Assessing Technology and Policy pathways towards GHG reduction targets in the EU

James Laird[1,2], Paul Timms1, Simon Shepherd1, Davide Fiorello[3]

ABSTRACT

This paper reports on the distributional impact of strategies to reduce green house gas from the EU transport sector. The multi-modal strategies include improvements in technology and changes to national and urban transport policies. We apply an assessment framework to look at economic and social indicators, as well as key environmental ones, to make comparisons across scenarios; to understand if there are any distributional patterns to the impacts; and to examine if urban impacts differ from those at the EU/Member state level. The impacts of the strategies were assessed using a world energy model, POLES, and two transport models, ASTRA and MARS with a time horizon until 2050. The strategies were determined using abatement cost estimates, potential CO_2 reductions and with feedback from stakeholders. An assessment framework was developed that covered the three elements of sustainability: environmental, economic and socio-political sustainability (or equity). The research found that vehicle technologies in isolation cannot achieve the EC's target of reducing GHG to 40% of 1990 levels by 2050 (EC, 2011). Primarily this arises as lower vehicle running costs increases vehicle use - vehicle drivers therefore benefit from the strategies. This headline however disguises significant variation by stakeholder. The strategies have a significant negative impact on rail patronage, government revenue/expenditure and reduce GDP/capita growth. Importantly variation also occurs between countries – typically with income – as well as between urban and inter-urban areas. The results of using a holistic assessment highlight distributional issues with the technology/policy strategies. This has implications for policy formulation. The uneven distribution of costs and benefits between users, government, urban trips, inter-urban trips and between Member States also suggests a number of implementation challenges to technology related GHG reduction policies will exist. Transport and economic policies will be needed to address the imbalances.

Keywords: Greenhouse gas reduction, vehicle technology pathways, distributional impacts

---

[1] Institute for Transport Studies, University of Leeds, Leeds, LS2 9JT,UK
[2] Corresponding author: J.J.Laird@its.leeds.ac.uk
[3] TRT Transporti e Territorio srl, Via Rutilia, 10/8, 20141 Milano, Italy

1 INTRODUCTION

Whilst many studies have been carried out in recent years to assess the effectiveness of transport technologies and other policies to reduce greenhouse gas (GHG) emissions, it is relatively rare for such studies to make an intensive analysis of the distributional impacts of such measures. The current paper addresses this issue in the context of predictions concerning various policy packages made by the EU-funded GHG TransPoRD project, as reported by Fiorello et al. (2012). The results reported in the latter document focus on GHG reductions and some of the underlying trends that give rise to them (e.g. changes in passenger and vehicle demand as well as changes in the vehicle fleet). The current paper complements those results by using an assessment framework to:

- look at economic and social indicators as well as environmental ones;
- to make comparisons across the policy packages tested,
- to understand if there are any distributional patterns to the impacts; and
- examine if urban impacts differ from those at the EU/Member state level.

The key contribution of this paper to the literature is to demonstrate that the impacts of the vehicle technology and policy pathways to GHG reductions have very different impacts by Member State and by urban and inter-urban areas.

The paper is structured as follows. Section 2 describes the method used to make the predictions on the impacts of policy measures, providing a description of the models used. It also provides a fuller description of the assessment framework. Section 3 describes the results from model tests using this assessment framework, whilst Section 4 provides a summary of policy implications and conclusions.

2 METHOD

2.1 Scenarios

Alternative strategies were assessed using simulation models. Strategies were defined as bundles of policy instruments. Several instruments had been identified and described in terms of potential effectiveness in reducing GHG emissions using estimates of abatement costs in previous tasks of the GHG-TransPoRD project (Akkermans et. al. 2010, Schade et al. 2011). They included technological measures as well as policy measures such as road charging, speed limits or eco-driving.

The approach followed was to set impact targets consistent with the EC’s 60% reduction in transport GHG by 2050 compared to 1990 levels and then put together bundles of measures with the potential to meet those targets according to the preliminary assessment available regarding their maximum potential (the actual impact of the measures is unknown as their interaction can give rise to non-additive effects). This is a form of cost effectiveness analysis (CEA). This is because the scenarios are outputs of the process that attempts to answer the question as to what is the cheapest method to achieve these GHG targets. A full description of the methods used to derive the least cost GHG reduction scenarios is contained in Fiorello et al. (2012).

There is of course an issue as to from whose perspective 'cheapest' should be calculated. In most assessments of infrastructure investment cost is calculated from the perspective of government (i.e. the tax payer). Here due to the differences between infrastructure investment (a public good) and changes in the technology of privately owned goods (owned and used by users) we have used two definitions, that of the user and that of society in general. In keeping with the concept of cost effectiveness the metric in use is 'out of pocket' costs and not generalised travel costs (as is used in other transport planning assessments).

Modelling tests were made on preliminary versions of policy bundles and eventually the following lists of scenarios were selected.

MAX_E&M: Maximum Efficiency at Market conditions. This scenario includes most of the technological measures identified for their potential contribution for all modes. Instruments include both improvements of conventional road vehicles (e.g. lightweight construction, engine control systems, aerodynamics) and innovative vehicles (e.g. Electric cars, Fuel Cells cars). Neither the latter nor biofuels are supported by dedicated policy to promote their penetration in the market. Market diffusion thus depends on the relative cost of different options and the cost development paths estimated with the learning curves.

EV: Electric Vehicles. In this scenario the technological effort is concentrated on electric vehicles (battery electric and plug-in hybrids). Market driven technological development is assumed also for conventional road vehicles and other modes. Furthermore, additional supporting policies for electric vehicles (e.g. feebate schemes) are supposed to be in place to promote the diffusion of electric vehicles.

HFC: Hydrogen Fuel Cell vehicles. This scenario follows the same approach of the EV scenario, but the technological effort and the supporting policies are focussed on the development and market diffusion of Hydrogen Fuel Cell vehicles.

AMB_TP: Ambitious Technology and Policy. This scenario shares the same technological measures as in the MAX_E&M scenario plus the additional supporting policies for Electric and Hydrogen Fuel Cells vehicles. Additionally other policy instruments are assumed at urban and universal level (including urban charges, promotion of walking and cycling, promotion of efficient logistics. Last but not least, a huge increase of fuel taxation (on average up to +200% with respect to 2010 value) is assumed in order to account for the demand rebound effect and offset fuel taxation revenues loss determined by more efficient vehicles.

In addition to the above scenarios another set of scenarios based on the technology and policy scenarios plus a set of urban measures were examined. These urban measures were urban based charging, investment in walking and cycling infrastructure and policy and the initiation of behavioural change towards more walking and cycling in the urban environment. They were selected from the preliminary urban modelling work on the impact on GHG of individual transport policy measures. Aside from walking and cycling measures and urban based road charging (distance based and cordon based) the MARS preliminary work also examined public transport quality improvements and fare reductions, changes in parking policy and charges, and changes in land use policy. As reported in Fiorello et al. (2012), in the main, these initiatives only led to a 1 to 5% reduction in GHG emissions. If however a cultural change in attitudes can be affected a reduction of the order of 50% reduction in GHG can be achieved. Urban based charging, investment in walking and cycling methods and the initiation of behavioural change towards more walking and cycling were selected as the best urban policy measures for further testing from the standpoint of GHG reductions.

2.2 Models

Three modelling tools were used for the assessment of the scenarios listed above. Two at the European/global level and one regional model. The two European/global models – ASTRA and POLES – have a long record of experience in scenarios simulation for European research projects. The regional model – MARS – has a different focus and was applied on a local scale for the case of Leeds in the UK.

ASTRA (Assessment of Transport Strategies) is applied for Integrated Assessment of policy strategies. The model is implemented as System Dynamics model. The ASTRA model has been developed and applied in a sequence of European research and consultancy projects for more than 10 years now by three Institutions: Fraunhofer-ISI, IWW and TRT. Applications include analysis of transport policy (e.g. TIPMAC, TRIAS), climate policy (e.g. ADAM project) or renewables policy (e.g. Employ-RES project). The ASTRA model consists of nine modules that are all implemented within one Vensim© system dynamics software file. For more details see Fiorello et al, (2010) as well as the ASTRA website (http://www.astra-model.eu/).

Of particular relevance for the simulation of the technological measures is the Vehicle Fleet Module (VFM) of ASTRA, which describes the vehicle fleet composition for all road modes differentiated into vehicle technologies and emission standards. In order to assess the prospective consumer demand for fuel efficiency regarding alternative fuel technologies in passenger cars, the ASTRA vehicle fleet module was extended. The interrelation of manufacturing costs for cars equipped with a certain new GHG reduction technology and the cumulated sales of these cars was represented in the new ASTRA version via learning curves.

The POLES (Prospective Outlook for the Long term Energy System) model is a global sectoral simulation model for the development of energy scenarios until 2050. POLES has been developed and applied in a variety of EU projects, e.g. the WETO, WETO-H2, TRIAS, HOP! and GRP project. The dynamics of the model is based on a recursive (year by year) simulation process of energy demand and supply. All energy prices are determined endogenously. The main exogenous variables are the population and GDP which for this application were derived iteratively with ASTRA. A recent module developed in POLES is the Biofuels model BioPol (Schade and Wiesenthal 2011). It has improved the capability of POLES to deal with a potentially relevant alternative source of energy for the transport sector.

The simulation process using ASTRA and POLES is summarised in Figure 1. The exogenous input is coded appropriately in the two models, which exchange intermediate results as mentioned above. At the end of this process, the output is available for a wide range of indicators at the year 2050.

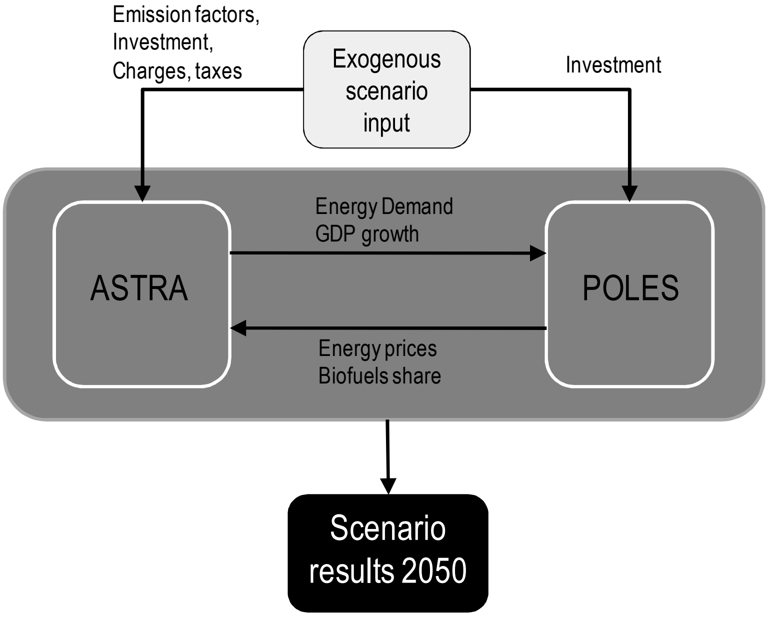

Figure 1 : Simulation process using the European/global models

MARS is a dynamic Land Use and Transport Integrated (LUTI) model. The basic underlying hypothesis of MARS is that settlements and activities within them are self organizing systems. Therefore MARS is based on the principles of systems dynamics and synergetics. The MARS model includes a transport model which simulates the travel behaviour of the population related to their housing and workplace location, a housing development model, a household location choice model, a workplace development model, a workplace location choice model, as well as a fuel consumption and emission model. The sub-models are run iteratively over a 30 year time period. They are on the one hand linked by accessibility as output of the transport model and input into the land use model and on the other hand by the population and workplace distribution as output of the land use model and input into the transport model. The application of MARS for the Leeds urban area was used within GHG-TransPoRD. For more details see for example Pfaffenbichler et al, (2010).

Therefore MARS was used to simulate different mixes of urban policies building on the same scenarios defined for the European tools in terms of technical measures and national instruments. As shown in Figure 2, MARS receives input concerning the fleet, emissions factors and fuel prices resulting from the ASTRA/POLES iterations and exogenous inputs concerning policy in order to estimate impacts at the urban level.

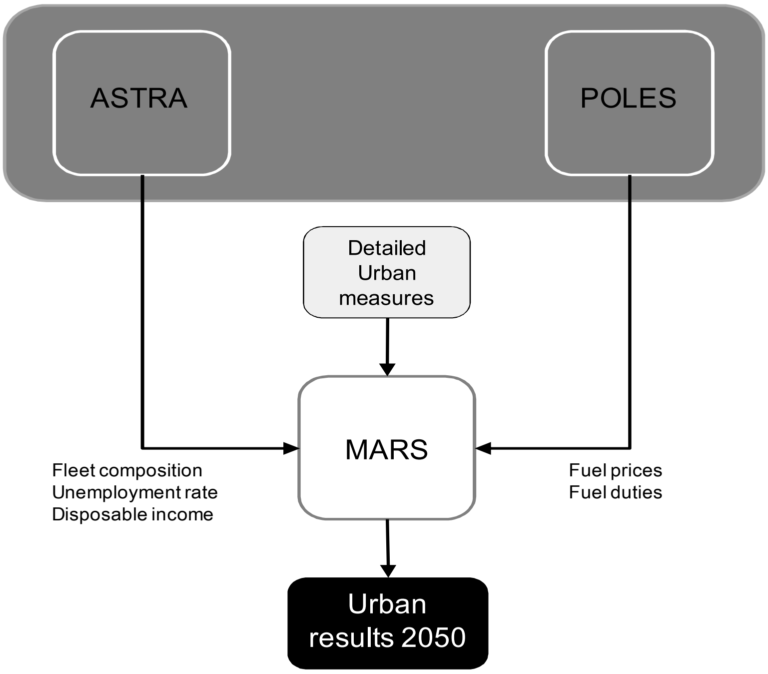

Figure 2 : Simulation process using the Urban model

The performance of the MARS Leeds model has also been assessed by evaluating out-turn elasticities, viz., fare and fuel elasticities. The out-turn fare elasticities are compared with standard values as in the report, The Demand for Public Transport: a Practical Guide, (Balcombe et al, 2004), commonly known as TRL Report 593. Similarly, the fuel elasticities are compared with the values published by Goodwin et al (2004). The fuel price elasticity was seen to be -0.1 which agrees with the mean value of Goodwin et al (2004), while the fare elasticity was seen to be -0.16 which is low but within in the range for urban areas as per TRL Report 593.

2.3 Assessment Framework

The assessment framework is the means by which the impacts of the different scenarios are summarised and therefore forms the basis for comparisons between the scenarios. Clearly, it is a tool to aid the identification of the strengths and weaknesses of the different technology/transport policies. Furthermore it is specific to this research. This is important as it can be tailored to meet the impacts of the policies being tested. It does not need to capture all impacts of all types of transports interventions – as say a national assessment framework would need to do.

The assessment framework needs be holistic and parsimonious. Holistic in the sense that all relevant impacts of the technology/transport policy scenarios need to be captured – including both positive and negative impacts. Parsimonious in that too many indicators cloud the main messages of the policy impacts and can make it difficult to understand the differences between the scenarios. Importantly in the context of our study the assessment framework is not being used to rank scenarios or to determine through its application the best scenario. Primarily the assessment framework's purpose is to summarise the impacts of each scenario. This is because each scenario has been developed to meet the same GHG reduction target. This is an important difference between the objective and purpose of this assessment framework and those employed in most ex ante studies of policy or investment by for example national or regional governments.

The three facets of sustainability, environmental sustainability, economic sustainability and socio-political sustainability (or equity) (World Commission on Environment and Development, 1987), form an ideal way of viewing transport technology and policy impacts. Performance indicators were therefore grouped into each of these three themes. A multi-pronged approach was used to determine the performance indicators. On one hand a concept of the potential impacts of the vehicle technology and transport policies may have on the environment, economy and society was developed and on the other we were constrained by what output the models could produce. The first stage was therefore to develop a long list of potential model outputs that could be used as indicators, whilst ensuring that they are as comprehensive in their coverage as possible. The second stage was to reduce this long list down to something shorter, whilst maintaining the breadth of coverage.

The final indicators are detailed in the results tables later in this paper (see Table 1, Table 2 and Table 3). Briefly there are:

- 8 environmental indicators focusing on changes in GHG in aggregate and by mode as well as abatement costs;
- 9 economy indicators focusing on changes in money (investment costs, costs to government and costs to users), GDP/capita, unemployment, travel time changes and freight impacts.
- 5 social impacts focusing on safety and changes in passenger transport. The latter as being an indicator in how the travel patterns of different transport users will be affected. For the urban analysis two further indicators were also utilised: accessibility to key services and accessibility for low income groups.

3 RESULTS

In this section we present the impacts of the vehicle and technology pathways at the EU level, and then consider whether these impacts are homogenous or vary in a systematic way across Europe. We then examine he impacts from an urban case study and compare them to those at the Member State/EU level.

3.1 European Union level impacts

3.1.1 Environment

Table 1 presents the key environmental indicators. In this table the scenarios have been ordered by GHG reduction impact. Thus the left hand most column presents the scenario with the smallest impact on transport related GHG (the electric vehicles scenario), whilst the right hand most column presents the scenario with the largest GHG reduction (the ambitious regulation scenario). Looking at the first row of this table, we can see that the technology only scenarios (with fiscal incentives for their take-up), whilst substantially reducing GHG do not achieve the EC's desired 60% reduction in GHG compared to 1990 levels[4]. Transport policy measures are also needed. In fact it is only through a combination of technology and strong transport policy measures including firm regulation (prohibiting the sale of new fossil fuel cars after 2035) that the 60% reduction is just about achieved.

Looking at the first row of this table we can also see that the two vehicle technology (electric and hydrogen fuel cells) strategies are to some extent substitutes for one another. Thus when the technologies are combined into one strategy (EV + HFC in the third column of the table) the GHG saving (10,392 million tonnes) is substantially less than the saving in GHG in the EV scenario (8,879 million tonnes) plus the saving in the HFC scenario (8,006 million tonnes). Furthermore we can see that focusing the technological effort on these two vehicle technologies appears to only achieve a similar level of reduction in GHG compared to letting market forces have their sway. A factor influencing this result is that in the three vehicle technology scenarios it is assumed that fossil fuel vehicles will only achieve 25% of the efficiency gain that they achieve in the Max E&M scenario.

The GHG reduction is achieved primarily through reductions in GHG output by cars. For the three pure technology scenarios (EV, HFC and EV + HFC) cars contribute 70% of the GHG reduction. However, it is not until the reduction in GHG from trucks increases through either better fuel efficiency (MAX_E&M) or tighter regulation (AMB_TP and AMB_REG) that the GHG output from the transport sector falls below 60% of 1990 levels.

---

[4] In interpreting these data it is important to be aware that aside from the transport related policies and technologies included in each scenario it has also been assumed that energy production will be much less GHG intensive in each scenario analysed compared to the Reference Case. Explicitly it has been assumed that an 80% reduction in GHG from the energy sector compared to 1990 levels would be achieved by 2050 in each test scenario. This is important as the reduction in GHG (in the first row of the table) from 78.6% of 1990 levels to between 25.2% and 36.3% is down to a mixture of cleaner energy production and the transport technologies and policies.

Table 1: Environment indicators for ASTRA/POLES scenarios

Environment Indicator			**Electric vehicles (EV)**	**Hydrogen Fuel Cell vehicles (HFC)**	**Electric and Hydrogen Fuel Cell vehicles (EV+HFC)**	**Maximum Efficiency at market conditions (Max_E&M)**	**Ambitious Technology and Policy (AMB_TP)**	**Ambitious regulation (AMB_REG)**
Transport tank to wheel CO2 in 2050 as percentage of 1990 levels	value of 2050 relative change to 1990	Test scenario	82.0%	81.0%	66.3%	65.1%	58.1%	40.6%
		Reference Case	123.7%	123.7%	123.7%	123.7%	123.7%	123.7%
Total CO2 in 2050 as percentage of 1990 levels	value of 2050 relative change to 1990	Test scenario	36.3%	34.1%	30.4%	29.8%	30.1%	25.2%
		Reference Case	78.6%	78.6%	78.6%	78.6%	78.6%	78.6%
Total CO2 tank to wheel emissions from transport	Total cumulated 2010-2050 (Million tonnes)	Car	14232	14692	12879	13629	12130	11031
		Truck	9988	10377	9820	7396	6862	6660
		Bus/Coach	2009	2016	2001	1682	1956	1943
		Pass Train	75	77	77	74	78	77
		Freight Train	177	181	179	180	173	174
		Plane	3300	3309	3311	3277	3338	3340
		Maritime	350	352	351	349	342	360
		All modes	*30131*	*31003*	*28618*	*26589*	*24878*	*23583*
Savings in CO2 tank to wheel emissions from transport with respect to Reference Case	Over the period 2010-2050 (Million tonnes)	Car	6105	5646	7459	6708	8208	9307
		Truck	1827	1438	1995	4419	4953	5154
		Bus/Coach	335	328	343	661	388	401
		Pass Train	9	7	7	10	6	7
		Freight Train	7	3	4	3	11	10
		Plane	592	583	581	615	554	552
		Maritime	4	2	3	5	12	-6
		All modes	*8879*	*8006*	*10392*	*12421*	*14131*	*15427*
CO2 tank to wheel emissions per capita from transport	In the year 2050 (Tonnes/individual)		1.87	1.90	1.60	1.57	1.43	1.14

Environment Indicator			**Electric vehicles (EV)**	**Hydrogen Fuel Cell vehicles (HFC)**	**Electric and Hydrogen Fuel Cell vehicles (EV+HFC)**	**Maximum Efficiency at market conditions (Max_E&M)**	**Ambitious Technology and Policy (AMB_TP)**	**Ambitious regulation (AMB_REG)**
Total abatement cost	Cumulated 2010-2050 (Euro/tonne) discounted back to 2010	User perspective	-973	-632	-444	-463	86	12
		Authority perspective	925	692	272	676	-210	-128
		Social perspective	-48	60	-172	214	-123	-116
Percentage change in energy demand of the transport sector	Between 2010 and 2050	Road	-16.6%	-8.1%	-22.6%	-40.1%	-44.4%	-57.9%
		Air	-4.5%	-2.9%	-3.0%	-6.7%	-1.5%	-1.0%
Percentage change in fossil fuel consumption	Between 2010 and 2050	Road	-24.1%	-36.8%	-52.5%	-55.4%	-51.6%	-84.1%
		Air	-50.1%	-5.7%	-48.7%	-21.0%	-47.3%	-46.6%

Source: GHG-TransPoRD

Table 2: Economy indicators for ASTRA/POLES scenarios

Economy Indicator			Electric vehicles (EV)	Hydrogen Fuel Cell vehicles (HFC)	Electric and Hydrogen Fuel Cell vehicles (EV+HFC)	Maximum Efficiency at market conditions (Max_E&M)	Ambitious Technology and Policy (AMB_TP)	Ambitious regulation (AMB_REG)
Investment costs as a proportion of GDP	Single year value	2020	0.017%	0.016%	0.033%	0.131%	0.132%	0.132%
		2050	0.006%	0.006%	0.012%	0.056%	0.058%	0.060%
	Cumulative	2010 to 2020	0.020%	0.020%	0.041%	0.162%	0.162%	0.163%
		2010 to 2050	0.012%	0.012%	0.024%	0.100%	0.102%	0.103%
Net impact on government finances	With respect to the reference scenario (Million Euros)	2020	-9,922	-44,022	30,182	-96,028	167,431	167,824
		2050	-246,369	-240,899	-139,376	-278,662	105,084	-22,006
Average additional transport cost per capita	With respect to the reference scenario (1000 Euro/year)	2020	-0.10	-0.07	-0.04	-0.16	-0.15	-0.15
		2050	-0.34	-0.34	-0.35	-0.47	-0.43	-0.61
Percentage change in GDP per capita	With respect to the reference scenario	2020	0.2%	0.3%	0.0%	1.2%	0.7%	0.3%
		2050	-3.2%	-1.7%	-4.4%	0.2%	-2.9%	-6.3%
Percentage change in unemployment rate	With respect to the reference scenario	2020	8.4%	8.6%	20.9%	1.6%	9.5%	12.2%
		2050	23.6%	6.8%	25.0%	7.9%	26.1%	27.1%
Average travel time change per trip	Percentage in the year 2050	car	2.6%	2.1%	1.9%	3.5%	14.3%	16.1%
		Bus/Coach	10.7%	12.0%	13.3%	12.4%	28.7%	35.4%
Change in freight tonnes carried	Percentage in the year 2050	Truck	-1.3%	-2.7%	-3.1%	0.5%	0.2%	-6.7%
		Freight Train	-14.5%	-4.6%	-15.6%	-2.5%	-11.8%	-17.6%
		Maritime	-5.0%	-0.9%	-5.1%	-2.0%	-7.0%	-0.2%
Change in tonne-kms	Percentage in the year 2050	Truck	-6.5%	-1.9%	-9.7%	2.6%	-0.5%	-9.3%
		Freight Train	-11.4%	-3.9%	-11.5%	-3.8%	-10.1%	-12.3%
		Maritime	-3.0%	-0.4%	-2.4%	-2.0%	-4.9%	7.5%
Change in freight tonne-hours	Percentage in the year 2050	Truck	-6.0%	-2.9%	-11.7%	8.8%	11.5%	-10.1%
		Freight Train	-27.4%	-9.5%	-29.6%	-2.1%	-21.2%	-35.1%
		Maritime	-10.6%	-1.8%	-10.3%	-4.0%	-14.0%	-0.8%

Table 3: Social indicators for ASTRA/POLES scenarios

Social Indicator			Electric vehicles (EV)	Hydrogen Fuel Cell vehicles (HFC)	Electric and Hydrogen Fuel Cell vehicles (EV+HFC)	Maximum Efficiency at market conditions (Max_E&M)	Ambitious Technology and Policy (AMB_TP)	Ambitious regulation (AMB_REG)
Percentage change of road fatalities	With respect to the reference scenario	2020	2.3%	1.8%	0.6%	3.6%	-3.0%	-3.1%
		2050	7.0%	7.4%	6.0%	8.9%	-0.6%	3.2%
Percentage change in person kms - 2020	With respect to the reference scenario	Car	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Bus/Coach	0.0%	0.0%	0.1%	0.0%	0.1%	0.1%
		Pass Train	-0.4%	-0.2%	-0.3%	-0.2%	-0.2%	-0.2%
		Plane	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Slow	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Percentage change in person kms - 2050	With respect to the reference scenario	Car	15.5%	15.5%	14.1%	18.3%	3.5%	11.3%
		Bus/Coach	-19.4%	-19.5%	-24.9%	-19.6%	11.7%	-0.7%
		Pass Train	-23.0%	-22.2%	-20.1%	-26.8%	-14.1%	-23.0%
		Plane	-2.9%	-1.9%	-2.9%	-4.7%	0.9%	-0.3%
		Slow	-6.9%	-6.9%	-6.3%	-9.6%	1.9%	-1.0%
Percentage change in average passenger length - 2020	With respect to the reference scenario	Car	-0.3%	-0.2%	-0.3%	-0.3%	4.2%	4.2%
		Bus/Coach	-1.5%	-1.0%	-0.6%	-2.1%	-3.7%	-3.7%
		Pass Train	-1.3%	-0.9%	-0.9%	-1.6%	3.7%	3.8%
		Plane	0.6%	0.5%	0.1%	0.8%	0.3%	0.3%
		Slow	-1.0%	-0.7%	-0.2%	-1.4%	-3.2%	-3.3%
Percentage change in average passenger length - 2050	With respect to the reference scenario	Car	-0.9%	-0.9%	-1.1%	-1.2%	7.3%	5.8%
		Bus/Coach	-4.0%	-4.3%	-4.5%	-5.1%	-8.4%	-10.3%
		Pass Train	-6.3%	-6.2%	-7.2%	-5.1%	8.3%	6.8%
		Plane	1.5%	1.4%	1.2%	1.8%	0.1%	0.7%
		Slow	-3.8%	-3.6%	-3.3%	-4.7%	-9.3%	-10.9%

The pattern between the scenarios regarding energy intensiveness and fossil fuel use broadly mimics the GHG reductions in each scenario. Where the GHG reduction is largest: firstly the switch to less energy intensive forms of transport is greatest; and secondly the greater is the reduction in fossil fuel use.

There are significant differences in abatement costs between the different scenarios. From a social perspective the discounted abatement costs are in the range of -172 euro/tonne to 214 euro/tonne. Four of the six scenarios have negative abatement costs: EV, EV+HFC, AMB_TP and AMB_REG. From a GHG reduction perspective this is good news as it means that, from society's perspective, it makes financial sense to invest in the new technologies/change behaviour that reduce GHGs. In two of the scenarios the abatement costs are positive (HFC and Max E&M). Here there is a financial cost to society as a whole associated with achieving the GHG reductions. The story however, is not as simple as that as the financial benefits and costs are spread unevenly between users and government and also vary between scenarios.

Looking at transport users in the first instance. In all the scenarios transport users face a substantial reduction in fuel costs. In the technology scenarios users also spend less on vehicles (as they are subsidised). Cheaper vehicles and fuel costs mean, in the three vehicle technology scenarios, that travellers switch to travelling by car from public transport and therefore save money on public transport fares. In the scenarios with road pricing and regulation (AMB_TP and AMB_REG) users still save on fuel, but the harder regulatory regimes mean that more money is spent on public transport fares and on tolls than in the Reference Case. Furthermore users spend more on vehicle purchases in these scenarios compared to the technology scenarios and the Reference Case. The net impact of this is that users are better off financially under the technology scenarios than under the policy and regulation scenarios.

The impact on government to a certain extent mirrors the impact on users. Where users save on fuel, the government loses fuel tax revenue; etc. For the three scenarios where the vehicle technologies are not actively encouraged (Max E&M, AMB_TP and AMB_REG) the government also makes significant transport related public investments. We therefore have the situation that for the scenarios where users are most financially better off (the vehicle technology scenarios) the cost to government of each tonne of CO_2 saved is very high. In the scenarios where mode shift to road is reduced and/or road pricing is levied the cost to government is much lower and in two scenarios the government actually receives a financial surplus (AMB_TP and AMB_REG) for each tonne of CO_2 saved.

3.1.2 Economy

Table 2 presents the key economy indicators. As can be seen from the first rows of this table investment costs in the transport technologies and policies do not seem high compared to GDP – certainly for the vehicle technology scenarios (EV, HFC and

EV+HFC). Investment costs are higher in the scenarios where vehicle technologies are not actively encouraged (Max E&M, AMB_TP and AMB_REG) but again are not overly large compared to GDP.

In contrast the impact of these technologies and policies on the government revenue stream can be high. As mentioned in the discussion on abatement costs, government loses substantial revenues from fuel tax and its public transport subsidy is dependent on whether the scenarios result in more or less public transport use[5]. Government is also the recipient of road pricing revenues. For three of the scenarios government revenues in 2050 fall by some €250 billion (EV, HFC and Max E&M). This amounts to a revenue fall of €500 euro per capita in 2050 – which is clearly large. In contrast governments across the EU lose €22 billion in 2050 (in the AMB_REG scenario) and make a surplus of €105 billion in AMB_TP scenario. These more favourable revenue streams to government arise as a consequence of government levelling new or increased transport taxes/charges in these scenarios.

In the main, the scenarios examined improve GDP/capita until 2020[6]. However by 2050 the rate of growth in GDP/capita has slipped below that in the Reference Case with the result that GDP/capita in 2050 is lower than in the Reference Case (aside from the Max E&M scenario which has the least government regulation). There is no distinct pattern between the scenarios regarding the variation in the change in GDP/capita. It no doubt arises from a mixture of competing factors – government revenue changes, household revenue changes, fiscal incentives that favour certain industries and regulation. A key observation is that the scenario with the least government intervention/regulation (Max E&M) is the only one that experiences a positive economic growth against the Reference Case. This is not to say that government intervention/regulation inhibits growth, but as modelled here maybe rather too blunt and/or could be directed towards less productive sectors (e.g. increased subsidisation of public transport). Similar negative outcomes for employment also occur. Unemployment in all the scenarios is above that in the Reference Case in both 2020 and 2050. Again it is difficult to know why this is occurring and whether the shift to greener energy production (compared to the Reference Case) rather than the transport technology and policy instruments has had any part to play. Further research is needed to better understand the macroeconomic impacts of these GHG reduction scenarios.

The final five rows of Table 2 deal with transport related economic indicators. Average transport costs per capita are consistently lower in the GHG scenarios than in the Reference Case (anything between €350 and €610 per annum lower in 2050).

---

[5] There is no change in public transport service provision between the Reference Case and the Scenarios. This allows accessibility by public transport to be maintained, but if demand for public transport falls this leads to a larger subsidy requirement.

[6] This is against the Reference Case – so it implies the rate of growth in GDP/capita in the scenarios exceeds that in the Reference Case

This arises due to reductions in fuel costs in particular and in some scenarios due to reductions in vehicle purchasing costs. These car based cost reductions lead to a switch from public transport to road and also generate new trips on the road network leading to both increasing trip lengths and to more congestion. Both of which are evidenced by the fact that average travel time per trip has increased. It should of course be noted that average trip times by car have also increased as substitution effects between car and public transport occur in each of the technology and policy scenarios. In the vehicle technology scenarios average trip times increase as longer distance trips switch to using car. In the scenarios with stronger regulation of the car in addition to this mode switch by longer distance trips to car, short distance trips are priced off the road on to public transport. The combined effect of which is to substantially increase average trip time by car in the AMB_TP and AMB_REG scenarios due to different distance mixes in the Reference Case and the scenarios..

The last three rows of Table 6-2 are concerned with the carriage of freight. As can be seen from these rows the freight indicators (freight tonnes carried, tonne-kms and freight tonne-hrs) are all down in 2050 compared to the Reference Case. This general trend is attributed to the fact that the economy is smaller in the GHG reduction scenarios compared to the Reference Case. What is interesting to observe however is that there has been a mode shift of freight towards road – driven by the lower costs associated with road. This goes against EC and Member State transport policies which aim to encourage mode shift towards public transport. The demand management strategies in the AMB_TP and AMB_REG do not appear to have stemmed this effect. Further refinement of these demand management policies would be necessary to meet EC and Member State transport policy objectives.

3.1.3 Society

Table 3 presents the key social indicators available in ASTRA/POLES. These give measures of changes in travel behaviour and also in safety. The lower cost of car travel to passengers/drivers, discussed earlier, encourages a general mode shift away from slow and public transport modes towards the car. In the scenarios without pricing or regulation (EV, HFC, EV+HFC and Max E&M) person-kms by car increase by between 14.1% and 18.3%, with corresponding large drops in travel by the public transport modes including plane. The largest drop is one of 26.8% in passenger kilometres by rail. Interestingly, aside from the plane, trip lengths also decrease. The implication is that the longer distance trips on each of the modes (aside from plane) are substituting car travel for their previous mode of travel.

In the transport policy and regulatory scenarios (AMB_TP and AMB_REG) growth in car trips still occurs but is smaller than in the other four scenarios. In the transport policy scenario (AMB_TP) there is a substantial growth in bus use, whilst in the AMB_REG scenario bus use is fairly similar to the Reference Case. There is growth in slow modes in the transport policy scenario and a small decrease in slow modes in the regulation scenario. As with the vehicle technology scenarios there is a substantial drop in passenger train use in both the transport policy and regulation scenarios. These contrasting effects are attributed to the fact that in the urban areas the transport policies and regulation are counteracting the effect of cheaper car costs preventing too much mode shift. However, for inter-urban trips mode switching towards the car still occurs, as the transport policies and regulation are less effective for these trip types. Changes in average trip length by mode reflect these changes in behaviour. Substitution between car and public transport decreases average trip length by bus/coach (as short urban trips transfer onto bus) and increases trip length by train (as longer city centre to city centre trips transfer to train).

The final social indicator is fatalities. Here we can see fatalities in 2050 are, aside from the AMB_TP scenario, all higher than in the Reference Case. Principally this reflects the changes in car and truck kilometres travelled. However, the changes are slightly more subtle than that as road accidents are more prevalent in urban areas than they are on inter-urban roads *ceteris paribus*. It is for this reason that the Ambitious Technology and Policy scenario which reduces car use in urban areas gives rise to the reduction in road accidents, whilst the other scenarios do not.

3.2 Distribution of impacts

The distributional analysis has been conducted by grouping countries into categories and then comparing across the categories. Two category types have been used: whether the Member State has recently joined the EU or whether the Member Sate is a more established member. These have been referred to as the EU12 and EU15 respectively. The second grouping is by GDP/capita, where the EU Member States plus Norway and Switzerland were split into 5 groups of either 5 or 6 countries[7] (see Table 4).

Table 4: Country groupings by GDP/capita

GDP/capita Group	Countries
1	Austria, Belgium, Luxemburg, Switzerland, Denmark, Norway
2	Finland, France, Great Britain, Germany, Netherlands, Sweden
3	Cyprus, Greece, Ireland, Italy, Slovenia, Spain

---

[7] The regional and income groupings do not have equal populations. The EU15 has 82% and the EU12 12% of the study area's population. Whilst for the GDP/capita groups: GDP/capita group one has 5% of the study area's population, GDP/capita group two 49%, three 26%, four 7% and GDP/capita group five 12%.

4	Czech Republic, Estonia, Hungary, Latvia, Malta, Portugal
5	Bulgaria, Lithuania, Poland, Romania, Slovakia

The impacts within each country group broadly mimic that of the EU27 discussed in the preceding section (see e.g. Figure 3 and Figure 4). There are however differences between the groups. As previously discussed the new technologies lead to a distinct mode shift away from public transport towards the car (see Figure 3). This is most obvious for the higher GDP/capita groups – as clearly with their purchasing power the new technologies are most available to households in these countries. The opposite is the case with respect to changes in bus/coach usage – the smallest falls occur in the lower income countries. The lower income countries also seem more sensitive to the introduction of transport policy and regulation measures aimed at curbing car use and increasing the use of public transport. These differences are also really quite striking when comparing the impacts on travel behaviour at the EU15 and EU12 level.

CO_2 emissions per capita are always highest in the high income countries and typically lowest in the low income countries (see Figure 4). Interestingly though the Group 2 GDP/capita countries (Finland, France, Great Britain, Germany, Netherlands and Sweden) have emissions as low as the lowest income countries and sometimes lower. Germany, France and Great Britain are large urbanised countries where existing levels of public transport in the cities (in particular) give rise to low CO_2 emissions per capita. Overall though it appears that, aside from the high income countries, the CO2 emissions per capita are broadly equitable across the remaining countries, and this also seems to be the case when comparing between the EU15 Member States and the EU12 Member States.

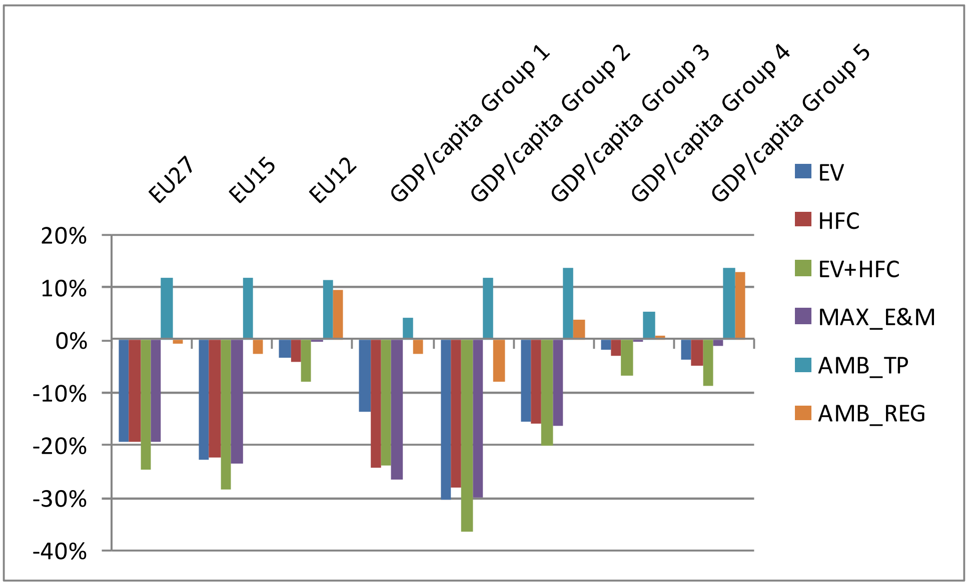

Figure 3 : Percentage change in bus/coach passenger kms (relative to reference case)

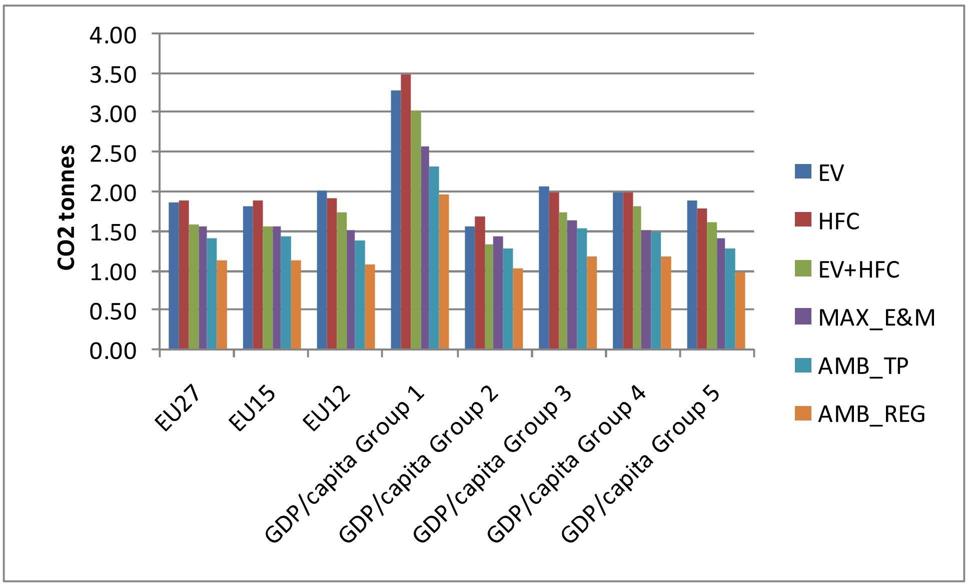

Figure 4 : Transport CO2 emitted per capita in 2050 (tonnes)

The transport technologies and policy scenarios examined have, as already discussed, a negative impact on economic growth – measured by GDP/capita. It has already been mentioned that further work is needed to understand the contributory reasons for this. Examining these impacts in greater detail it can be seen it is the Member States with the lowest CO_2 emissions per capita (groups 2 and 5) that have the best (or least worst) economic growth projections (see Figure 5). In fact for four of the six scenarios examined GDP/capita growth in the lowest income group is better than in the Reference Case. The worst economic impacts are felt by GDP/capita group 3 (Cyprus, Greece, Ireland, Italy, Slovenia, Spain). Clearly there is not a simple explanation as to why economic growth varies between the counties as a result of these transport technology and policy scenarios and this remains an area for future work – possibly it arises as a consequence of the types of industries located in the different countries and how they are incentivised through the fiscal regimes associated with each scenario.

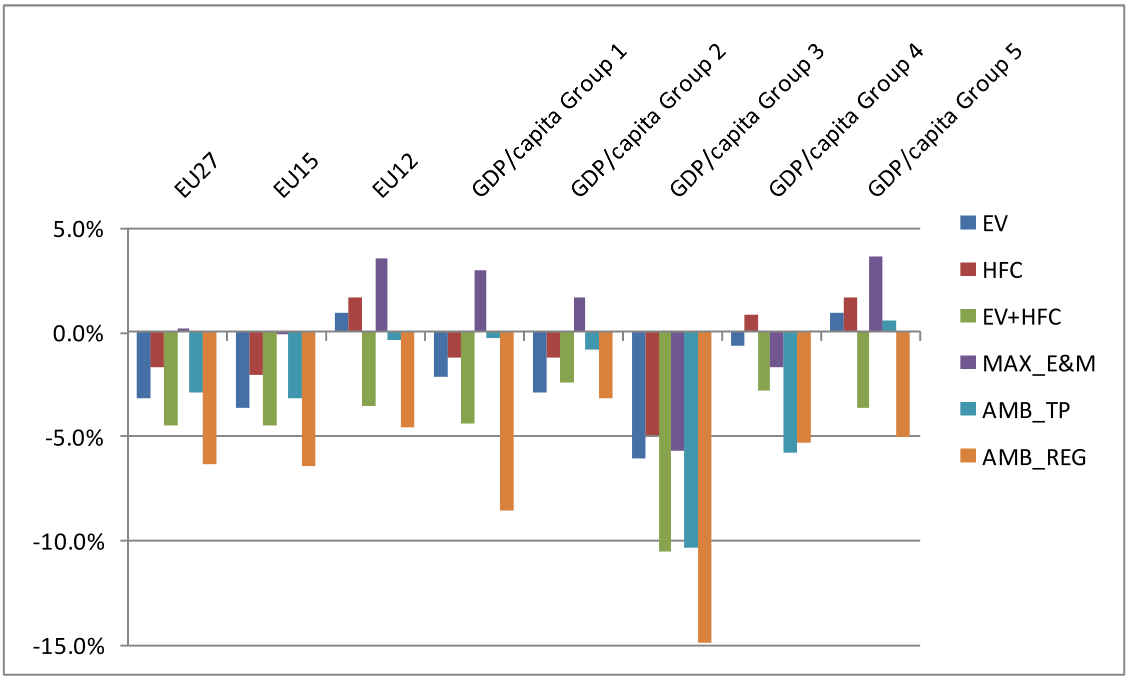

Figure 5 : Change in GDP/capita change relative to reference scenario – 2050

Turning to government revenue we find that where vehicle technology uptake is high and the switch from public transport is high, the burden on government per capita is also high. This arises due to a loss in fuel tax revenue but also increased subsidy for public transport to compensate for the declining fare revenue. Thus the financial burden on government is highest for the vehicle technology scenarios in the high income countries. In contrast for the Member States with lowest GDP/capita three of the six scenarios (EV+HFC, AMB_TP and AMB_REG) government makes a revenue surplus of up to 200 euro per capita in 2050.

3.3 Urban impacts

In this section we report the impact of the technology and policy scenarios at the urban level – based on the modelling work undertaken using the MARS model and the Leeds case study.

In the urban setting the vehicle technology scenarios (EV, HFC and Max_E&M) are much closer to achieving the 60% target reduction than they are at a national/international level (with between a 51% and 55% reduction in GHG). Clearly the circumstances of the urban environment make GHG reductions easier to achieve for urban based trips compared to rural or inter-urban trips. The lower CO_2 emissions per capita – approximately one fifth to one third of those reported for Group 2 GDP/capita countries in Figure 4 – are also a testament to this. The introduction of the urban policy package, including behaviour change towards walking and cycling, bring emission levels well below the 60% reduction target (with between a 75% and 77% reduction in GHG). Without a widespread cultural change in behaviour, emission levels in the urban areas are likely to be just above the 60% reduction target.

The impacts on the urban economy are broadly similar to those at the international level. Firstly the new vehicle technologies reduce the cost of making a trip – even in the presence of urban charging (in the urban packages). This reduction is large (average trip costs are approximately two thirds of those in the Reference Case). The loss of fuel tax revenue and VAT receipts result in government receiving between €171 and 208 million less revenue in 2050 than in the Reference Case for the vehicle technology scenarios. The introduction of the urban package (which includes urban road charging) reduces this deficit to some extent – but due to the public investment costs in infrastructure and operation – the cost to government per annum is still large (between €128 and 201 million in 2050). These deficits are the equivalent of between €120 and €190 per capita.

We also find that some reductions in passenger delay in 2050 in the peak period for car users relative to the Reference Case in the vehicle technology scenarios, and an almost complete eradication of delay in the scenarios that also include the urban package of policy measures (i.e. including behavioural change). Reductions in car ownership, arising due to the lower GDP/capita growth in these scenarios and the higher cost of cars, gives rise to lower car ownership levels in the urban environment (Fiorello et al. 2012). This in turn leads to a reduction in car use and therefore some of the congestion in the vehicle technology scenarios. The enormous reduction in vehicle delay with the urban package is primarily down to the cultural shift in behaviour and mode switching away from car use. These results contrast with the national/international picture portrayed in Table 2 – there we saw that car use increases. A comparison between these two sets of results would tend to suggest that the increase in car use at the national/international level is primarily driven by inter-urban (long distance) trips switching to car.

With respect to the social indicators we find that car trip lengths increase in the vehicle technology scenarios and bus trip lengths fall. This arises as the longer distance urban trips substitute the car for public transport (i.e. the distance mix in the different modes alters). When the urban package of measures is introduced this effect is reversed and car trip length falls below that in the Reference Case and bus trip lengths increase above that in the Reference Case. This is the same effect as we observed in the national/international data. One difference between that data and these data is that overall there is a general reduction in passenger kilometres in the technology and policy scenarios compared to the Reference Case. This, as mentioned already, is attributed to lower car ownership levels in the scenarios than in the Reference Case. The inclusion of cultural shift in behaviour reduces person-kms travelled in Leeds to something which is only just above 2010 levels despite the 40% growth in population.

We also found that the accessibility indicators for access to key services and for low income groups increase relative to the Reference Case. This is a positive point in relation to social equity.

4 POLICY IMPLICATIONS AND CONCLUSIONS

The focus of the research has been the potential that vehicle technologies and transport policies can make to achieving GHG reductions and achieving the EC's target of reducing GHG to 40% of 1990 levels by 2050. The results presented here demonstrate that behavioural responses to the vehicle technologies (primarily increasing vehicle use due to lower running costs) mean that vehicle technologies in isolation will not achieve this target. Transport policies are also needed if the goals of the Transport White Paper are to be achieved (EC, 2011). Additional undesirable side effects of the scenarios examined include a significant negative impact on government revenue/expenditure and lower GDP/capita growth. There also exist differences in the impact between countries – which typically, but not always, vary systematically with income – as well as differences in impact between urban and inter-urban trips.

The uneven distribution of costs and benefits between users, government, urban trips, inter-urban trips and between Member States also suggests a number of implementation challenges will exist. Policies which are inequitable are typically unpopular, furthermore policies which are expensive for government are also difficult to implement. Transport policies will therefore be needed to address these imbalances, and economic policies will need to ensure growth is maximised. A key tool of transport policy is likely to be road user charging – to prevent adverse impacts on public transport and to give a secure revenue stream to government in the absence of fuel excise duty. Success to date at implementing road charging measures has been limited to motorways and a handful of city centres. Significant efforts will therefore need to be made in this policy area. The spatial variation in impacts between Member States would also suggest that policy needs to be sensitive to local conditions. If implementation challenges prevent the adoption of policy measures (such as road charging) and the free market is allowed to dictate, a likely outcome is the Max_E&M scenario. Such an outcome is of course dependent on industry innovating and developing the required new technologies.

A number of issues have arisen from this research that warrant further investigation. There is a need to better understand the reasons that give rise to the negative macroeconomic findings: the role of greening the energy sector, the regulatory environment, which industries subsidies are directed to including towards public transport. The large difference in impacts between urban and inter-urban travel also raise issues about methods used to manage inter-urban travel and what role they could play in such a future scenario. Our assessment framework is heavily dependent on the outputs from the modelling tools used in the analysis. As such it is weakest on social/accessibility impacts. Further work analysing aspects of equality (e.g. income equality) and social inclusion is therefore also necessary before the full impacts of the vehicle technology and policy pathways to GHG reduction can be understood. Finally we have conjectured that the distributional impacts associated with the pathways will lead to a number of policy implementation challenges. Research on the size of these challenges and what can be done to ameliorate them is also needed.

BIBLIOGRAPHY

Akkermans L., Vanherle, K., Moizo A., Raganato P., Schade B., Leduc G., Wiesenthal T., Shepherd S., , Tight, M., Guehnemann, A., Krail M., & Schade W. (2010): *Ranking of measures to reduce GHG emissions of transport: reduction potentials and qualification of feasibility.* Deliverable D2.1 of GHG-TransPoRD: Project co-funded by European Commission 7th RTD Programme. Transport & Mobility Leuven, Belgium.

Balcombe, R., Mackett, R., Paulley, N., Preston, J., Shires, J., Titheridge, H., Wardman, M. and White, P. (2004) *The Demand for Public Transport: A Practical Guide*, TRL Report 593, Transport Research Laboratory

Fiorello, D., Fermi, F., Bielanska, D. (2010) The ASTRA model for strategic assessment of transport policies. *System Dynamics Review* vol 26, No 3 (July–September 2010): 283–290 Published online in Wiley Online Library (wileyonlinelibrary.com) DOI: 10.1002/sdr.452

Fiorello D., Akkermans L., Krail M., Schade B., Schade W, Shepherd S. (2012): *Results of the techno-economic analysis of the R&D and transport policy packages for the time horizons 2020 and 2050*. Deliverable D4.1 of GHG-TransPoRD: Project co-funded by European Commission 7th RTD Programme. TRT Trasporti e Territorio SRL, Milan, Italy.

Goodwin, Phil , Dargay, Joyce and Hanly, Mark(2004) 'Elasticities of Road Traffic and Fuel Consumption with Respect to Price and Income: A Review', *Transport Reviews*, 24: 3, 275-292.

Pfaffenbichler, P., Emberger, G. and Shepherd, S.P. (2010): A system dynamics approach to land use transport interaction modelling: the strategic model MARS and its application. *System Dynamics Review* vol 26, No 3 (July–September 2010): 262–282.

Schade B., Wiesenthal T., Gay St.H., Leduc G. (2011): Potential of Biofuels to Reduce Greenhouse Gas Emissions of the European Transport Sector. In: Rothengatter W., Hayashi Y., Schade W. (Editors) (2011):*Transport Moving to*

Climate Intelligence. New Chances for Controlling Climate Impacts of Transport after the Economic Crisis. Springer, Heidelberg.

Schade W., Akkermans L., Fiorello D., Jopson A., Köhler J., Krail M., Moizo A., Schade B., Shepherd S.,Sievers L., Tercero L., vanHerle K., Weiss C., Wiesenthal T. (2011): *Bottom-up quantifications of selected measures to reduce GHG emissions of transport for the time horizons 2020 and 2050: Cost assessment of GHG mitigation measures of transport.* Deliverable D3.1 of GHG-TransPoRD (Reducing greenhouse-gas emissions of transport beyond 2020: linking R&D, transport policies and reduction targets). Project co-funded by European Commission 7th RTD Programme. Fraunhofer-ISI, Karlsruhe, Germany.

World Commission on Environment and Development (1987) *Our Common Future*, Oxford: Oxford University Press. ISBN 0-19-282080-X

ACKNOWLEDGEMENTS

The authors are grateful to the EC DG Research (DG RTD) who funded the GHG-Transpord project. We are also grateful to our colleagues at the Fraunhofer Institute Systems and Innovation Research (ISI), the Institute for Prospective Technological Studies (IPTS) and Transport & Mobility Leuven (TML), particularly Wolfgang Schade, Burkhard Schade, Michael Krail, Lars Akkermans and Tobias Wiesenthal, who assisted in the research.