to understand the impact of modern constraints, generated by a more diffused green oriented consensus, on sustainability in the automotive industry, from the literature viewpoint, within the business and management context, in order to face the technical and technological aspects; a proposal for a cleaner production of an up-to-date product will then be made.

## 2. The impact of sustainability on the automotive industry

During the 1980s and '90s, some serious international environmental problems, such as a reduction in the ozone layer and climate changes, began to stimulate greater attention towards the concept of '*sustainable growth*'. The modern concepts of sustainability began to take shape during the 1990s. Recent years have witnessed a proliferation in business and management literature, and even an explosion in international literature, of publications in which sustainability is the main theme and in which it is used to describe problems related to technology, economic development and managerial approaches in various areas such as '*sustainable technology*', '*sustainable economics*', '*sustainable business*' and certainly sustainable transport. Thus, in order to progress towards ensuring a sustainable economy and production, various key areas have been explored. In particular the environmental effects and the consequences on nature of an unconstrained economic growth, along with the prospects of economic activity that takes greater account of the social and environmental consequences of market behaviour, have been analysed (Lovins et al., 2007). The concept of sustainability is often associated with the term social innovation. In this context, the institutions and the governance at a regional and *local level* play fundamental roles in promoting sustainable growth.

The transport context is influenced by sustainability at two levels: from the macro-operational point of view of the vehicles and personal mobility, as synthesised in the previous section, and from the micro-industrial one.

Car makers have become more involved in social and environmental issues within the community over the last two decades indicatively: they are market players who operate within a variety of relationships with economic, political and social parties; they are subject to the constraints of international organisations and local governments and to the pressure of civil society; they have to comply with laws and to take into account ethical values in full respect of the individuals, the community and the environment. In this network of interconnections, car makers are inevitably social and political actors who are called upon, by governments and other stakeholders to be cost-effective, and socially and environmentally responsible, and have even been pushed or self-oriented in recent years to publish Sustainability Reports. Nowadays, this all constitutes a large burden, which risks making automotive production

unbearable in some cases, unless government subsidies are provided or worldwide economies of scale are pursued. However, a technological solution has to be found, otherwise it will be necessary to renounce mobility and logistics or to give up the production of modern vehicles that are able to satisfy such constraints, and this in itself would represent losing behaviour, like hearing a policy maker or a private citizen say: “I’m going to give up my car and move by bicycle, on foot, by public or shared transport (i.e. *I interpret mobility as a service*) because cars are no longer environmental friendly or economically competitive”.

It is necessary to be aware of the fact that the automotive sector has always been characterised by expensive product features that lead the firms to require extremely large initial capital investments and to achieve economies of scale<sup>1</sup>. It is also necessary to be aware of the fact that the automotive industry has nearly always benefited – in a more or less evident way – from governmental financial sustainment, especially when a new concept of vehicle has been proposed. However, car makers are “prisoners of enormous sunk costs which they treat as unamortized assets” ... “This mind-set is a critical obstacle” (Lovins, 1993). The advantages for these companies originate from the increase in the production scales, together with the complexity of both the products and the manufacturing systems. However, the risk of failing is high, and this is why both product and process technologies are often developed incrementally. Nevertheless, if the innovation is successful, the impact can be significant in terms of revenues. Finally, the recession witnessed in these last few years has weakened multinational automotive companies that operate on traditional markets, with particular reference to Europe. The strategies that have prevailingly been adopted by the most important business groups have involved a contraction of the traditional markets and development of high growth rate ones. European automobile companies in particular, as a result of the economic crisis<sup>2</sup>, which involved the Euro area countries to a great extent, and with the aim of containing the loss of market shares, have been forced to sell at competitive prices, compared to the past. In general, they rationalised their activities by adopting actions aimed at containing costs - most of which were introduced because of environmental constraints, such as those pertaining to the Euro 1 up to the Euro 6 engines – by introducing lay-offs and disinvestments of entire production lines in order to satisfy the new pollution constraints. The search for profitability and development opportunities on other markets has forced these companies to aggregate and search for strategic alliances, thus making the global automotive market a high-concentration one, with significant barriers to new competitors. In some countries, such as India, the market demand has called for adaptations of the product to the local market. Nevertheless, the general trend of car makers has been to search for scale economy and product standardisation for large-volume sales and to limit the costs generated

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<sup>1</sup> “This constitutes a trap as each competitor has to sell a large number of vehicles in order to reach a break-even-point” (Zapata et al, 2010).

<sup>2</sup> “Crisis” is here used with reference to one of its etymologies: “crisis” as that of “cross”, with “choice” being the Greek root of the term.

by the introduction of adaptations by producing in different geographic areas. This has led to *economies of scale for internal combustion engines*, that is, those that were chosen approximately one century ago, in spite of the existence and efficiency of electric motors, ?a scale (economy) difficulty reachable in a few years with alternative motors.

In spite of all this, new demands are pushing the automotive market towards a change. The stakeholders, and governments in particular, the local communities and the consumers are requesting more attention towards *energy efficiency*, as well as partial *independence* from black-oil, with consequent decreases in pollution and increases in safety and quality, which translate, for instance, into reliability of the vehicle, infotainment and in general into an economic, social and environmental impact by car makers. The limited margin of investment forces them towards the conquest of high volumes of production and even to strive to reach a leadership position, irrespective of the laws, in order to obtain economies of scale, thus risking the company's credibility and the market share itself.

The move towards change has therefore become highly pressing and sometimes vital for these companies. As is the case of other industries, automotive companies are also called upon to increase their internal sustainable value<sup>3</sup>. This issue is becoming particularly significant and strategically relevant for car makers<sup>4</sup>. The recent evolution in the role of multinational companies has led to the recognition of a social and environmental aspect of their activities, which obliges them to seek sustainable growth<sup>5</sup> (Labuschagne et al, 2005) and innovation as conditions for success in the medium-long term. Thus, the above factors become strategically significant, and the adoption of socially responsible practices represents the way towards long-term profits and solid foundations<sup>6</sup>. The economic crisis and its social consequences have shaken the trust of consumers; greater attention has subsequently been requested from companies towards social and ethical aspects (EC, 25/10/2011; Christensen,

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<sup>3</sup> In the Communication from the Commission of the European Communities on the European Union Strategy for Sustainable Development (EC, 15/5/2001), the Commission invited all publicly-quoted companies with at least 500 members of staff to publish a "triple bottom line" in their annual reports to shareholders that measures their performance against economic, environmental and social criteria.

<sup>4</sup> The developed product has special features: cars can be a cause of excessive pollution, road accidents, stress and the like, thus damaging both the personal interests of the individuals and the general collectivity.

<sup>5</sup> As defined by the World Commission on Environment and Development (WCED), the "Brundtland Commission" (1987): "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

<sup>6</sup> "When looked at strategically, corporate social responsibility can become a source of tremendous social progress, as the business applies its considerable resources, expertise and insights to activities that benefit society" (Porter and Kramer, 2006). "Companies must take the lead in bringing business and society back together." ... "The solution lies in the principle of shared value, which involves creating economic value in a way that also creates value for society by addressing its needs and challenges. Businesses must reconnect company success to social progress." (Porter and Kramer, 2011). The attention of stakeholders is also requested when the objective of the enterprise is the creation of value for its own shareholders and is oriented towards value-based management (Copeland et al, 2000, Cornelius, Davies, 1997; Pellicelli, 2007). As the EU Commission also underlines: "... enterprises should have in place a process to integrate social, environmental, ethical, human rights and consumer concerns in their business operations and core strategy in close collaboration with their stakeholders, with the aim of: maximising the creation of a shared value for their owners/shareholders and for their other stakeholders and society at large." (EC, 25/10/2011).

2011). Certainly, decision making in the energy and environmental management fields includes the application of tools to support decision making on environmental strategies and operations (Lai et al, 2008), tools such as: Life Cycle Assessment (LCA), Cumulative Energy Requirement Analysis (CERA), Material Flow Accounting (MFA), Total Cost Accounting Analysis (TCA) and Environmental Risk Assessment (ERA). The results and corporate sustainability should also be controlled by means of sustainability indicators (according to Triple Bottom Line and GRI guidelines) and *sustainable production indicators* (Veleva and Ellenbecker, 2001).

In the last few years, both the USA and European governments have been fostering – through allocations of funds for research and financing to enterprises - the search for clean air solutions and – behind this, being an economic issue for the balance of payments of entire nations - alternatives to black-oil as a source of energy for vehicles, as well as innovative technological solutions. For example, according to EU Directive 2009/33/EC and subsequent adaptations, European car makers are called upon to provide future mobility solutions in an extremely competitive global environment, and therefore to spread the adoption of green cars and heavy-duty vehicles as well as of systems that contribute towards improving road safety and fight pollution (such as Intelligent Transport Systems - ITS).

In this context, the development of innovation also becomes a strategic factor to achieve sustainability and social consensus. Already in the nineteen seventies, Ansoff suggested trying to acquire new technologies as they surfaced or, as an alternative, leaving the market and shifting resources from old technologies to new ones as soon as an opportunity of marketing the new products arose (Ansoff, 1965). Usually, once a technological innovation passes the initial market phase, it may/can generate significant competitive advantages for the company that introduces it. This translates into a greater capacity to diversify than the competitors (Porter, 2008a; Porter 2008b). Markides and Geroski (2005) highlighted to what extent radical innovations (i.e. those that have an important effect on both the behaviour of the consumers and the competitors) can generate a new market by influencing the consumers and revolutionising the existing business patterns.

In the automotive industry, companies innovate in order to satisfy the consumers' demand, to increase their market share and profits as well as to compete on the global market (Lin and Lu, 2006). Generally, pushing eco-innovations onto the market, when consumers presumably do not dare, are not interested in or do not want to buy this genre of innovative products, may even result in a losing strategy for the manufacturers. If the stimulus to adopt innovation instead stems from the consumers' needs, and manufacturers develop technologies accordingly, innovations might be adopted quickly (Zhang et al., 2011).

### 3. Methods: the sustainability of the transport system in automotive literature

Up to the end of the last century, none of the elements that influenced the almost continuous increase in motorised mobility were as significant as they are today, since they affect - at its very base - the current sustainability of the *transport system* as a whole, including automotive development in most developed countries. This paper is addressed to an analysis of the *users' and society's requirements* – the demand - with respect to alternative cleaner and sustainable industrial solutions pertaining to past and present motorised mobility, which might be electric or hybrid vehicles, and to the indirect analysis of the emissions; the latter usually considers an *overall energy analysis* (here intended from the source) as of less importance or even ignores it, though energy stays earlier in the process and on which we rely our man attention. These aspects have already been addressed in literature, in particular over the last twelve years.

Starting from alternative solutions to internal combustion engines, in order to address the energy and environmental issues of sustainability, which are generally exhibited through electric traction, Graham-Rowe et al., 2012, reported a qualitative analysis of the responses to the demand for electric cars or plug-in hybrid cars, based on semi-structured interviews conducted with 40 non-commercial drivers in the UK. The results highlight the potential barriers to the adoption of current-generation (2010) plug-in electric cars by mainstream consumers. Years before, Chéron, E., Zins (1997) analysed the buyers' purchasing intentions towards electric vehicles and pointed out the constraints.

Vance and Hedel, 2007, in a study which had the aim of contributing to this line of inquiry, estimated econometric models on a panel of travel-diary data collected in Germany between 1996 and 2003, focusing on individual automobile journeys. The authors employed the two-part model (2PM), a procedure that involves a probit model and OLS estimators, to assess the determinants of the discrete decision to use a car and the continuous decision of distance travelled. Unlike much of the work to date, the results suggest the urban form has a causative impact on car use, a finding that is robust to alternative econometric specifications. In fact, these results need to be considered here because of their relations with the compliancy of *frequent and short daily trips in urban contexts* with the *autonomy of electric batteries*, without changing the behaviour of nearly  $\frac{3}{4}$  of the European population, which lives in metropolitan areas so carries out for most of the week journeys of 10-20 km.

The paper by Kim and Ulfarsson (2008) reports a transportation modal choice for short home-based trips, using a 1999 activity survey from the Puget Sound region of Washington State, U.S.A, and it claims that an environment that attracts the interest of people and provides activity opportunities also encourages people to walk short trips or - as authors we add - to use vehicles whose autonomy and recharging possibilities are compliant with such distances, again particularly electric ones. This aspect shall be addressed later on in the present paper. Influencing the choice of the transport mode of people on short trips should be an important part of the efforts that are necessary to encourage the use of non-automobile alternatives, such as metros, surface public transport or electric traction. The paper by Scheiner and Holz-Rau,

2013 examines changes in travel modes after residential relocations using structural equation modelling. The findings show that relocations and the associated changes in the built environment induce significant changes in car ownership and in the travel mode, and may thus be regarded as key events in an individual's mobility biography.

Schwanen et al, 2011 focused their research on climate change mitigation in transport systems and related land vehicles: the analysis points out that ecological modernisation and neo-liberal govern-mentality in general provide the context for the current focus on and belief in technological, behaviour change and especially market-based mitigation strategies; this is an input that will here be used later on when referring to industrial choices.

The paper by Te Brömmelstroet and Bertolini, 2010, analysed the central position of the integrated automotive Use and Transport (LUT) strategy development in establishing more efficient and sustainable urban environments, and it introduced the concept of 'knowledge generation' as a potentially useful mechanism to close the gap between support tools and planning practice: these results have proved useful for the authors of the present paper to assign the most suitable transport modes and new concept of automobiles, in terms of sustainability (traffic, energy, environment, safety) and of the appropriate distances.

An analysis of the rapid development of motorisation in Asian cities, in terms of urban transport infrastructure, spatial development and travel behaviour, was made by (Kitamura and Mohamad, 2009) from another point of view, that is, of the most quickly evolving countries, considering diffused personal motorised mobility.

The paper by Frondel et al., 2011, critically assesses EU legislation, with reference to its economic and technological underpinnings: the need to more accurately reflect the industry's technological status quo is outlined, and alternative targets are proposed which seem to be related to the subsequent proposals in this paper.

The paper by Wells et al., 2013, analyses the issue of whether governmental regulation results in higher producer costs, which then result in higher prices for the consumer. They conducted a longitudinal study of the European automotive market and dealt with features related to energy use and, above all to the emissions of vehicles with alternative traction or propulsion. They concluded that regulators need a better understanding of what the 'cost of regulation' entails over the longer term. This suggestion has been considered relevant in the present paper for dealing with governmental policies on energy, which have been related to that of *subsidies to more oil independent transport modes* in order to pursue energy independence, at least in those countries that want to reduce their economic *reliance on other countries that extract black-oil*.

Mathez et al., 2013, have focused on the city of Montreal, which has invested large amounts in alternative transportation systems, and have considered the recent initiatives to significantly reduce the consequences of the use of black-oil derived fuels, by containing the overall greenhouse (GHG) emissions from the transport sector. The paper presents a methodology that was developed to estimate the GHG emissions generated by commuters; this

methodology is linked to a multimodal approach which reserves to *metropolitan trips by means of the electric traction*, no matter where it is used (on public or private vehicles).

The paper by van Ristell et al., 2013, examines the traffic and environmental impacts of the school choice policy in England and analyses whether the reduction in vehicle miles travelled could lead to less congestion on the roads during the morning rush hour and fewer cars driving near school gates, besides – for this paper - allowing a greater usability of *private vehicles with limited autonomy, such as electric ones*.

The effect of the London congestion charge on road casualties was analysed by Noland, et al., 2008: an intervention analysis was conducted to investigate the effect of the congestion charge on traffic casualties for motorists, pedestrians, cyclists and motorcyclists, both within the charging zone and in areas of London outside the zone. We use this with a critic: we intend to address rather an *urban policy based on engines and motors*, therefore on pollution rather than on congestion, being energy and environment much more interesting when considering cleaner industrial policies.

Looking back to the bases of ITS, as a support for the energy efficiency issue and related dependency on black-oil, when using electric traction for private mobility and multimodal transport, Kanninen, 1996, in what was likely one of the first analyses in the field, discussed the congestion relief and environmental impacts that could be expected from Intelligent Transportation Systems (ITS), on the basis of a qualitative assessment of the generated incentives. He argued that although ITS is intended to improve system efficiency, the technology could in fact exacerbate the already existing, economic inefficiencies in the surface transportation system and that policies to correct these inefficiencies could become all the more crucial if the implementation of ITS is considered. Several policies that target environmental externalities were discussed as possible complements to ITS; ITS, we add, is a necessary basis for electric traction when we think about the needs to book charging spots, to choose optimal routing for recharging and the like, being *recharging much more restricting than fuelling*.

The role of ICTs in the transformation and the experience of travelling has been taken into account in the paper by Lee-Gosselin and Buliung, 2012, in which the role of ITS in a more oil independent transport system is emphasised.

*Hybrid vehicles projects* have been investigated in the paper by Hannan et al, 2014, who gave details about related industrial technologies and their shortcomings; some studies on renewable energy technologies, energy management systems and other related topics have been reinvestigated.

The papers by Aftabuzzaman and Mazloumi, 2011, Shaik Amjad Neelakrishnan, Rudramoorthy, 2010, and Al-Alawi and Bradley, 2013, present both energy issues, which are hereafter analysed, and comprehensive summaries on HEV, PHEV and EV penetration rates studies, their methods and their recommendations. In the third one, these studies have been applied with a set of analytical and computational tools to model the consumers' acceptability of these technologies under a wide variety of policy and macro-economic scenarios.

#### 4. Recent trends in demand and transport policy concerning energy in automotive field

From the previous paragraphs, a few main elements emerge: in the present century, the strengthening of sustainability issues and the development of *motionless communication* have been conditioning the increase in transport, and therefore the use of automobiles, at least in the most technologically advanced areas in the world. In recent years, the constraints on *emissions* have also had important effects on the production of engines, and have opened the door to *alternative solutions*; automobile makers have tried to respond to these twofold restraints by merging for pursuing economies of scale and by innovating, in order to have the possibility of investing. However, they cannot make faults on such revolutionary investments on cleaner production that road transport sustainability requires. The double-attacking sustainability concept has to be faced with a *winning cleaner solution* that will be able to satisfy the current modern transport demand. An attempt has here been made to try to understand this latter aspect at both a macro level and then at a personal choice level.

Starting from the macro level, attention has here been focused on Europe, as Europe is at the core of this issue and one of the main supporters of energy and environmental issues. The European Union appears to be determined to tackle the energy issues pertaining to transport sustainability: its White Paper “Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system” (COM/2011/144, EC, 28.3.2011) targets ambitious objectives concerning *independence from black oil* as well as the utilisation of technologies in such a pursuit, in line with “Horizon 2020”; the USA has also made significant steps (April 2013) towards independence from black oil for the traction and propulsion of transport systems. In 2016, Japan declared the will to reduce carbon dioxide emissions from transport usage.

In order to lay the bases for viable future technological evolutions and industrial outcomes, the authors here intend to deal specifically with the following topics on the demand and use of energy in transport systems:

1. to what extent transport systems and road transport have an impact on the use of energy;
2. how energy consumption has evolved in transport systems and in the automotive industry;
3. to what extent the use of energy has an impact on road transport;
4. what the involvement of the governments is in the use of oil-derived energy for automobiles;
5. what cleaner industrial solutions can be prospected in a changing economy, related to both the traction of vehicles and the economic interest of the public administrations.

The following sections first gather and synthesise a general framing on the role and impact of transport systems on the overall energy consumption, with the related evolution, and –

conversely – on the impact of consumption on the operational cost of the different transport modes. These elements are essential for a better understanding of where and to what extent energy efficiency can have an impact on automotive transport, and they provide the grounds for some general considerations on the energy demand in transportation, as well as on its subsequent impact on economics in general.

As mentioned above, the literature on this subject has produced a multitude of technical reports, analyses and descriptive articles; however, a more accurate investigation of the general matter still seems to be useful. The aim of the present paper has been to provide a perspective of consequent *industrial choices*, engines, automobiles and preferable transport solutions, taking into consideration the per-capita energy use in transport modes, which, in this frame, becomes essential.

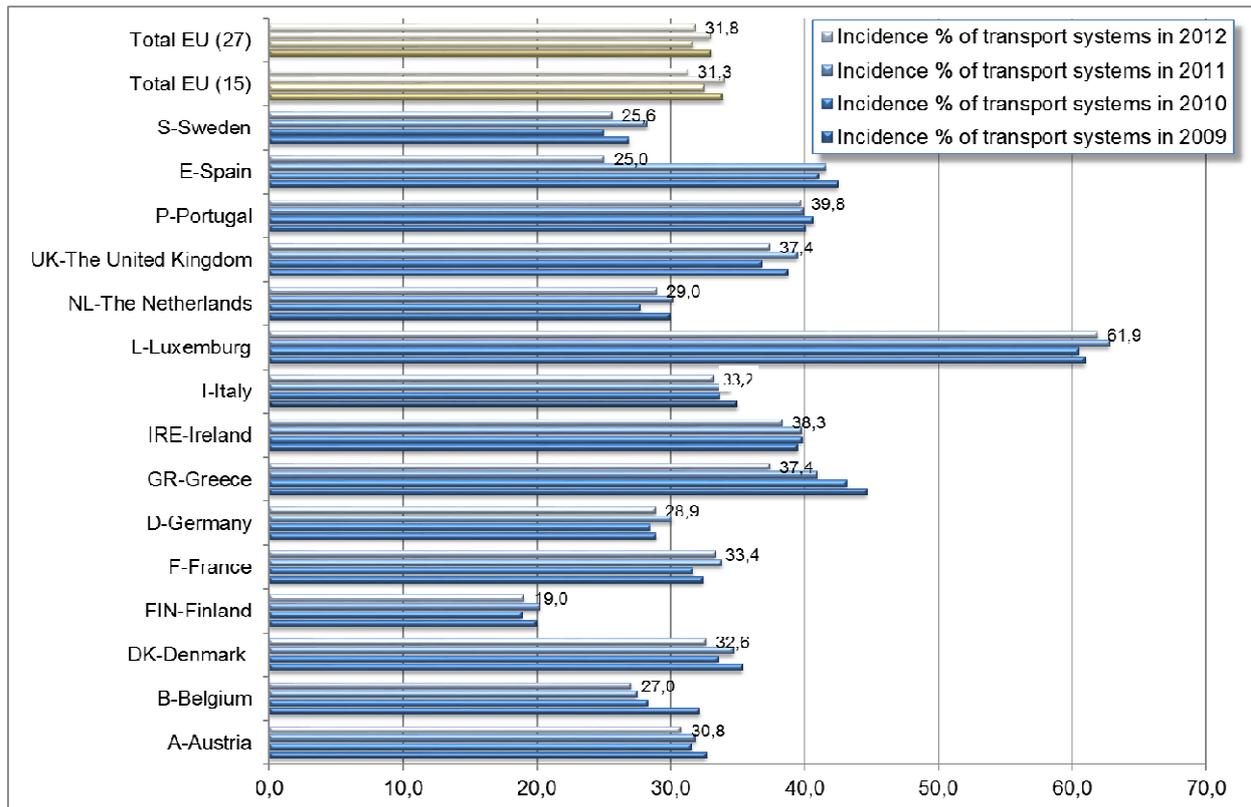
## 5. Impact of the transport systems in general on energy usage

The transport industry is mainly characterised by the use of *distributed energy* vehicles, with the exception, in general terms, of those systems which operate on tracks or fixed installations, such as railways, subways, cableways and automated people movers (Dalla Chiara et al, 2008a). As will be specified further on, in most cases, the energy source is combusted directly by engines on-board vehicles - be they on road, sea, inland waterways or air – that are provided with a fuel tank.

Almost all these transport systems are based upon oil derived fuels, and the current alternatives often show significant limits. The transport systems operating on fixed installations do not depend only on the aforementioned fuels since – as is well known – they also use, with the exception of infrequent Diesel traction vehicles, electric lines supplied by power stations, irrespective of the energy source used to supply such stations. Moreover, the automobile field is the only one which is almost exclusively based upon a sole primary source (Dalla Chiara et al, 2008b). For example, the data supplied by the Italian Ministry of Economic Development in 2010 have shown that, in Italy, such a dependence was nearly 93.4% for use in transport system (road, rail, ...), although this figure seems to be reducing compared to 2005, when the use of black oil was nearly 97%: This dependence on black oil was estimated as 98.2% in Great Britain in 2011 (Department of Energy and Climate Change, 2012), 98.5% in Switzerland in 2011 (Federal Department of the Environment, 2012) and 99% in Australia in 2002 (ABARE, 2004). Some figures, at a European level, dating back to the beginning of the decade (2001 EC White Book on transports [COM/2001/0370 def.]) estimated this value as 98% while it was estimated as 96% in the USA in the same period, although it reduced to 93.2% in 2010 (US Transportation, Energy Data Book, 2011). The 2011 White book on Transport Systems reports a figure of 96% in the EU. These values also

include capital expenditures: for example, nearly 67.4 billion Euros - nearly 30 of which of industrial component - for Italian drivers each year, in 2012-2013-2014: this value was somewhat lower in 2015 because of the reduction in cost per barrel of oil; reducing the overall amount by the industrial component, the remaining part is mainly associated with taxes absorbed by the government.

According to Eurostat, the impact of transport systems in Europe (EU-25) on the overall energy consumption in EU countries in 2004 resulted to be equal to 30.7%; such a value grew to approximately 32% (2006) and to 33-34% (2008) in the following years (Dalla Chiara, 2010; Dalla Chiara et al, 2008b; EIA, 2006 and 2008). The impact of the transport systems in Europe is nearly 10% greater than the world average (estimated as 20.42% in 2003), due to the presence of a larger average motorised mobility than in other continents. Europe shows variability in the impact of transport consumption on the overall final values reported for the different countries (Unione Petrolifera, 2009, 2011, 2013, 2014) (Fig. 2). Transportation accounted for almost 70% of petroleum use in the USA from 2008 to 2014 and had an impact of 28% *on the total energy use in the USA*. The total petroleum consumption reached more than 20 million barrels per day in 2007, but has been below that level from 2008 onwards (U.S. Department of Energy, Energy Information Administration, Monthly Energy Review, June 2015).



**Fig. 2.** Impact of the energy consumption of transport on the final domestic consumption in Europe and in the relevant nations, - data from 2006-'08-'10-'11 (Dalla Chiara, 2010; Unione Petrolifera, 2009, 2011, 2013, 2014).

According to publications referring to EU25 (EC, 2004, 2005, 2006), within the framework of motor transport systems, road haulage covers a share of the overall energy consumption (equivalent tons of oil) of approximately 82.5%, and is therefore predominant - at a continental scale - over other modalities (EC, 2007); railways have been estimated to be approximately 3% below (Table 1).

**Table 1.** EU-25, consumption of transport modality in 1990, 2004 and 2010, in 1000 toe<sup>7</sup> (EC, 2007 and EU Transport – Statistical Pocketbook 2012).

Transport modes	EU-25					Share of the overall energy consumption, 2010 (%)
	1990	2004	2010	1990-2004 Variation (%)	2004-2010 Variation (%)	
Road	227'957	290'013	299'700	27%	3.3%	<b>82.6%</b>
Railway	9'125	9'250	7'400	1%	-20%	<b>2%</b>
Air	28'378	47'420	49'800	67%	5%	<b>13.7%</b>
Inland navigation	6'578	5'047	5'900	-23%	+17%	<b>1.7%</b>

## 6. Evolution of energy consumption in transport systems and in automotive field

In order to start answering the second question, circulating vehicles need to be considered. The number of automobiles in European countries can be seen to have experienced continuous growth in the second half of the 20<sup>th</sup> century (Fig. 3, referring to Italy), as has also been shown for Germany (Woldeamanuel et al., 2009).

In 2008, approximately 176.5 million vehicles out of the 806 million ones in the whole world (Fig. 4) were circulating in China alone, that is, approximately 21% of the whole world's fleet (Dalla Chiara, 2010)<sup>8</sup>.

However, more worrisome data are expected for the future (The Worldwatch Institute, 2007): the European population is approx. 500 mln. inhabitants, i.e. one fifth of the overall population of China and India.

<sup>7</sup> Equivalent tons of oil.

<sup>8</sup> To define the present consumption, it would also be necessary to examine the use people make of such a circulating fleet, which is related to both the average distance covered and the relevant occupancy rate; the latter aspect cannot be obtained as reliable information.

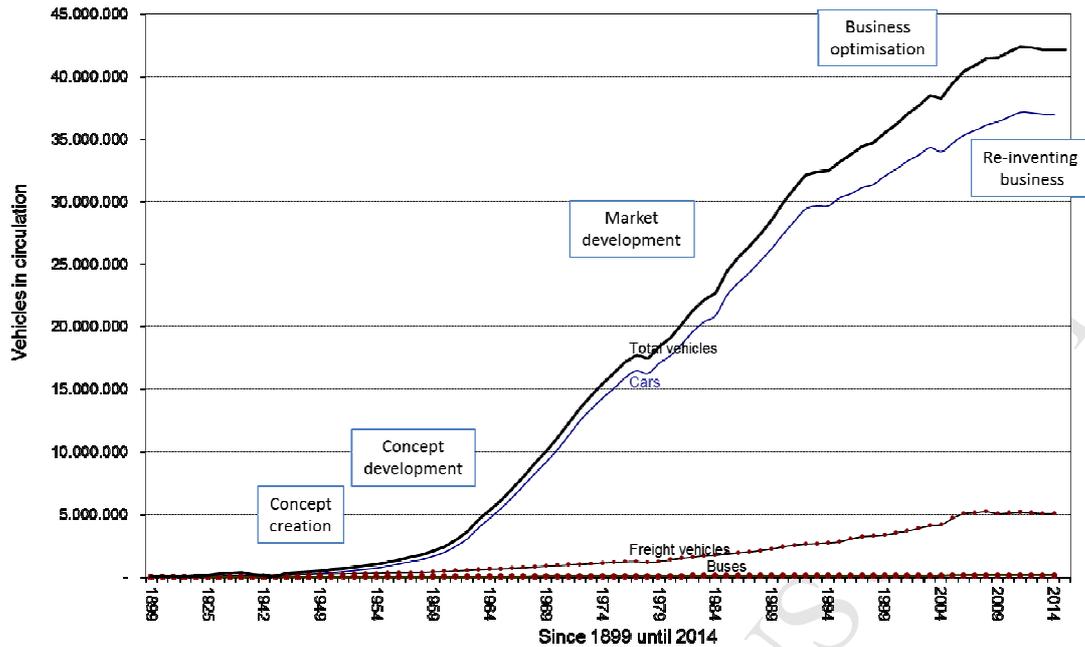


Fig. 3. Evolution of light and heavy-duty vehicles in Italy from the end of the 19<sup>th</sup> century until today (elaborated on data collected by Maggi, 2005; ACI/ANFIA-I, for various years) and our association to a typical or generic phases of business evolution.

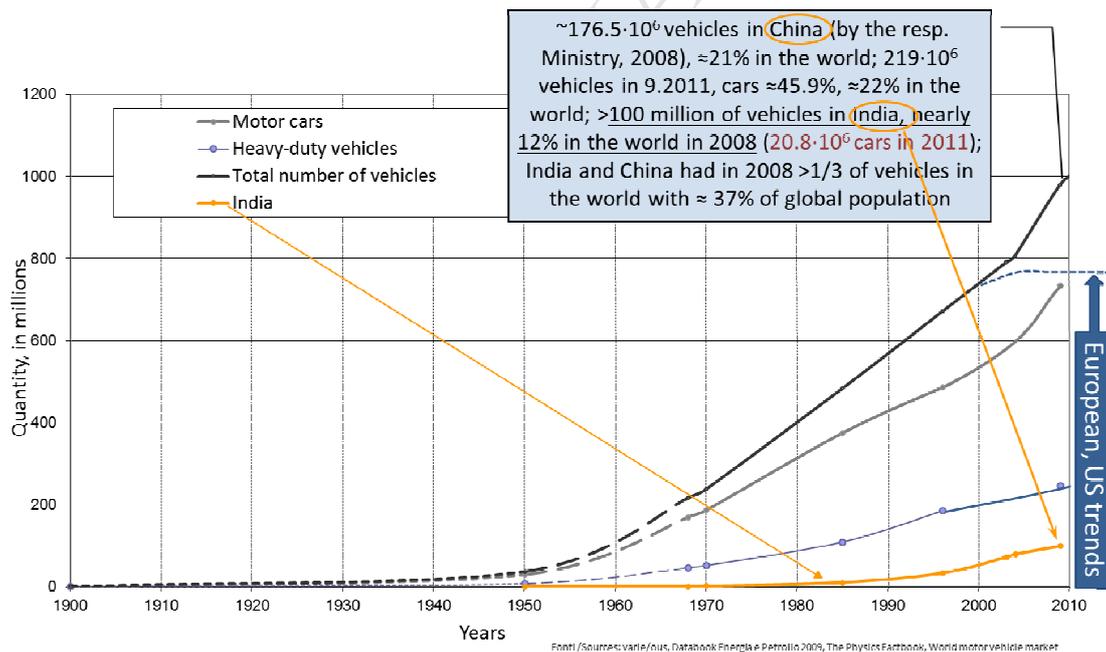
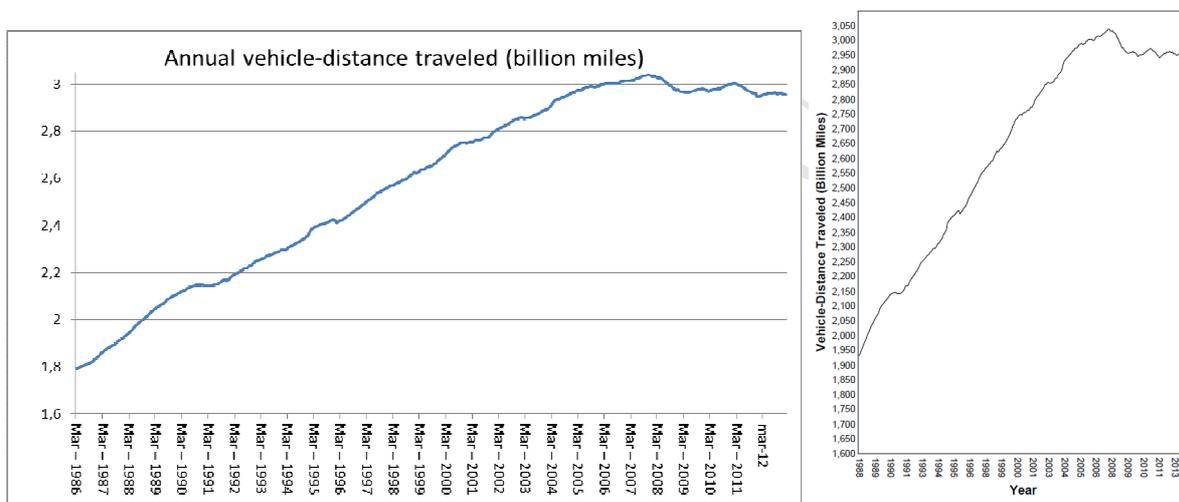


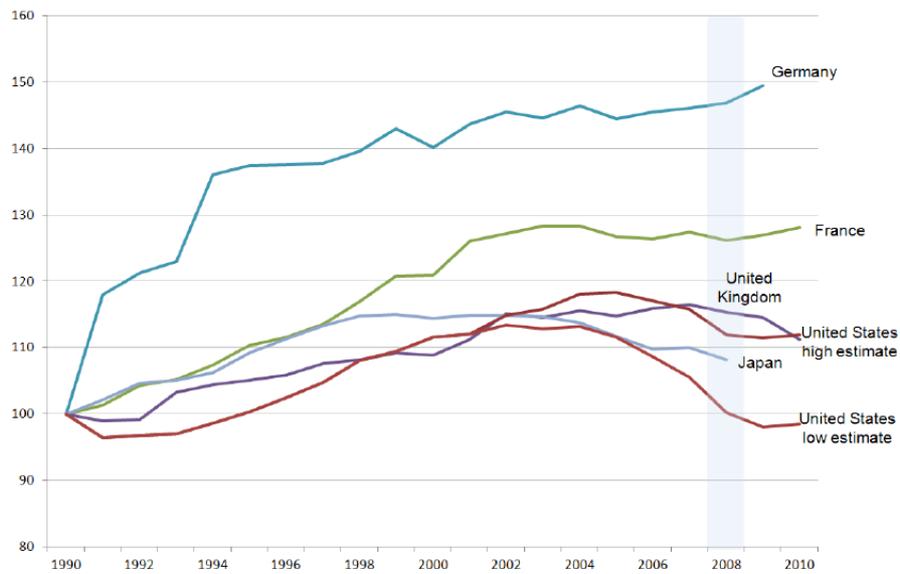
Fig. 4. Vehicles circulating in the world: approximate trend on the basis of a few known data and estimates from different sources (Sources: miscellaneous; Unione Petrolifera, 2009, 2011; The Physics Factbook, World motor vehicle market report, 2010).

Consequently, if, according to the current trend, these two countries reach an average level of motorisation equal to the European one, the conditions might come to a head, since the demand for oil in these Countries would grow at a very fast rate, with an expectable subsequent increase in its sale price, except – of course – in the case of very competitive alternative resources. In China, in the last 40 years (i.e. between 1965 and 2005), oil consumption has increased from approximately 11 million tons per year to 327 million tons (Dalla Chiara, 2010): i.e. a 2,900% increment for an average increase of approximately 72.5% each year.

Considering the above information an attempt will here be made to verify whether the recent almost *constant values of circulating vehicles* in most industrialised countries can be confirmed by the current mobility of people; recent trends of individual motorised mobility in Europe and USA show a nearly constant trend (Fig. 5, Fig. 6).



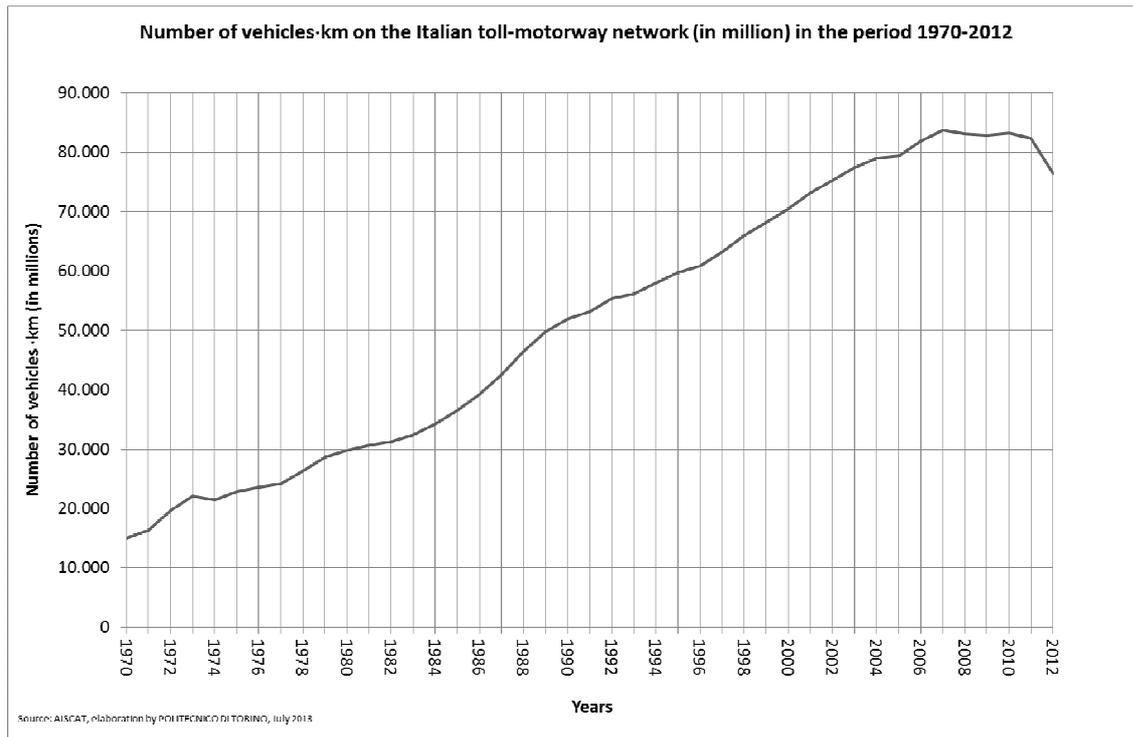
**Fig. 5.** Annual vehicle distance covered on highways in the USA, *Moving 12-month total on all highways* (US Department of Transportation, 2013; US Department of Transportation, Federal Highways Administration (FHA); 2013, Traffic volume trends; Compiled with available data from January 17, 2014).



Source: ITF statistics; the high estimate for the USA assumes car occupancy rates remain at the level measured in 2001, and the low one that they decline as of 2001 to the level observed in the most recent household travel survey.

**Fig. 6.** Passenger kilometres travelled by private cars and light trucks, 1990-2010 (index 1990=100) (OECD, 2013).

As an example, it can be observed that the total distance covered by light vehicles along Italian toll-paying motorways (figure 6) decreased by 1.6% in 2011 compared to 2010; as far as heavy-duty vehicles are concerned, the v·km were almost equal to those of 2010 (-0,1%); the traffic of heavy-duty vehicles was less in 2011 than that recorded in 2003. The comparison shows -23.5% t·km for toll-paying motorways in France between 2007 and 2012 (FNTR, 2013). The traffic was almost constant between 2012 and 2015, but there has been a slight increase since 2014 and a notable increase in 2016.



**Fig. 7.** Vehicles per kilometre for all vehicles, 1970-2012 (elaboration by the authors on data obtained from AISCAT, 2013).

All the aforementioned conditioning aspects associated with sustainable transport – i.e. land use, energy use, environmental impact, maintenance, increased safety, level of personal mobility – seem to have had a real impact on mobility and therefore require an appropriate analysis for a subsequent general economic and *cleaner industrial solution* in the automotive field. Attention has here been focused on the energy aspect, given this *monopolistic situation* on the used energy source and on the driving population – which has become consolidated over nearly/almost one century – together with the implications it has on technological innovation, industrial production and, consequently, on the environment.

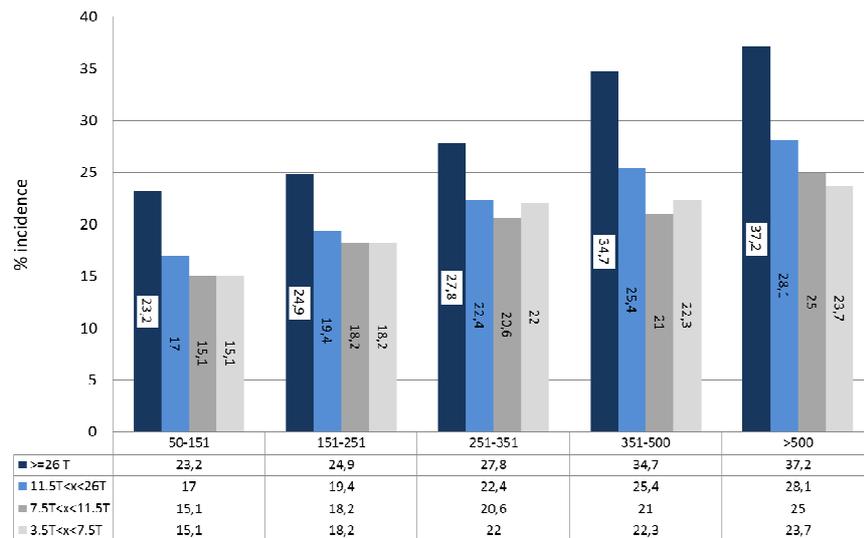
The *almost complete monopoly of one energy source* in this field is *not necessarily negative*, since it creates a global standard for both production and for the maintainability of internal combustion engines, while their production is balanced between two options, on the basis of the availability and prices of oil-derivate fuels: It also creates *economies of competence*: one century of results cannot be disregarded. However, it could become an issue if one or more of the already long-lasting threats begins to compromise the already slaving balance of payments of those nations that cannot take advantage of internal oil extraction at competitive costs, being exporters of black oil part of an oligopoly: the exhaustion of oil-wells producing oil so far available at reasonable prices, which are being taken over by unpredictable self-establishing and self-declaring states, because of the unsettled conditions of the Islam area, the convenience of the WTW analysis (see below), environmental constrains – such as, for

example, those officially stated on CO<sub>2</sub> emissions in Europe – which, as far as all combustion products are concerned, are closely related to both climate change aspects and Public health, could all play a role. There is still a need to examine the energy usage pertaining to land transport into more detail for our subsequent proposals concerning the automotive industry.

## **7. Energy usage in the road transport sector**

The impact of energy consumption on road transport vehicles is extremely variable, mainly because of the very different kinds of vehicles that circulate: those with from 2 up to 10 wheels and sometimes more, with related masses and mutable usage in terms of grades of roads, speeds of vehicles and their variations. As an example, it is possible to mention the exceptional impact of energy consumption on the running cost of freight - i.e. heavy-duty vehicles – in many industrialised countries between 2008 and 2010, a value that was approximately equal to 25 to 35%, with further peaks of up to 37% in the 2011-2015 period. The incidence of road freight transport, including industrial and commercial vehicles, on the overall road transport energy consumption reached approximately 39.5% in 2008 (Dalla Chiara and, Pinna, 2012).

The purely indicative example reported in Fig. 8 shows the incidence of the cost of gasoil on road haulage, as taken from data supplied by the Italian Ministry of Infrastructures and Transport. The values obviously vary on the basis of the total weight and average yearly coverage of the heavy-duty (industrial) and commercial vehicles, but there is no particular reason for such different percentages in other similar countries, apart from a variability of State taxes, as modern freight vehicles are all similar in terms of average consumption.



**Fig. 8.** Incidence of the cost of gasoil on freight road haulage, elaborated on the basis of Ministerial data for 2011 and on field data for the 2012-2014 period (for Italy): the columns report the distance classes [km], while the lines report the total weight on the ground.

The incidence of road transport energy consumption on the overall energy consumption in a given country can be estimated from this information. If Italy is taken as an example, energy consumption can be seen to have consistently increased during the second half of the 20<sup>th</sup> century as a result of the progressively large number of circulating vehicles: such a growth was moderate from the second half of the nineteen forties until the first half of the nineteen sixties (nearly 430,000 commercial and industrial vehicles were circulating in Italy in 1960), but increased remarkably faster – on average – in the nineteen seventies and eighties (nearly 1,370,000 in 1980) and then decreased (negative second derivative) in the last fifteen or so years. In the last 12-15 years, the number of registered vehicles – both light and heavy duty ones – has remained nearly constant in Italy, i.e. approx. 3 million units. This trend is rather similar to that of other European countries.

However, although the scenario of the circulating fleet, which is obviously not the only factor that affects energy consumption, shows a trend going towards saturation in European countries, the worldwide status is rather different; the 46,614,342 heavy-duty vehicles estimated in 1968 (i.e. 21.5% of the overall fleet) rose to approximately 109,000,000 in 1985 (22.5% of the total) and to approximately 185.404.000 in 1996 (27.6%). Nowadays, according to data derived from the literature, heavy-duty vehicles may amount to approximately 300 million units, with a continuous increase that has mainly been ascribed to industrially evolving areas throughout the world.

The evolution of petrol and gasoil consumption for automotive traction in industrialised countries can be calculated; a trend that has constantly grown over various decades for different nations as well as a reduction over the last few years (see, for example, Maggi, 2005;

Dalla Chiara and Pinna, 2012; The Executive Office of the President of the United States, 2015) can be observed.

If Italian data are again considered as an example, it can be seen that the consumption of petrol and gasoil in 2005 resulted to be:

- approximately 18,766 billion litres of petrol;
- approximately 29,85 billion litres of gasoil;
- approximately 47,851 billion litres in total.

These figures rose to 12,530 billion litres of fuel in 2011 and 30,000 10<sup>9</sup> of litres of gas oil (diesel); in in 2013 these were 11,146 10<sup>9</sup> litres of fuel and 30,488 10<sup>9</sup> of litres of gas oil (diesel). It can therefore be seen that a remarkable reduction has taken place. Gasoil consumption results to be much higher than that of petrol, even though the number of petrol-fuelled vehicles in Italy was more than double o gasoil-fuelled ones; this is because of two partially obvious reasons, namely:

- the yearly average road coverage of gasoil vehicles is far greater than that of petrol vehicles;
- approximately 91% of the road vehicles devoted to the transport of goods are gasoil fuelled; it is well known that they cover long distances per year and their consumption is higher than that of passenger cars.

During the last five-year period, gasoil consumption in Italy has been recorded as being approximately 60 to 70% of the total consumption (petrol and gasoil), with a growing trend in the last few years; the average road coverage of heavy-duty vehicles compared to that of passenger cars is not known: however, some estimates can be made to identify the energy impact.

The total consumption of fuels is obtained by adding the consumption of petrol-fuelled vehicles to that of light vehicles, multiplied by the relevant road coverage plus that of diesel and the heavy-duty vehicles, multiplied by the respective values. The above mentioned individual factors, although they cannot be established precisely for the current situation, may be ascertained in the future, through the use of black boxes<sup>9</sup>. However, the overall refuelling data at petrol stations are instead available.

The data provided by the *Conto Nazionale dei Trasporti* (i.e. the Italian Report on National Transport Data) reported that, in 2004, the fleet of diesel cars - even though they represented little more than 25% of the total fleet- consumed almost 38% of oil derived fuels.

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<sup>9</sup> In April 2015, the European Parliament voted in favour of an eCall regulation which requires all new cars to be equipped with eCall technology from April 2018 onwards. In the event of a serious accident, eCall automatically dials 112 – the established emergency number throughout Europe, according to Commission Delegated Regulation (EU) No 305/2013 of 26.11.2012, which updates Directive 2010/40/EU of the European Parliament and of the Council with regard to the harmonised provision of an interoperable EU-wide eCall.

The same source also shows, with reference to in 2010, that the percentage of gasoil cars had increased over the previous few years: 14.72% in 2000, 19% in 2002, 25.23% in 2004, 31.18% in 2006 and 35.47% in 2008, up to 44.6% in 2014 (41.1 considering the new electric and natural gas vehicles).

Furthermore, the circulating fleet of industrial and commercial vehicles being known (4.672.659 in 2005, 5.039.327 in 2015), as well as that of buses and diesel cars, it can be inferred that diesel traction vehicles consumed an average of *little less than 2000 litres per vehicle per year in those years*; with diversified assessments on the consumption of passenger cars and heavy vehicles, it is possible to estimate *an impact of between 35 and 40% of the total litres consumed for traction by heavy vehicles* : these vehicles have represented approximately 12 to 13% of the total number of vehicles and approximately 29 to 32% of the Diesel vehicles in the last 5 to 6 years: However, it can easily be assumed that their average road coverage is higher than that of cars.

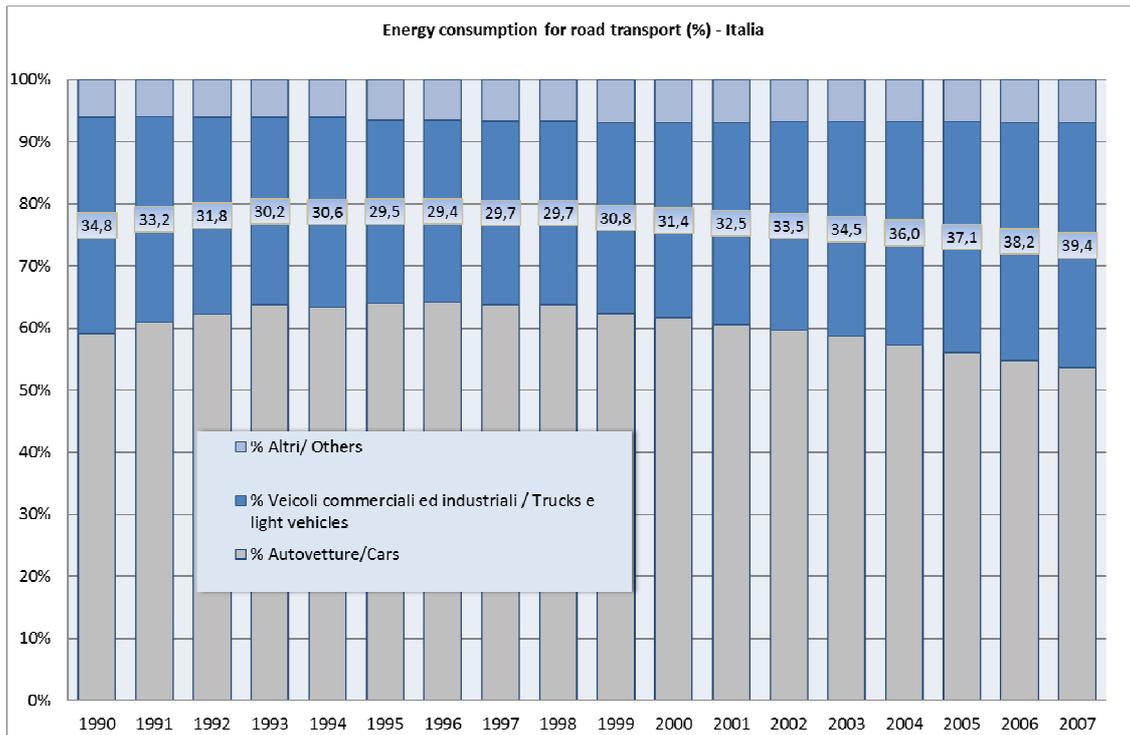
On the other hand, other analyses (e.g. that of ENEA) show that the impact of heavy vehicles on road energy consumption in Italy is approximately 35 to 40%; these values are essentially similar to the aforementioned ones.

In comparison to other countries in Europe, it results that such a value – was at a minimum of 23.8 in Germany in 1990 and a maximum of 36 in France. As an example, the percentage impact of energy consumption of heavy-duty vehicles on the total figure was 33.5% in Austria in 2007, 34.3% in Croatia, 41% in France and 29.2 in Germany (Energy Efficiency Indicators taken from Europe, Odysee, 2011).

All the above information leads to the fact that - on the basis of the 2012 data, i.e. the most completely available ones, since at that time transports were impacting for approx. 33.2% of the overall energy consumption in Italy, if we reasonably assume that the European average of 82.6% approx. as energetic impact of road transport on the transports applies to this country as well - the freight vehicles and the connected activities of external logistics consume approx. 10% of the overall energy; with the values of the most recent years, we reach an impact of 11 to 12%.

Fig. 9 reports the impact of road freight transport on the overall road transport energy consumption. A value close to 40% is shown for Italy. Data from the USA Transportation, Energy Data book (for 2012 and 2015) show that approximately 22% of consumption is for medium and heavy trucks.

As far as the use of alternative fuels is concerned, the percentage of Biofuel in Italy was 0.9 in 2006, 0.9 in 2007 and 2.3 in 2008; the European average over 27 countries was 2, 2.6 and 3.5, respectively.



**Fig. 9.** Impact of road haulage on the overall energy consumption for road transport (Italy).

What do all these values actually mean for this paper? The sustainability of road transport passes through a reliable quantification of its incidence on energy production and, reversely, the comprehension of energy impact on road transport operation. As black oil has emerged as a relevant problem, whether in terms of prices, availability, reserves, political stability or emissions, an *industrial solution for production* should be proposed than should be compliant with constraints and the available technological solutions, while respecting economies of scale and engineering competence associated with oil usage, as will be pointed out in more detail hereafter.

However, it is also necessary to recall that the automotive field is currently put in competition with both *motionless communications* (e.g. teleworking, teleconferences, etc.) and with more competitive *trains*: automated undergrounds in metropolitan contexts as well as regional or high-speed trains over medium and long distances, of up to approximately 600-800 km/direction per day. Motionless communication is competitive in terms of costs and of energy usage. However, the impact on the operational cost of energy consumption for the main land transport alternatives such as railways, subways and tramways, are meaningful. Some indicative data, which are similar to one another, show values of between ~4-5% and ~6% (Dalla Chiara, 2010.), in terms of energy impact for operating rail systems on their overall costs (we have seen a 30-35% for the heavy-duty trucks, less of course for automobiles but the ratio remains around 1/5-1/7 as that of the rolling resistance). This means

that, when applicable, they potentially constitute a very important alternative to road vehicles, in terms of energy and environmental sustainability, as well as to motorised and clean means (such as bicycles, bike-sharing services, car sharing using electric cars, ...), for short ranges. It is therefore possible to wonder whether *automotive production has a way-out or solution in this context*: for this purpose, if the usage of either alternative fuels or energy carriers represents a solution, a more extended analysis on the overall energy consumption is required for a sustainable technological and economic solution in terms of a clean production for the market.

## 8. A comprehensive analysis based on the overall energy consumption

In order to provide an appropriate analysis on energy consumption, within its sustainability context, and to trace an appropriate technological perspective - which can be considered as satisfactory from a methodological point of view - related to all transport systems, the well-to-wheel (WTW) index (a tool which was first proposed and consolidated in the automotive industry, but which is rarely applied to the other modes) needs to be applied once we decided to abandon the near-monopoly of black oil and the direct combustion of its derivatives on board.

WTW is an absolute energy index, whose function enables combinations of different propulsion technologies and different fuels or energy carriers (i.e. hydrogen and electricity, which - once they are produced - can be considered as fuels), obtained from a wide variety of primary sources to be compared.

The WTW index, which can be defined as the integration of all the processes required to produce and distribute fuel (starting from its primary energy source) and to use it in a vehicle (EC, 2004 and 2007), consists of the combination of two more specific sub-indexes, namely: the well-to-tank (WTT) and tank-to-wheel (TTW) indexes, although an intermediate index, referring to the charging solution, i.e. how the tank or battery is charged or refuelled, is introduced when useful.

WTT considers the amount of energy required to make fuel available from the primary energy source (energy expenditure for extraction, for the chemical transformation processes and for transport) to the supply to the car tank, in a broad meaning; it is usually expressed as  $MJ_t/MJ_f$ , where  $MJ_t$  is the overall amount of energy spent to make such an MJ of fuel available and  $MJ_f$  is the energy contained in the fuel stored in the vehicle tank.

TTW instead considers the amount of energy used to move a means of transport over a given distance, which depends on the combination of the fuel and of the used propulsive technology. From the analysis point of view, the assessment of the WTW index is obtained from the following ratio:

$$WTW \left[ \frac{MJ_t}{km} \right] = WTT \left[ \frac{MJ_t}{MJ_f} \right] \cdot TTW \left[ \frac{MJ_f}{km} \right] \quad (1)$$

In the automotive industry, TTW can be determined through standardised guiding processes, where the speeds and the driving conditions (i.e. stops at traffic lights and slopes) are as close to reality as possible (typical driving cycles).

It should be mentioned that calculating WTW for the rolling stock is instead a complex exercise. The standard pathway on which the consumption of the different trains is calculated, as well as the broad heterogeneity of the circulating stock and the relevant performances all represent significant drawbacks of this method. Because of the lack of availability to the public of data from energy counters either on board locomotives (Dalla Chiara et al, 2008b) or at sub-stations, pertaining to the connected rail traffic, three alternative options need to be taken into account, namely:

- the use of empirical formulas, which have to be specific for each section and for each type of train; this option is more functional in a case study scenario, since, because of the broad heterogeneity of lines and vehicles, it cannot provide general indications as the car WTW (instead) can;
- the use of other empirical formulas based upon the resistances of the train and therefore on the equation of motion;
- the use of analytical models to establish the dynamics of train motion; this would call for highly accurate data which are often difficult to find.

While the mass of a vehicle is highly significant in rail transport, since it prevails over the weight of the transported passengers, it has little significance in the car industry. This is why, when only conducting a comparison between different trains, analysing and proposing the data in  $MJ_f/(p \cdot km)$  is not always sufficient, and it would sometimes be more meaningful to consider the handled load, e.g. in  $MJ_f/(t \cdot km)$ .

Another parameter that has to be known in order to determine the WTW of trains is the load factor, which, reporting the number of passengers as a percentage of the seats available on a train, quantifies its occupancy and therefore establishes an index for its utilisation.

In order to calculate the absolute energy expenditure of each mode, the WTW needs to be multiplied by the number of transported passengers and by the kilometres covered by each vehicle.

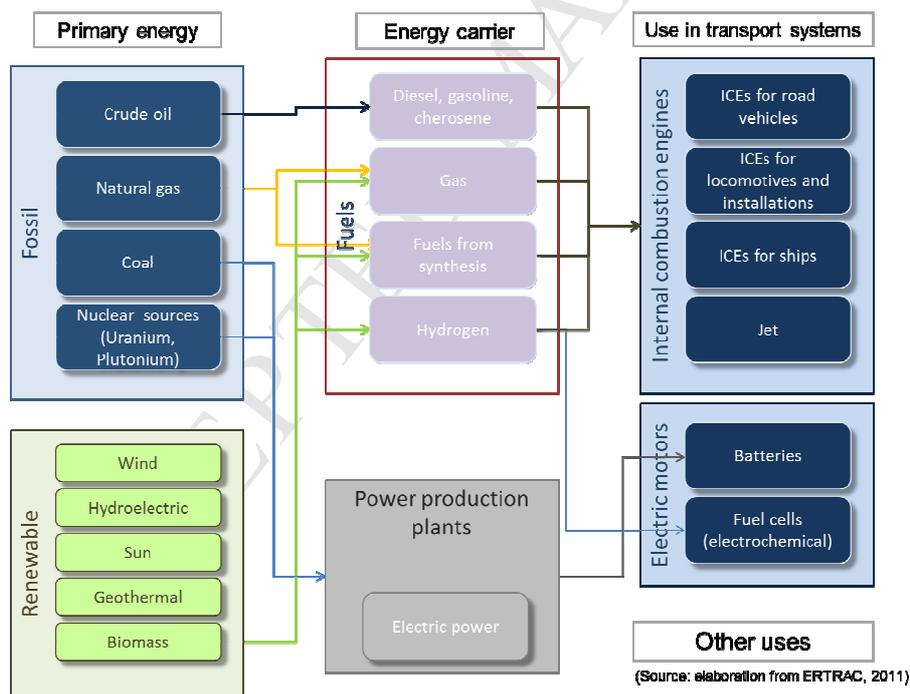
This section shows that road transport can only be sustainable as far as it can remain competitive not only from the TTW analysis, which has implicitly accompanied our market and our car manufacturers for almost all of the last century, but also from the overall energy chain viewpoint, that is the WTW. The latter index is competitive for trains as far as they are well used, that is do not transport almost “air” but passengers or freight. So the sustainability

seems again to burden much the automotive field, leaving market to trains when they are well satisfying the demand in terms of services.

## 9. Potential energy migrations

An important consideration here needs to be pointed out: the WTW analysis becomes necessary when it is needed or present policies (as in EU) oblige one to migrate from one transport market, which is almost completely dominated by black oil - through the products of its distillation, as the primary energy source chosen nearly one century ago – to a different one; any alternative has to be evaluated on the basis of the energy needed to obtain it - especially in the case in which it is not used directly, i.e. burnt, inside the vehicle, as occurs with fuels – with particular reference to energy carriers (Fig. 10).

Once the energy monopoly has partially been abandoned in the automotive field, the energy supply for transport could take a large number of different pathways, as shown in Fig. 10. Alternative fuels would gradually become a much more significant part of the energy mix. However, it is difficult to identify a single candidate for a cleaner market and, consequently, production; the fuel demand and the challenges set by greenhouse gases will most likely imply the use of *a wide variety of primary energies*. There is rather broad agreement that all the available sustainable fuels will be needed to resolve the expected supply/demand tensions.



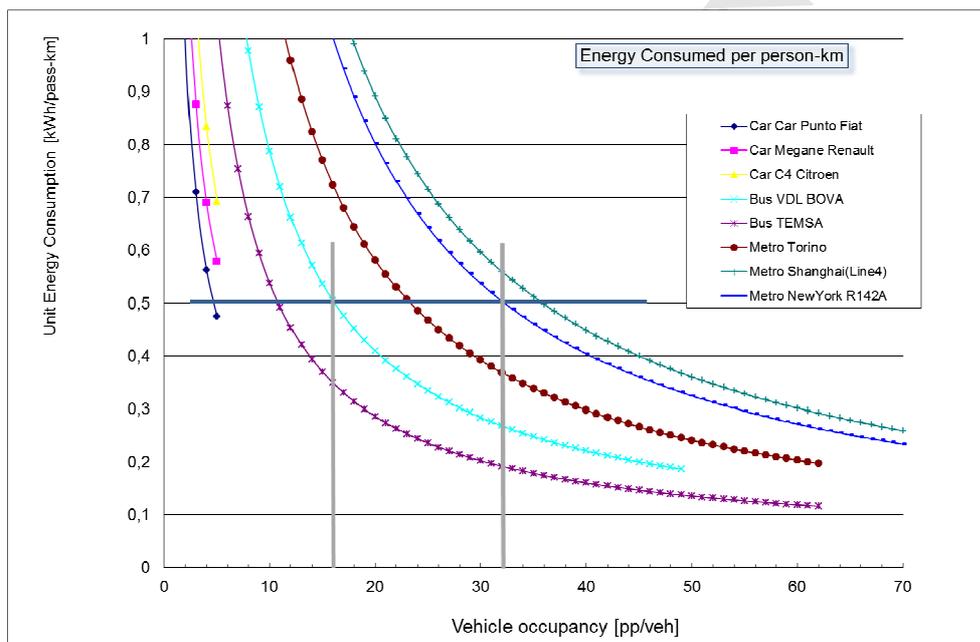
**Fig. 10.** Energy pathways in transport and other sectors (Source: our/the authors' modifications of ERTRAC, 2011).

Irrespective of the costs and prices of the energy source, which are subject to variations due to the market fluctuations, it is necessary to underline that the WTW index varies over time and space, since it is related to the current or known availability of sources and to the kind of energy in use within a given country or region.

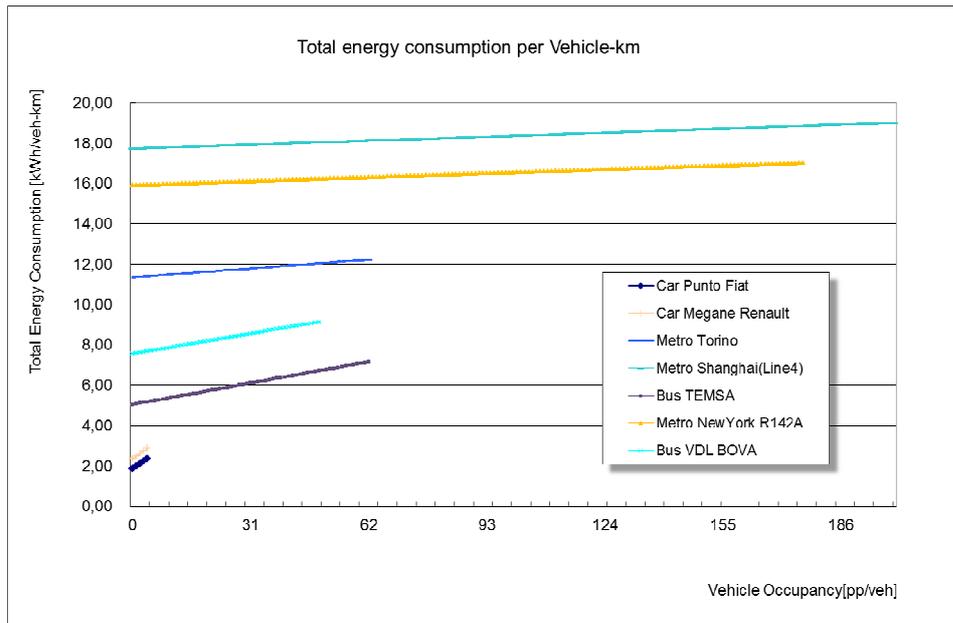
## 10. The role of occupancy and load

As previously mentioned, a merely quantitative analysis would not be sufficient for the aim of this paper. Instead, the actual use of each and every transport mode should be taken into consideration. From this point of view, public transport is obviously favoured, especially rail, cableways and underground systems, because of their lack of dependence on black oil. However, occupancy is also a relevant factor. The graphs reported in Fig. 11 and in

Fig. 12 represent the energy consumed on board per person per kilometre and for each vehicle kilometre, on the basis of the calculation of energy dissipation for an aerodynamic, specific resistance along a straight and plane path.



**Fig. 11.** Energy consumed per person-km



**Fig. 12.** Energy consumed per vehicle-km.

From these graphs, it is possible to observe how relevant the good use of a vehicle can be to obtain its sustainability, also quantifying the competition with other transport alternatives.

## 11. Economic issues and their potential evolutions

In such a general energy context related to sustainability, which is characterised by the almost exclusive use of oil derived fuel in the automotive transport systems, the role of Governments should not to be underestimated: this role is quite significant in some cases, and has been of particular relevance since the second half of the past century. This fact has been clearly documented, for example, for road transport in Italy: the tax components weigh by roughly 60% on the overall cost of one litre of fuel, and has remained almost the same over the last ten years.

Hence, the significance of the consumption of energy for transport - mainly road transport – on Italian state revenues can be highlighted:

- income for petrol excise taxes in 2013 =  $0,7284 \text{ €/litre} \cdot 11,298,792,958 \text{ litres} = 8,230,040,790 \text{ €}$ ;
- income for gas oil excise taxes in 2013 =  $0,6174 \text{ €/litre} \cdot 29,642,129,870 \text{ litres} = 18,301,050,982 \text{ €}$ ;

- total revenue for excise taxes in 2013 = 8,230,040,790 + 18,301,050,982 = 26,531,091,772 €

Such values can also be estimated on the basis of the average distance covered yearly by vehicles in Italy, which, according to a analyses of data collected by the “National Transport Account” over several years, multiplied by the average consumption and the money income from the excise taxes, is approximately equal to 12,500 km.

The data, which have been obtained theoretically, can be compared with and confirmed by those found in the State Budget. The aforementioned derived data on excise taxes can be added to the income obtained from V.A.T.

Subsequently, the consumption of fuels generated revenues for the State - as excise taxes and V.A.T- of approximately 38,610,127,961 € in 2013 (31,712,424,567 € in 2005). This value can be added to the income from V.A.T. for the purchase of vehicles and to road taxes; the total revenue for excise duties in 2005 was 22,532,494,656 €.

The last six to seven decades have witnessed a positive economic cycle in many industrialised countries, where an increase in the road infrastructures has been accompanied by an increase in the national circulating fleet and vice-versa, as well as by an increase in the overall fuel consumption, and hence in the State income: *an economically profitable loop for the car industry, its staff, Governments, road manufacturers and infrastructure managers*. Since approximately the turn of the century, the conditioning elements listed in § 1 have taken on more relevance, and an upper limit has been reached – together with the saturation of the market – for this positive collaboration within our industrial society over the last century.

This has triggered the scientific community to search for alternative solutions, both for the general Economy and for a cleaner production, by studying typical distances covered by cars, the competitiveness of more oil independent and environmentally-friendly vehicles and ITS (Intelligent Transport Systems) based on the intensive use of ICT. The main streams and recent results in literature pertaining to these aspects have already been synthesised.

On the basis of the available data on the vehicle fleet, the average distances covered per year and the average emissions of the vehicles (EC, 2004, 2005; Jørgensen and Soreson, 1997; Strelow, 2006), the total emissions can also be estimated for different means of transport, although they remain a consequence of the chosen energy.

An assumption that can be derived from the previous observations concerns what kind of payment can be applied to the use of the natural resources utilised to meet the modern requirements of transport and mobility, namely:

- A charge on oxygen, accompanied by the well-known considerations on CO<sub>2</sub>, which is instead a combustion product and has arisen in the international panorama according to Kyoto’s and subsequent agreements, does not seem to be realistic at all;

- Payment related to the actual the road usage, intended as payment for the coverage of the infrastructure (*road pricing*), with the support of transport telematics, would seem far more realistic and has already been applied in a few countries.

This would have an impact on the transport demand, as it would generate the awareness of the actual utilisation of the distances covered by means of one's own motor vehicle, and a correction could be applied on the basis of the related market. In many countries, the current tax system responds to a logic which does not depend on the covered mileage, but is a function of the power and emission class of the engine. This innovation aspect could be considered in the mosaic that is traced hereafter for a cleaner production and cleaner automobiles.

What has emerged from the previous remarks implies that, in most industrialised countries, a continuous increase should not necessarily be expected in either mobility or in the consumption related to it – as occurred for many decades–while safety, quality and efficiency – mainly as far as energy is concerned – should be pursued (Deflorio et al., 2008).

Subsequently, the industrialised economic system, i.e. that of one of the most mature countries, from the industrial point of view, seems to be passing from a context that is prevalently based on both industrial and civil *production*, the latter being intended specifically as the building of transport infrastructures, to another one based upon *maintenance*, but also on *efficiency, quality and safety*.

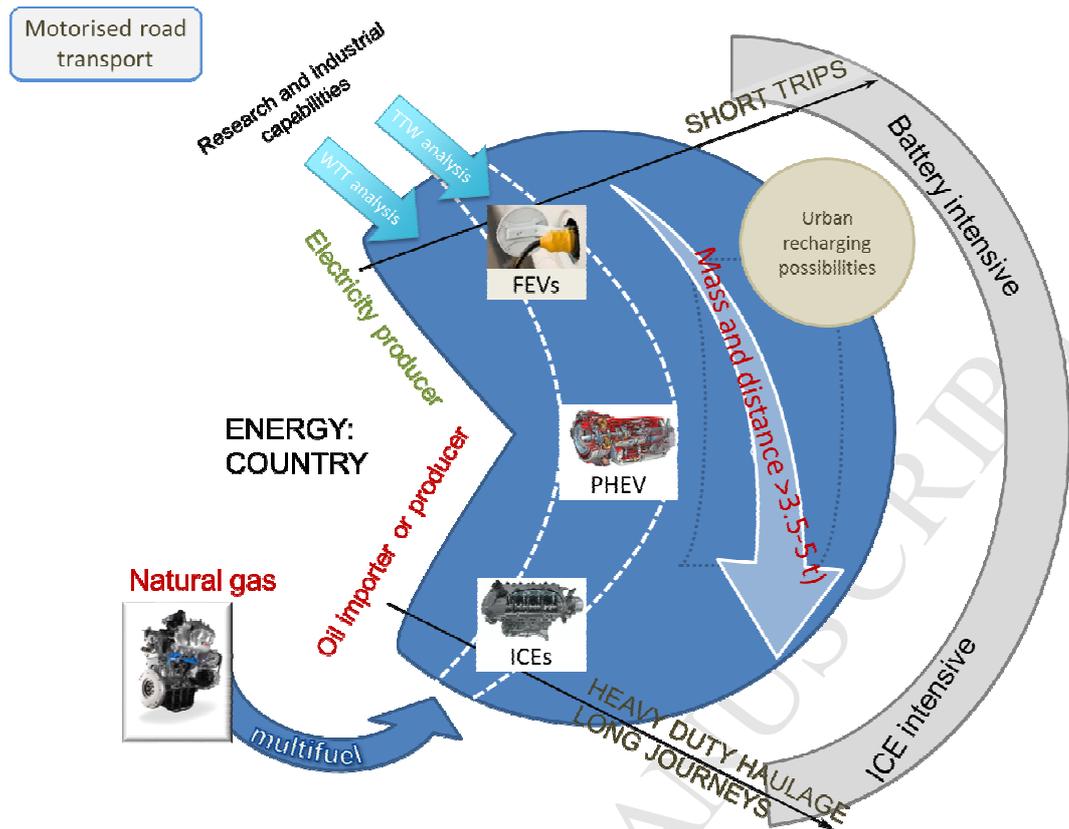
However, considering the world scenario, one of the main challenges our society is facing remains the procurement and management of energy for transport fuels and carriers, as well as the consequences of their use on both people and the environment, in the wide meaning of the word.

Such issues have a great influence on all the sectors of energy consumption, and on land transport in particular.

For this reason, an important step has been taken with EU Directive 2009/33/EC of the European Parliament and of the Council on the promotion of clean and energy-efficient road transport vehicles. However, other relevant activities have also been carried out, as in the USA and other nations around the world. The directive considers the emissions that occur during Tank-To-Wheel (TTW) energy use. Details of various categories and sub-categories of vehicles can be obtained by adopting this methodology. It should be borne in mind that, given the variability of sources for WTT, the WTW index, which varies in time and space, has to be considered as a necessary and unavoidable instrument to choose innovation in transport systems, although it is not necessarily a mathematical instrument of choice.

## 12. Not a single fuel

As regards *road vehicles*, on the basis of the previous analysis, Fig. 13 reports a viable scenario, in the authors' opinion, for future traction and propulsion, on the basis of the WTW analysis and all the aforementioned considerations, interactions of production with the territory and energy availability (European Expert Group on Future Transport Fuel Report, 2011). The concept expressed within the graph is that, according to the energy availability and environmental sensibility within a country (left side) and the research plus industrial capabilities throughout the territory, the production and usage of internal combustion engines (e.g. in an oil producing area, such as an Arab country) or electric vehicles (e.g. in an electric current producing area from nuclear power, such as in France), will be favoured, with all the intermediate mixtures leading to different kinds of hybrid vehicles in relation to the weight of black oil or alternative carriers within energy economy. Moreover, the availability of recharging spots available either in private areas or on public land, together with the usage (mass, distances) made of vehicles will help to frame the market: short trips and light-duty vehicles, of up to approximately 3.5-5 tons of gross vehicle weight (GVW), will lead people to prefer electric traction (not necessarily by fully electric vehicles, but perhaps by the electric motor of plug-in hybrid one) while higher masses or long distances will continue to be covered by internal combustion engines (gasoil, compressed or liquid natural gas, liquefied propane gas); in the latter case, the availability of recharging spots has been found to not be of great importance. Flexible engines, such as multi-fuel ones, help where high masses and long journeys need alternatives to black-oil derivative fuels (e.g. in Brasil). This is a differentiated market, more oil independent and respectful of the local energy preferences, addressed to a cleaner production and operation of road vehicles.



**Fig. 13.** A perspective of road vehicle traction and propulsion on the basis of an WTW analysis, an interaction of the production with the territory and energy availability (elaborated on Dalla Chiara and Pinna, 2012).

The present analysis leads to the conclusion that there is *no single solution* that could be used for all transport modes in order to respect the recent environmental constraints; a viable *energy carrier*, such as *biofuels*, cannot be sustainably produced in the required quantities for this purpose. Biofuels could therefore be used selectively for transport modes in which electric vehicles and fuel cells are not expected to be technically viable. *Rechargeable Hybrid electric vehicles (R-HEVs)*, that is, battery and fuel cell vehicles could be developed for passenger cars and light-duty vehicles (LDVs), bearing in mind the different upfront costs of these two technologies and the local, regional and national energy production (WTT).

The viability of a large-scale market penetration of both battery and fuel cell vehicles depends to a great extent on the forthcoming developments of the basic technology they both require. Literature sources claim that such technologies may achieve sufficient development to start penetrating the market within the next 10 to 15 years. If only one of the two technologies reaches the development required to penetrate the market of light-duty vehicles (i.e. covering all the possible distance and weight segments of LDVs), refuelling/recharging

infrastructures will need to be built at the same time as, or shortly before, any large scale penetration, and this technology could then dominate the market and could even replace oil-based fuels. In addition, if an energy carrier is produced with low or free carbon sources, the developments could easily lead to reductions of as much as 60% in transportation emissions by 2050.

The development of both the aforementioned technologies, as already mentioned, would depend to a great extent on the conducted research and development as well as on the implementation of infrastructures, which, to a certain extent, would need to rely on public resources and investments. The development of rechargeable hybrid road vehicles, mainly light-duty ones, would be much freer. These would need to maintain the global standardisation so far introduced for internal combustion engines and leave both the user and the public administrations greater ranges of freedom in the use of either electric motors or internal combustion engines, according to both the WTT and the TTW, besides respecting any constraint imposed by local administration (e.g., city centres allowed only to non-polluting vehicles) and also leaving the Governments some grades of freedom to impose excise taxes on the use of fuels or (fast) electric current (the slow domestic one can be distinguished with difficulty from other uses as oven and refrigerators rather than for charging a vehicle).

Therefore, the problem might be solved by partially reversing the energy used by a sector onto the electric grid. This energy constitutes nearly one third of the overall energy consumption in Europe, which aims to exit from the monopoly of the source that was chosen at the beginning of the last century. Various solutions could be adopted, from the higher efficiency of the internal combustion engines to the hybrid-electric, fully-electric vehicles (charged on the grid, at a price that would likely vary from nation to nation and from Region to Region), to a higher load on electric powered public transport, to alternative primary energies, including *Natural Gas*.

The potential scenario outlined in this paper could determine remarkable changes for corporate systems that operate in the automotive field. In recent years, different alternative proposals to the use of oil have been made and significant forward-looking technologies have been developed to improve energy efficiency and emissions to the environment, together with the implementation of ITS, infotainment systems and other innovative characteristics in a perspective of reducing the purchase cost of vehicles as well as the costs related to their utilisation. However, some aspects have hindered a fast transition in this direction. Only a few companies have connected and innovated their productions. Some have proposed innovative models in the energy field, while others have developed product innovations to attract their customers. However, mass production still focuses on the most conventional products i.e. those that make use of the black oil monopoly, most likely because of the uncertainty of the responses by the market and the capability of oil producers to apply dumping on new markets (e.g. shale gas) which do not ponder them enough. The choice of the technologies to introduce is particularly complex, as described: some solutions may result to be winning, and

governments may foster the spreading of some of them or introduce different standards (for electric recharging, for emissions, for taxation with excise duties), for different geographic areas, thus creating unavoidable barriers to entry on their markets.

In this way, production in the automotive field could evolve in this changing economy, otherwise it will lose the battle, because of the environmental constraints, against alternative more energy-friendly transport modes (bicycles, electric car sharing, fully automated undergrounds, high speed trains, mobility as a service), and against motionless communication, from the saturation of the market viewpoint.

The range of technologies that can be implemented is currently wide and, as observed, the choice could be implemented as a function of the availability of the different energy resources throughout the different territories, and this could also occur at an international level, with adaptations, if required, – on the local markets. The search for partners in order to develop innovative technologies might lead to a significant increase in mergers, acquisitions and strategic alliances in the USA, Europe and Japan as well as in emerging countries. The strategy adopted by the automotive field to develop innovation and creativity is based on the cooperation strategy. There have been many cooperation agreements, with suppliers (for production) and also with their competitors (Williams et al., 2011). The proposals of innovative cars might also come from companies or other industries.

Therefore, the European automotive manufacturers who win the challenge and manage to sell green cars and vehicles provided with ITS at a large scale might make their market more attractive and also meet the consumers' demands on the international markets, thus increasing their share and – subsequently – their global usage economic results. These manufacturers could meet the primary needs of other stakeholders, and thus achieve sustainable growth and social consensus by developing eco-innovations and generating new economies.

Only if European automotive industry companies manage to develop, produce and spread the use of vehicles fuelled by alternative sources to oil and which are equipped with ITS systems in the forthcoming years, with the support of governments, will they also be able to strengthen their competitiveness on international markets; numerous countries that are currently oil-dependent could converge to be independent of the use of oil. As an example, Italian drivers spend 60 to 70 billion Euros per year on purchasing oil (a total of 67.4 billion Euros was spent at petrol and gasoil pumps in 2012); in European Union, they spend a few hundreds of million Euros/year for the same purpose.

### **13. Conclusions**

In this historical period, technology is offered as a crossover solution to resolve energy and the consequent environmental issues, as well as a tool through which Automotive production

can remedy the fact that the resource which was prevalently utilised for transport during the last century may become scarce, compromised politically unmanageable and not environmentally-acceptable or could be perceived as such. Moreover, this is happening at the same time as the explosion of motionless communication, a phenomenon which has become diffused with an almost contemporaneous saturation of the road vehicle market. This technological solution can be obtained by improving the efficiency of engines or of journeys or even by rationalising the consumption of the related activities by using ITS (Intelligent Transport Systems) and by developing a production which can become sustainable by limiting the use of fossil fuels.

The main results of this work can be synthesised as follows: there is a need to respect the centenarian economies of competence and of scale gravitating around internal combustion engines, to pursue independence from the main source, which is almost a monopoly, and to use lower unitary energy in motorised mobility in order to reduce the fuel consumption per person or per ton and – consequently – emissions. This aim can be pursued either through higher capacity transport modes, such as trains, while guaranteeing that vehicles are loaded more than their break-even in energy as much as possible, or with a low level of oil-derived energy used for operating road vehicles. The WTW analysis in fact synthesises most of these ideas.

Production in the automotive field is therefore called upon to evolve in this changing economy, otherwise it may lose the battle because of the environmental constraints, the saturation of the traditional market, in favour of alternative more energy-friendly transport modes, when suitable (bicycles, bike-sharing, electric car-sharing, full automated undergrounds in metropolitan areas, high speed trains for medium range travels, also integrated through personal cards for mobility as a service), or of motionless communications.

An improvement in road transport can be pursued, in terms of quality, safety and efficiency of engines, and through the support of ITS. It would be necessary to try to develop independency in transport from the almost only energy resource, i.e. oil, so as not to be restrained by it and temporarily immobilised: the path that should be followed is through both efficiency and alternative energies.

The present analysis has pointed out that there is *no single solution* which could be used for all transport modes to respect the recently introduced environmental constraints. *Rechargeable Hybrid electric vehicles (R-HEV)*, that is, battery and fuel cell vehicles, have to be developed for passenger cars and light-duty vehicles (LDVs), while bearing in mind the different upfront costs of these two technologies and the local, regional and national energy production (WTT).

On the basis of the energy available and environmental sensibility within a country as well as the research plus industrial capabilities throughout the territory, a range of internal

combustion engines to electric vehicles, with a prevalence of intermediate hybrid vehicles will evolve in relation to the lack of black oil or richness of alternative carriers within a national or regional energy economy. Moreover, the availability of recharging spots in either private areas (preferable, up to indicatively the 90% of recharges, with slow charging) or on public land, together with the usage (mass, distances) made of vehicles will frame the market: short trips and light-duty vehicles, up to approximately 3.5-5 tons of total weight on the ground will lead to electric traction (FEV or R-HEV) being favoured, while internal combustion engines will continue to be used for higher masses and long journeys. Flexible engines, such as multi-fuel ones, help to resolve the problem when high masses and long journeys require alternatives to black-oil derivate fuels. This in fact represents a differentiated market, which would be more oil independent and respectful of the local energy preferences but also a much cleaner production.

For policy makers, a *hybrid solution* which could guarantee both *independent recharging* (fuel and grid) and *independent motorisation* – by electric traction or ICE propulsion – currently (approx. 2016-2021) results to be the most viable solution for a green, connected road vehicle, equipped for assisted driving and which could last for a number of years, as it would have to be compliant with the natural cyclical renewal of personal cars. In a couple of years an engineering footprint might also be quantifiable, on the base of the actual efficiency of hybrid solutions and related impacts on the electric grid.

## References

- [1] ACI, Annuario Statistico, Annuario Statistico 2015, 2015.
- [2] ABARE (Australian Government, Department of Industry, Tourism and Resources), 2004. Energy in Australia.
- [3] AISCAT, 1970-2013. Informazioni (Data book).
- [4] Aftabuzzaman, M., Mazloumi, E., 2011. Achieving sustainable urban transport mobility in post peak oil era. *Transport Policy*. 18(5), September, 695-702.
- [5] Al-Alawi, B.M., Bradley, T.H., 2013. Review of hybrid, plug-in hybrid, and electric vehicle market modelling. *Studies Renewable and Sustainable Energy Reviews*, 21, May, 190-203.
- [6] Ansoff, H., 1965. *Corporate Strategy*, McGraw-Hill, New York.
- [7] Chéron, E., Zins M., 1997. Electric vehicle purchasing intentions: The concern over battery charge duration. *Transportation Research Part A: Policy and Practice*. 31(3), May, 235-243.
- [8] Christensen, T.B., 2011. Modularised eco-innovation in the auto industry. *Journal of Cleaner Production*. 19(2), 212-220.
- [9] Commission of the European Communities (EC), 2001. *A Sustainable Europe for a Better World: A European Union Strategy for Sustainable Development*, COM/2001/0264 final, Brussels, 15 May.
- [10] Commission of the European Communities (EC), 2011. *A renewed EU strategy 2011-14 for Corporate Social Responsibility*, COM/2011/0681 final, Bruxelles, 25 October.
- [11] Copeland, T., Koller, T., Murrin, J., 2000. *Valuation: Measuring and Managing the Value of Companies*, third ed. John Wiley & Sons, New York.
- [12] Cornelius, I., Davies, M., 1997. *Shareholder Value*, Financial Times, Pearson Professional, London.
- [13] Dalla Chiara, B., Degioanni, P., Fumarola, F.P., 2008a. Riepilogo di sistemi di trasporto innovativi. *Ingegneria Ferroviaria*. LXIII(1).
- [14] Dalla Chiara, B., Ricagno, R., Santarelli, M., 2008b. Sostenibilità energetica dei trasporti: analisi dei consumi e della soluzione ferroviaria. *Ingegneria Ferroviaria*. LXIII(6), 531-543.

- [15] Dalla Chiara, B., 2010. Considerations on the demand and use of energy in the transport systems / Considerazioni sulla domanda ed impiego di energia nei sistemi di trasporto. *Ingegneria Ferroviaria*. LXV(7-8), July-August, 673-685.
- [16] Dalla Chiara, B., Pinna, I., 2012. Sustainable development of automotive industry On issues of sustainable transport. Proceedings of the International congress on Motor vehicles and Motors 2012, Kragujevac, 3<sup>rd</sup>-5<sup>th</sup> October.
- [17] Deflorio, F., Dalla Chiara, B., Barosso, M., 2008. Controllo accessi in aree urbane: comparazione di strategie basate su sistemi telematici (ITS) mediante modelli di micro-simulazione del traffico. Scientific Seminar on Interventi e metodologie di progetto per una mobilità sostenibile, 189-203.
- [18] Department of Energy and Climate Change, 2012. Energy consumption in the United Kingdom: 2012, Transport energy consumption in the UK since 1970, National Statistics.
- [19] Directive 2009/33/EC of the European Parliament and the Council of 23 April 2009 on the promotion of clean and energy-efficient road transport vehicles, Official Journal of the European Union, L, 120, 5–12.
- [20] Energy Information Administration (EIA), 2006 and 2008. International Energy Outlook, June.
- [21] European Commission (EC), 2005. The annual energy and transport review for 2004. December.
- [22] European Commission (EC), 2005. Energy and Transport in Figures.
- [23] European Commission (EC), 2006. European Energy and Transport: scenarios on energy efficiency and renewables.
- [24] European Commission (EC), 2006. European Energy and Transport: scenarios on high oil and gas prices.
- [25] European Commission (EC), 2007. Eurostat, G. Campbell, Panorama of Transport, Luxembourg.
- [26] European Commission (EC), 2007. Well-to-Wheel analysis of future fuels and powertrains in the European context: WELL-to-WHEEL, Version 1b, March 2007 (previous edition in 2004).
- [27] European Commission (EC), 2011. Proposal for a Directive of the European Parliament and the Council, Brussels, 25.10.2011, COM(2011) 684 final.
- [28] European Commission (EC), 2011. Clean Transport Systems, Final Report, November.
- [29] European Commission (EC), 2012, EU Transport in Figures, Statistical Pocketbook 2012, European Union
- [30] European Expert Group on Future Transport Fuel Report, 2011. Alternative Fuels, December.
- [31] Executive Office of the President of the United States, 2015. Explaining the U.S. Petroleum consumption surprise, June.
- [32] Federal Department of the Environment, Transport, Energy and Communications (DETEC), 2012. Energy Consumption in Switzerland 2011, Swiss Federal Office of Energy (SFOE).
- [33] FNTR (Fédération Nationale des Transports Routier), 2013. Traffic data.
- [34] Frondel, M., Schmidt, C.M., Vance, C., 2011. A regression on climate policy: The European Commission's legislation to reduce CO2 emissions from automobiles. *Transportation Research Part A: Policy and Practice*. 45(10), December, 1043-1051.
- [35] Graham-Rowe, E., Gardner, B., Abraham, C., Skippon, S., Dittmar, H., Hutchins, R., Stannard, J., 2012. Mainstream consumers driving plug-in battery-electric and plug-in hybrid electric cars: A qualitative analysis of responses and evaluations. *Transportation Research Part A: Policy and Practice*. 46(1), January, 140-153.
- [36] Hannan, M.A., Azidin, F.A., Mohamed, F.A., 2014. Hybrid electric vehicles and their challenges: A review. *Renewable and Sustainable Energy Reviews*. 29, January, 135-150
- [37] Jørgensen, M.W., Sorenson, S.C., 1997. Estimating Emissions from Railway Traffic, Report for the Project MEET – Methodologies for Estimating air pollutant Emission from Transport, July.
- [38] Kanninen, B.J., 1996. Intelligent transportation systems: An economic and environmental policy assessment. *Transportation Research Part A: Policy and Practice*. 30(1), January, 1-10.
- [39] Kim, S., Ulfarsson, G.F., 2008. Curbing automobile use for sustainable transportation: Analysis of mode choice on short home-based trips. *Transportation*. 35 (6), 723-737.
- [40] Kitamura, R., Mohamad, J., 2009. Rapid motorization in Asian cities: Urban transport infrastructure, spatial development and travel behaviour. *Transportation*. 36(3), 269-274.
- [41] Lai, J., Harjati, A., McGinnis, L., Zhou, C., Guldberg, T., 2008. An economic and environmental framework for analyzing globally sourced auto parts packaging system. *Journal of Cleaner Production*. 16(15), 1632-1646.
- [42] Labuschagne, C., Brent, A.C., Van Erck, R.P., 2005. Assessing the sustainability performances of industries. *Journal of cleaner production*. 13(4), 373-385.
- [43] Lee-Gosselin, M.E.H., Buliung, R.N., 2012. The role of ICTs in the transformation and the experience of travel. *Transportation*. 39(5), 873-876.
- [44] Lin, L.H., Lu, I.Y., 2006. Product Quality as a Determinant of Product Innovation: an Empirical Analysis of the Global Automotive Industry. *Total Quality Management*. 17(2), March, 141–147.
- [45] Lovins, A., Barnett, J., Lovins, L., 1993. Supercars, the coming light vehicle revolution, summer study. Summer Study of European council for energy-efficient economy, Rungstedgard, June, 1–5.

- [46] Lovins, A.B., Lovins, L.H., Hawken, P., 2007. A road map for natural capitalism. *Harvard Business Review*. 85(7/8), 172-183.
- [47] Maggi, S., 2005. *Storia dei trasporti in Italia*, Il Mulino, Bologna.
- [48] Mathez, A., Manaugh, K., Chakour, V., El-Geneidy, A., Hatzopoulou, M., 2013. How can we alter our carbon footprint? Estimating GHG emissions based on travel survey information. *Transportation*. 40(1), 131-149.
- [49] Markides, C., Geroski, P., 2005. *Fast second. How smart companies bypass radical innovation to enter and dominate new markets*, Jossey-Bass, San Francisco.
- [50] Ministero delle Infrastrutture e dei Trasporti (Italy), *Conto Nazionale delle Infrastrutture e dei Trasporti - Anni 2012-2013*, Luglio 2014.
- [51] Noland, R.B., Quddus, M.A., Ochieng, W.Y., 2008. The effect of the London congestion charge on road casualties: An intervention analysis. *Transportation*. 35 (1), 73-91.
- [52] Odyssee-Mure, Energy efficiency indicators in Europe, <http://www.indicators.odyssee-mure.eu/online-indicators.html>, consulted in Oct 2015.
- [53] OECD, 2013. *International Transport Forum, ITF Statistics*.
- [54] Pant, K., Pinna, I., Dalla Chiara, B., Bensaid, S., 2013. Transport and energy in India. Energy used by Indian transport systems and consequent emissions: the need for quantitative analyses (Well-to-Wheel, Lifecycle), EBTC Report, 1-51.
- [55] Pavitt, K., 1984. Sectoral patterns of technical change: Towards a taxonomy and a theory. *Research Policy*. 13, 343-373.
- [56] Pellicelli, M., 2007. *Creazione di valore e value based management*, Giappichelli, Torino.
- [57] Pinna, I., Dalla Chiara, B., Pant, K., 2013. Energy used by transport systems in India: role of urban population, sources, alternative modes and quantitative analyses. *Proceedings of the Nineteenth International Conference on Urban Transport and the Environment*, Kos, Greece, 29<sup>th</sup>-31<sup>st</sup> May.
- [58] Porter, M.E., Kramer, M.R., 2006. Companies must take the lead in bringing business and society back together. *Harvard Business Review*. December, 78-93.
- [59] Porter, M.E. 2008a. *On competition*, eleventh ed. Harvard Business Press, Cambridge.
- [60] Porter, M.E., 2008b. *The Competitive Advantage: Creating and Sustaining Superior Performance*, The Free Press, New York.
- [61] Porter, M.E., Kramer, M.R., 2011. The Big Idea. *Creating Shared Value*. *Harvard Business Review*. January-February, 62-77.
- [62] Scheiner, J., Holz-Rau, C., 2013. Changes in travel mode use after residential relocation: A contribution to mobility biographies. *Transportation*. 40(2), 431-458.
- [63] Schwanen, T., Banister, D., Anable, J., 2011. Scientific research about climate change mitigation in transport: A critical review. *Transportation Research Part A: Policy and Practice*. 45(10), December, 993-1006.
- [64] Shaik Amjad Neelakrishnan S., Rudramoorthy, E., 2010. Review of design considerations and technological challenges for successful development and deployment of plug-in hybrid electric vehicles *Renewable and Sustainable Energy Reviews*. 14(3), April, 1104-1110.
- [65] The Physics Factbook, *World motor vehicle market report*, 2010.
- [66] Ristell (van), J., Quddus, M., Enoch, M., Wang, C., Hardy, P., 2013. Quantifying the transport-related impacts of parental school choice in England. *Transportation*. 40(1), 69-90.
- [67] Strelow, H., 2006. *Statistic in focus: Passenger Transport in the European Union*, September.
- [68] Te Brömmelstroet, M., Bertolini, L., 2010. Integrating land use and transport knowledge in strategy-making. *Transportation*. 37(1), 85-104.
- [69] The Worldwatch Institute, 2007. *State of the World 2007, our urban future*.
- [70] Trenitalia, 2005. *Rapporto Ambientale 2005*.
- [71] Unione Petrolifera, 2008-2009-2011-2013-2014. *Data book, Energia e Petrolio*.
- [72] US Department of Transportation, Federal Highways Administration (FHA), 2013. *Travel Monitoring and Traffic Volume*, January.
- [73] US Department of Energy, 2011, *Transportation Energy Data Book, Edition 30*, Office of Energy Efficiency and Renewable Energy, June 2011
- [74] US National Laboratory Oak Ridge, *Transportation Energy Data Book 2011*, Ed30.
- [75] US National Laboratory Oak Ridge, *Transportation Energy Data Book, Edition 34 Released September 30, 2015*.
- [76] Vance, C., Hedel, R., 2007. The impact of urban form on automobile travel: Disentangling causation from correlation *Transportation* 34(5), 575-588.
- [77] Veleva, V., Ellenbecker, M., 2001. Indicators of sustainable production: framework and methodology. *Journal of Cleaner Production* 9(6), 519-549.

- [78] Wells, P., Varma, A., Newman, D., Kay, D., Gibson, G., Beevor, J., Skinner, I., 2013. Governmental regulation impact on producers and consumers: A longitudinal analysis of the European automotive market. *Transportation Research Part A: Policy and Practice*. 47, January, 28-41.
- [79] Williams, C., Fuenmayor, A., Das, S., 2011. Innovation and creativity in the automobile industry: environmental proposals and initiatives. *The Service Industries Journal*. 31(12), September, 1931–1942.
- [80] Woldeamanuel Mintesnot, G., Cyganski, R., Schulz, A., Justen, A., 2009. Variation of households' car ownership across time: application of a panel data model. *Transportation*. 36(4), July, 371-387.
- [81] World Commission on Environment and Development (WCED), The Brundtland Commission, 1987. *Our common future*, United Nations General Assembly.
- [82] Zapata, C., Nieuwenhuis, P., 2010. Exploring innovation in the automotive industry: new technologies for cleaner cars. *Journal of Cleaner Production*. 18, 14-20.
- [83] Zhang, T., Gensler, S., Garcia, R., 2011. A Study of the Diffusion of Alternative Fuel Vehicles: An Agent-Based Modeling Approach. *Journal of Product Innovation Management*. 28, 152–168.

**Highlights:**

1. We introduce the role of sustainability in road transport, focusing on energy and emissions
2. We let emerge the impact of sustainability concepts on the automotive industry
3. We synthesise recent trends in demand and transport policies concerning energy in the automotive field
4. We quantify energy usage in the road transport sector, outlining the need for a comprehensive analysis
5. We propose a transport and industrial policy with solutions for automotive production together with “mobility as a service”