The impacts of long-term CO$_2$ objectives on short-term transportation trends in the European Union

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In 2001, the Sustainable Development Strategy was formulated by the European Union and, for the first time, a framework aimed at incorporating methods of sustainable development into European policy-making was adopted. In 2004, the European Union launched a review of the strategy and it has since been strengthened in a renewed strategy launched in 2006. Central to the renewed strategy is a commitment to cap global temperature rises to 2º C over pre-industrial levels by the end of this century. The EU has recently agreed on a target of reducing greenhouse gases by between 60 and 80 % by 2050 in order to achieve this goal. There has been little research on how the achievement of such a target would impact on European transportation trends. Given the new policy reality, this research develops projections simulating the impact of such a long-term target on road transportation growth in the European Union, and assesses how much of specific interim transport targets are implied by the presence of this long-term target. The projections are based on harmonised energy-economy simulations of the IMACLIM-R and POLES models. They cover the EU-27 disaggregated into 23 zones and track emissions of CO$_2$ for a range of vehicles and technologies. The results indicate that while mobility trends are only marginally altered by the presence of a stringent climate change mitigation policy, energy efficiency in transport is improved significantly. However, we also find that the presence of an overarching climate change objective is not enough to guarantee meeting a number of interim transportation sub-targets.

1. Introduction

In 2001, the European Union published two important documents relating to transportation and sustainability on the continent. The first, a White Paper on Transport, investigated the trends in transport for the coming decade and proposed a number of policy packages. The second document, the Sustainable Development Strategy (SDS), established for the first time the EU policy on sustainability – an issue that has moved towards the centre of policy-making. Both documents have recently been reviewed and the commitments provided for in each have been reaffirmed by European policy-makers. While the White Paper on Transport has received considerable attention from policy-makers and researchers, relatively little academic focus has centred on the impact of the SDS on transportation trends in the European Union. This is particularly interesting given that the overriding environmental objective outlined in the SDS is to cap the increase in global temperature rise to no more than 2º C above pre-industrial levels by the end of this century. In order to achieve this goal, the European Union has committed itself to a stringent interim target of reduction in carbon dioxide (CO$_2$) emissions by 2050. This objective aims to reduce emis-

sions from the EU by between 60 % and 80 % compared to 1990 levels [CEU, 2007]. It is clear that the pursuit and achievement of such a target will impact on future trends in European transportation.

Accordingly, in this paper, we investigate the impact of the overall objective of reducing CO$_2$ emissions by between 60 and 80 % by 2050 on the more focused transportation objectives outlined in the SDS. To do this, we compare the state and trends of European transportation up to 2050 in a business-as-usual or reference scenario, and in an ambitious carbon-pricing scenario compatible with the proposed 2º C cap on temperature increase. Both scenarios are harmonised projections of the global dynamic recursive computable general equilibrium model IMACLIM-R, and of the POLES model of global energy markets, thereby guaranteeing full consistency between the macroeconomic and energy balances. We explore whether reaching the ambitious target of a 60 % to 80 % reduction in CO$_2$ by 2050 "dominates" other targets specifically related to the transport sphere. In other words, we assess if by achieving this ambitious CO$_2$ reduction target by mid-century, sub-targets related to transport outlined in the SDS will be, almost by definition, achieved or

even overshot.

The outline of the paper is as follows: Section 2 presents some key transportation trends in the European Union as it stands, outlines some of the problems associated with transport, and investigates some of the policy responses pursued by European policy-makers. Section 3 briefly reviews the SDS, paying particular attention to its role in relation to transport. Section 4 presents an overview of the IMACLIM-R and POLES models and reports key assumptions and general results of the baseline and policy projections. Section 5 tests the hypothesis outlined above. Finally, Section 6 concludes with some policy observations.

2. Transportation trends in the European Union

The demand for transportation in Europe has been growing rapidly in recent decades and that trend largely continues today. This has had a significant impact on Europe's consumption of oil and the resulting emissions of greenhouse gases and specifically CO_2. Personal mobility on the continent now averages 35 km a day – doubling since 1970 [CEC, 2006]. Meanwhile, the number of cars in the EU has tripled and we are witnessing a growth rate in the region of 3 million cars a year [CEC, 2001a]. These trends have manifested themselves in significant growth in road transportation demand – between 1995 and 2004 road transportation grew by 19 % for passenger cars and by 35 % for freight movement (measured by passenger-kilometres and tonne-kilometres respectively). The road transportation sector now accounts for 44 % of total freight transport and almost 85 % of total passenger transport. With regard to the latter area, the private car accounts for three-quarters of passenger transport while transport by bus and coach (long-distance bus) combined accounts for less than 10 % (these latter modes have grown by a modest 5 % over the last decade). Rail transport has continued to decline in importance and now only accounts for 10 % of freight transport and 7 % of total passenger transport. As a result of such trends, private cars account for more than half of all oil consumed by transport. Emissions from transport contributed 28 % of all CO_2 emissions in Europe – one of the fastest-growing sectors. With road transportation heavily dependent on oil (it accounts for 67 % of final European demand for oil), it alone accounts for almost 85 % of CO_2 emissions from transport [CEC, 2006]. In tandem with environmental concerns, security of supply issues and institutional changes within the EU, transportation has moved onto the European policy agenda over the last two decades[1].

The European Commission (EC)'s first White Paper on Transport [CEC, 1992] focused on the achievement of a single market in transport rather than on sustainability issues. However, it did characterise the problems arising from excessive growth in road transport demand, through linking unequal modal share development to increased congestion and harmful environmental effects. The related White Paper on Growth, Competitiveness and Employment [CEC, 1993] warned about the dangers of congestion impacting negatively on productivity. Such negative

impacts can occur because of the nature of congestion. It can be defined in some respects as excessive demand and can occur because once road tax is paid, every user has access to the road network at all times (with the exception of tolled roads). As usage of the road network increases, so typically do marginal costs associated with road transportation. The costs of transport are not restricted to users of the infrastructure. Indeed, the external costs of road traffic congestion[2] alone can amount to 0.5 % of EU gross domestic product (GDP) and traffic forecasts for the next decade indicate that in the absence of policy interventions, road congestion will increase significantly by 2010. These congestion costs will also increase by 142 % to reach 80 billion euros a year, which is approximately 1 % of the EU's GDP [CEC, 2001a]. In addition to traffic congestion, the external costs of transport include accidents, road damage externalities and environmental costs. The latter costs consist of regional environmental effects (including barrier effects[3], acidification, and noise; for more see [Sterner, 2003]), air pollution (with both local and global impacts), noise, and barrier effects.

The economic problem of traffic congestion is related to the "public good" nature of road space (i.e., restricting access to it is difficult). However, road space is in reality rarely a "pure" public good – beyond a certain point of demand, congestion and rivalry exists. As road usage levels increase, the non-excludable nature of the public good exerts itself and as one user "consumes" the road space, it impacts on the ability of other road users to do the same – congestion increases and the utility derived by each user is a decreasing function of the number of other users. As more users demand the limited space, the social marginal cost (the additional costs to society) diverges from a user's private marginal cost. The former includes the sum of the time costs caused by the delays that the motorist imposes on all other road users (motorist and non-motorist alike). The latter only includes fuel and vehicle-related costs plus the motorist's own time and other costs. The social marginal costs also include the environmental external costs, notably air pollution and greenhouse gas (GHG) emissions, which increase as congestion intensifies. This latter point is especially relevant given European commitments to the Kyoto Protocol and other initiatives to reduce GHG emissions. Transport-related GHG emissions have increased significantly and domestic transport now accounts for 21 % of GHG emissions [CEC, 2006a]. As a result of increasing emissions from transport sources (up by 23 % since 1990 [CEC, 2006a]), many countries are now struggling to meet their commitments to adhere to agreed Kyoto Protocol limits[4].

Consequently, the focus of European policy-makers in the area of transportation has widened from a primarily economic analysis (as per the White Paper of 1992) to encompass the other main spheres of sustainability, namely the environmental and social areas. This has been mirrored in the development of the White Papers. This recognition that transportation impacts on areas beyond the movement of people and goods (because of the aforementioned externalities) has allowed for the development

of policy objectives aimed at addressing the aforementioned sustainability questions.

As noted, the first comprehensive policy intervention in transportation by the EC focused primarily on economic issues related to the movement of goods and people [CEC, 1992]. The follow-up policy document in 2001 outlined a number of key objectives for transportation in Europe:

- to offer a high level of mobility to people and businesses throughout the EU;
- to protect the environment, ensure energy security, promote minimum labour standards for the sector and protect the passenger and the citizen;
- to allow for innovation in support of the first two aims by increasing the efficiency and sustainability of the transport sector;
- to connect internationally by projecting the EU's policies to reinforce sustainable mobility, protection and innovation [CEC, 2006].

In addition, 60 EU-level specific measures are outlined covering 13 areas. The time horizon of this strategy extends to 2010 and the mid-term review of the White Paper [CEC, 2006] notes the above objectives put the EU's transport policy at the heart of the Lisbon agenda for growth and jobs (this strategy also forwarded projections to 2020)[5]. Longer-term objectives in relation to balancing "the imperatives of economic growth, social welfare and environmental protection in all policy choices" are referred to in the White Paper. However, specific long-term policy outcomes are beyond the scope of the strategy. Consequently, while the interrelations between transport and other areas in the economic, environmental and social spheres are alluded to, we must look towards the SDS [CEC, 2001b] for specific longer-term objectives aimed at addressing climate change directly.

3. The European Union Sustainable Development Strategy

The issue of sustainability has moved towards the centre of European policy-making in the past two decades. The initial stimulus in this process was the foundation and reporting of the World Commission on Environment and Development – the "Bruntland Commission" – in 1987 [UN, 1987]. Its definition of sustainability – development is said to be "sustainable" if it meets the needs of the present without compromising the ability of future generations to meet their own needs – is the most frequently used one. The Bruntland Commission was followed by the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, Brazil, in 1992. This conference adopted Agenda 21, otherwise known as the Rio Declaration on Environment and Development. This spurred interest at a European level, and the process of incorporating sustainability into EU policy-making began with the European Council discussing "A Sustainable Europe for a Better World: A European Strategy for Sustainable Development" [CEC, 2001b]. This was proposed by the EC at the Gothenburg Council meeting of 2001 and was adopted as the SDS.

Initially a broad statement of intention recognising the relationship between long-term economic growth, social cohesion and environmental protection, the strategy was reviewed, and specific targets updated and developed[6]. The relaunch by the European Council in 2006 resulted from a review process that began in 2004 involving the EC, the European Parliament and the European Economic and Social Council. The EC presented a document for review at the end of 2005 establishing a framework for action on sustainability [CEC, 2005]. The European Council adopted this as a basis for the renewed strategy in June 2006 [CEU, 2006]. The renewed strategy aims to implement a coherent long-term strategy in relation to sustainable development, and places emphasis both on immediate problems and also on longer-term objectives. In the sphere of climate change and clean energy, it states the absolute target of a 15-30 % reduction over 1990 CO_2 emission levels by 2020[7]. It also defines the 2º C cap on temperature increases over the century compared to pre-industrial levels – subsequently translated into an EU objective of 60 % to 80 % reduction over 1990 levels in 2050 by the European Council [CEU, 2007]. The overall transportation objective is identified as ensuring that transport systems meet society's economic, social and environmental needs whilst minimising negative transport-related externalities in these areas. The following sub-targets are identified, inter alia:

- decoupling economic growth and the demand for transport with the aim of reducing environmental impact;
- achieving sustainable levels of transport energy use and reducing transport GHG emissions;
- reducing pollutant emissions from transport and their impact on human health;
- achieving a balanced shift towards environmentally-friendly transport modes (this has already been formulated as a return to 1998 modal shares by 2010); and
- reducing CO_2 emission from light-duty vehicles to 120 g/km by 2012.

Given the short time horizon between the original SDS and the renewed strategy, it is interesting to note the flexibility in target formulation and development. In the intervening period, a number of these targets were altered, revealing flexibility in the policy process. However, despite this, neither the strategy nor the related transport white papers explore how the achievement of the long-term climate change goal will impact on these shorter-term transportation targets. While some targets have broad interpretations so as to be able to incorporate the impacts of the long-term targets, others are more specific. This juxtaposition between the short-term sub-targets in EU policy-making related to transportation and the long-term climate change objectives develops into an interesting story for researchers. We investigate this relationship by developing a number of policy scenarios aimed at exploring the impact of achieving the ultimate climate change aim of a 60-80 % reduction in CO_2 emissions by 2050 on transport sub-targets.

4. Scenario development

The baseline and the policy scenario that allow us to test our research hypothesis are based on harmonised projections of the IMACLIM-R and POLES models. These are outlined below.

4.1. IMACLIM-R model

IMACLIM-R (IMpact Assessment of CLIMate policies-Recursive version) is a dynamic recursive computable general equilibrium model specifically built to interface with bottom-up expertise on energy systems [Crassous et al., 2006]. The version that produced the scenarios commented upon in this paper projects the world economy every year up to 2050. It details 12 world regions, including Europe[8], and 12 economic sectors, among which air, sea, and land transportation activities are defined as three distinct sectors. In IMACLIM-R, economic growth mainly results from exogenous assumptions about population and labour productivity dynamics. However, international trade, particularly that of energy commodities, and imperfect markets for both labour (wage curve) and capital (constrained capital flows, varying utilisation rates) significantly impact on the equilibrium growth resulting from these assumptions. In this general framework, transportation demands result from the following.

- *Intermediate consumption of transport by all sectors:* the three transportation activities are inputs into the 12 sectors detailed. They consecutively grow as the sectors expand, in a proportion depending on price-induced variations in each sector's transportation intensity. For the scenarios reported here these variations were calibrated on POLES results.

- *Household demand:* This has an elaborate specification. Mobility, defined as an aggregate of four imperfectly substitutable travelling modes (air travel, public terrestrial modes, personal cars and non-motorised modes), is one of the elements of the utility function of the representative household of each region. In addition, on top of their budget constraint, households are subject to a travelling-time constraint[9]. Last but not least, the "travelling time efficiency" (average distance covered in an hour of time) of each mode is described as an increasing function of public investment in the infrastructure dedicated to this mode.

4.2 POLES model

The POLES (Prospective Outlook on Long term Energy Systems) model projects the energy systems and markets of a 47-zone world every year up to a 2050 horizon, based on main assumptions of GDP and population growth [Criqui, 2001]. The supply side of energy markets consists of fully endogenous world and regional markets for oil, coal and gas[10], together with a comprehensive description of current and future electricity-producing technologies. Energy demand is broadly disaggregated among transportation, industry, residential and service usages. Each of these categories is in turn disaggregated into sub-activities, with varying levels of technological detail. Road transportation is distinguished between passenger and freight transport. Passenger transport is split between personal cars, motorcycles and buses; the corresponding pas-senger-kilometre (pkm) demands are projected following an econometric specification (the trend modified by per capita income and short- and long-term average fuel price elasticities, with asymmetrical elasticities to price increases and decreases) without explicit modal substitution. Vintages of six personal car technologies are represented, with their dynamics based on the endogenous relative prices of fuels and exogenous assumptions about vehicle costs and fuel efficiency, operation and maintenance (O&M) expenses, a discount rate and limits to the penetration rates. As regards freight, the tonne-kilometre (tkm) demand of road freight transport is projected following an econometric specification with total GDP and short- and long-term fuel price elasticities as arguments.

4.3. Modelling carbon policies

In the aggregate economic framework of both IMACLIM-R and POLES, the complex mix of policy tools aiming at curbing carbon dioxide emissions (ranging from market instruments to command and control measures, on varying geographical scales) is usually symbolised by a region-specific uniform carbon pricing. This pricing is introduced in the form of an excise tax, with the carbon content of each specific energy consumption as a basis; in both the harmonised runs developed for this research, the revenue raised is "lump-sum recycled", i.e., directly transferred to households – aggregated to their labour and capital revenues to define their budget constraint.

Although both models can be used to assess more subtle policy and revenue recycling options, this fairly standard policy perspective, summed up by its carbon pricing, allows for a ready comparison with other modelling exercises. (See, e.g., [Weyant and Hill, 1999] or [IPCC, 2001] for frequently-quoted surveys of modelling results expressed in such terms.)

4.4. Scenario development

Harmonised runs of the two models were developed through a "soft-linking" approach, that is an iterative running with back-and-forth exchanges of modelling outputs – the only assumption common to both models, total population, having been identically matched to the 2004 median projection of the UN. In a nutshell, the successive IMACLIM-R runs were made to exploit POLES's expertise on energy matters (fundamental trends on primary energy markets, energy intensities and mixes for the different sectors and households, etc.). The successive POLES runs themselves resorted to the updated GDP and sectoral outputs (the latter being used as activity indicators) computed by IMACLIM-R. The complementary nature of the two models allowed for reaching a satisfactory degree of convergence quite rapidly.

The harmonised baseline or "reference" (REF) scenario projects our business-as-usual assumptions in which (cf. Table 1):

- Europe and the other industrialised countries limit the impact of increasingly low demographics by maintaining a steady growth in labour productivity[11];
- China and India see their currently high growth rates slow down, as (1) their labour productivity increases to a peak, (2) their demography stabilises, and (3) rap-

Table 1. Average annual growth (in %) of real GDP, REF scenario

	2001-15	2016-30	2030-50	2001-50
Europe	2.1	2.1	1.4	1.8
Other industrialised countries	2.1	1.8	1.8	1.9
China and India	5.3	2.3	1.7	2.8
Fossil fuel exporters	4.4	3.2	2.3	3.1
Rest of the world	4.2	3.7	2.0	3.1

Table 2. Average annual growth (in %) of CO_2 emissions, REF scenario

	2001-15	2016-30	2030-50	2001-50
Europe	1.1	1.1	0.3	0.8
Other industrialised countries	1.0	0.7	0.6	0.7
China and India	3.7	1.0	0.5	1.5
Fossil fuel exporters	2.1	1.4	1.3	1.6
Rest of the world	3.6	3.8	1.8	2.9

idly increasing energy prices hamper their relatively energy-intensive economic activity;

- fossil fuel exporters, despite stabilising demographics, greatly benefit from the rents they extract from increasingly tense energy markets;
- in the rest of the world, increases in labour productivity slowly take over the sheer impact of demographics as the latter effect slows down.

The 2001 Transport White Paper was supported by data from the ASSESS project, which used the TREMOVE model[12]. Similar to the ASSESS baseline, the REF scenario simulates a slow development of policy actions targeting carbon emissions over the period – extending and developing already existing policy impulses. The underlying complex mix of policy tools (ranging from market instruments to command and control measures, on different geographical scales) is summed up as a uniform pricing of carbon, starting at different dates in each region of the world. Europe, which we assume takes a leading position, introduces a (US)$ 5 per tonne (t) of CO_2 (2001 US$) price signal in 2005. This linearly increases to $ 10 in 2010, and then to $ 30 by 2030. The rest of the Kyoto Protocol Annex 1 countries[13] follow in a toned-down manner, introducing a signal of $ 1 in 2005, climbing to $ 5 in 2010, and reaching $ 15 in 2050[14]. The developing world, either because it gives in (to a limited extent) to international pressure, or because of the further development of foreign-financed projects akin to the Clean Development Mechanism (CDM)[15], implements a signal linearly increasing from zero in 2010 to reach the same $ 15 in 2050. Table 2 reports the carbon dioxide emission increases resulting from the economic growth above, including these moderate policies.

Comparing Tables 1 and 2 reveals some decoupling of growth and emissions (i.e., we see CO_2 emissions growing at a slower rate than GDP). This is mainly due (in the absence of a proactive emission reduction policy) to a dematerialisation of growth. Such a relationship typically exists when economies move from a base that is more dependent on (energy-intensive) heavy industry to one in which services dominate. The dematerialisation feature is true for the industrialised world, to a lesser extent for China and India, and also in a subtly different way for fossil fuel exporters (in their case, the increasing rents they draw from energy markets are a major source of dematerialisation). However, it is much less true for the rest of the world. This is because of the "mimetic development" assumption backing the REF scenario. Developing countries are assumed to pursue the same lifestyle as industrialised countries as their per capita income increases: they increase the size of their homes and buy more home equipment, switch to personal cars as their dominant transportation mode, etc[16].

The harmonised "Factor 4" (F4) scenario differs from the REF scenario in its hypotheses only insofar as it envisages an extremely ambitious set of climate change mitigation policies aimed at curbing global carbon dioxide emissions to a level guaranteeing an atmospheric concentration no higher than 450 parts per million by volume (ppmv)[17]. A trajectory compatible with this concentration necessitates global emissions (1) to peak before 2020, and (2), in 2050, to amount to two-thirds to three-quarters of their 1990 levels[18]. On the basis of these prerequisites, the trajectory developed for our F4 scenario is indeed similar to the WRE450 trajectory [Wigley et al., 1996] for the years beyond 2010. The global cap on emissions was then targeted by scaling up the price signal structure already present in the REF scenario, allowing for an inflexion point (acceleration of price signal increases) in 2017. The right-hand-side graph of Figure 1 plots the resulting emission path for the five world regions previously outlined. In 2050 Europe ends up close to the laxer bound of its overarching policy objective, i.e., at 37 % of its 1990 level.

Focusing on Europe, we find that in our REF scenario, in which moderate actions are undertaken, European emissions of CO_2 rise by 35 % over 1990 levels by 2030 and continue to 43 % over 1990 levels by 2050. Conversely, in the F4 scenario, in which very stringent targets are established, emissions in Europe fall to 67 % of 1990 levels by 2030 and 37 % by 2050. As hinted at by this dichotomy in outcomes and the comparison of the REF and F4 graphs of Figure 1, reaching the F4 objective necessitates policy measures both immediate and massive, symbolised by a region-specific uniform pricing of carbon (cf. above). In the F4 scenario, we see impressive figures of $ 248/tCO_2 in Europe and in the other industrialised countries (OIC). In China and India and the rest of the world, we see the price /tCO_2 climb to a more modest but still substantial $ 74. The technology database of POLES (and consequently the input-output assumptions of IMACLIM-R) was specifically expanded to allow such signals to trigger massive changes, which manifest themselves as:
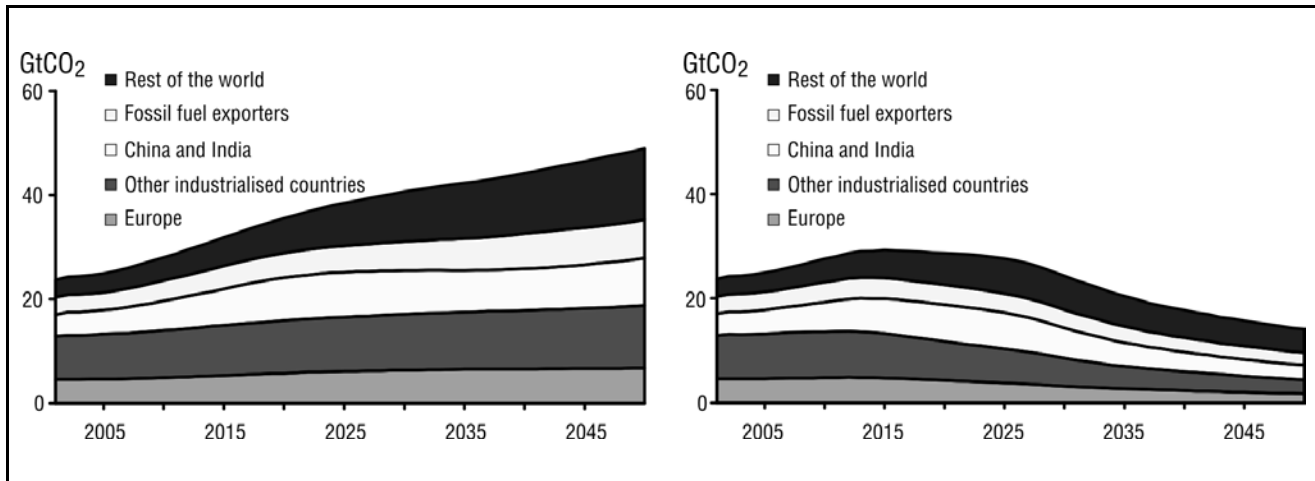
Figure 1. CO₂ emissions, REF (left) vs. F4 (right) scenario. Emissions are shown in gigatonnes (Gt) CO₂

- the rapid diffusion of very-low-emission equipment in the building, transportation, and industrial sectors;
- the increased development and diffusion of low- or no-carbon energy technologies, such as renewables, third generation nuclear power, and carbon capture and storage; and
- the development and diffusion of industrial production techniques of radically innovative materials.

Still, the scenario as it stands is somewhat conservative as it does not hypothesise induced changes in lifestyles, location and urbanisation choices. It would be reasonable to assume that such behavioural changes would allow for even more radical changes.

Integrating this extended POLES expertise, IMACLIM-R computes macroeconomic conditions up to 2050. We find that the general macroeconomic consequences of such major mutations of the energy systems are not as dramatic as one might expect. Such consequences are largely dependent on the particular characteristics of each region (cf. Table 3). Comparing Tables 3 and 1, we see that the burden of implementing the stringent climate change constraint (i.e., that by 2050, European emissions are 37 % of 1990 levels) is felt in the medium term. This indicates that economies, hampered by the inertia of their energy systems, bear the brunt in the shorter run. In the longer term, when the necessary adjustments have taken place, growth tends back towards its REF levels, and even overshoots it in some regions. Europe is obviously the most impacted region – its relatively higher REF energy efficiency makes it particularly sensitive to high carbon prices. Over the period, we see average annual growth fall from about 1.6 % in 2001-15 to 1.2 % for the following 15 years. Between 2030 and 2050, we see average annual growth return to about 1.4 % and this has the effect of stabilising the annual growth rate at 1.4 % over the whole period 2001-2050. In the REF scenario, annual growth is estimated at 1.8 % over the same period. However, there are some significant divergences earlier on in the period. For instance, growth up to 2030 averages 2.1 % per annum in the REF case, which is between 0.5 %-0.9 % higher than in our F4 scenario. After 2030, the average growth rates converge.

Table 3. Average annual growth (in %) of real GDP, F4 scenario

	2001-15	2016-30	2030-50	2001-50
Europe	1.6	1.2	1.4	1.4
Other industrialised countries	2.1	1.5	1.9	1.8
China and India	5.0	2.3	2.3	3.0
Fossil fuel exporters	4.2	2.4	1.8	2.6
Rest of the world	4.1	3.4	2.4	3.1

What might be of concern to policy-makers and researchers alike is that the likely reduction in annual growth rates is front-loaded, with the benefits being felt further in the future. The impact on the other industrialised countries, on India and China, and on the rest of the world is smaller (annual growth is reduced by an average of 0.1 % and 0.2 % respectively for the first two regions while the rest of the world sees no negative aggregate impact over the period). However, fossil fuel exporters see annual growth fall from 3.1 % to 2.6 % per annum up to 2050. This is related to the fact that (1) their export volumes are greatly reduced, and (2) the consequently much lower tensions on the oil and gas markets allow for much lower rents.

5. European road transportation: from current trends to an F4 European Union

With a convergence process close to but not 100 %, the following detailed road transportation results are systematically derived from applying POLES technological detail (technology mixes, relative fuel efficiencies and carbon intensities) and regional breakdown[19] to the aggregate IMACLIM-R figures of transportation activities and energy consumptions.

Figure 2 outlines the impact of the overarching 2050 agenda on mobility (expressed as vehicle-kilometres, v-km) and modal share. We see very little difference between the REF scenario and the F4 scenario for either the absolute numbers of v-km, their trends, or indeed the split between light-duty vehicles (LDVs, i.e., personal cars)
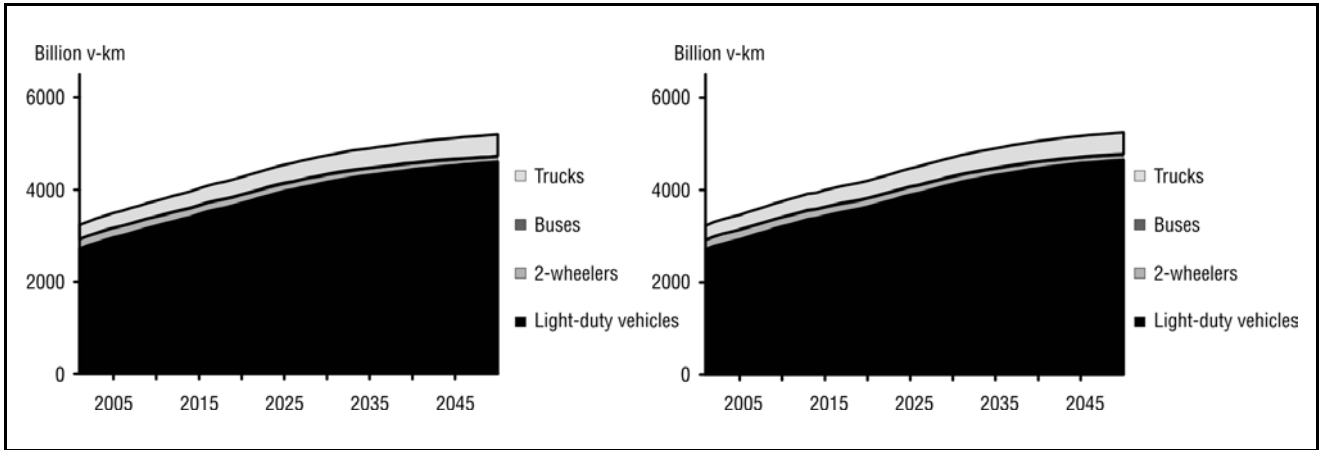
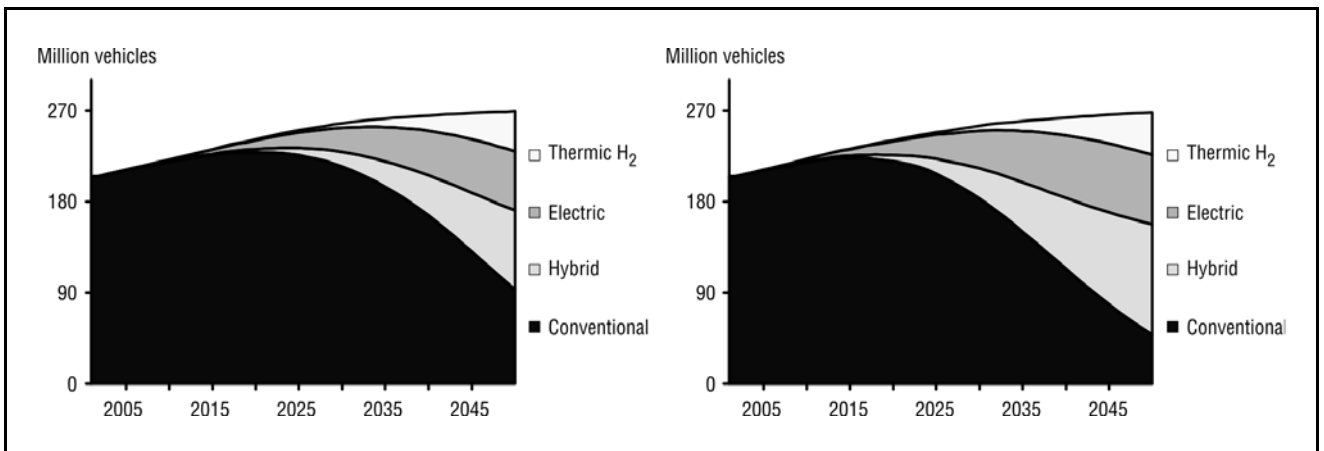Figure 2. EU 27 transportation activity, REF (left) vs. F4 (right) scenario

Figure 3. LDV fleet, REF (left) vs. F4 (right) scenario

and two-wheelers, and public transportation (buses). This confirms the oft-reported finding (see, e.g., [Espey, 1998] or [Goodwin et al., 2004] for a survey), somewhat disturbing for policy-makers, that carbon pricing (even at significant levels) has only a marginal impact on mobility and the modal shares. That overall v-km are so inelastic to even large price changes has important implications for policy in this arena. What we present in the F4 scenario is a situation in which stringent restrictions are placed on emissions of CO_2. Yet, despite this, the mobility trends (i.e., v-km) are largely unaffected.

To investigate these trends further, we detail the composition of the fleet of LDVs, which represent approximately 90 % of all v-km[20]. When doing this (cf. Figure 3), we do see a significant impact on the composition of the fleet. In the stringent F4 scenario high carbon prices act as a signal and the fleet shares of less emitting technologies are boosted. Indeed, the share of non-conventional vehicles in 2030 increases from 17 % in the REF scenario to 28 % in the F4 scenarios. We see further sustained growth in these technologies up to 2050 where they account for 66 % of on-road LDVs in the REF scenario and 82 % in the F4 scenario[21]. This seems to imply that while overall mobility is not affected by the carbon pricing strategy, the composition of the fleet (in terms of fuel choice and efficiency) undergoes some significant changes. Interestingly, we do see some catch-up in the

REF scenario towards the end of the time period. This trend occurs because of the expected increase in oil prices towards mid-century and such increases create their own price signals to consumers. However, the stronger shift towards the cleaner technologies occurs in the F4 scenarios due to the massive carbon pricing (whereas the increases in oil prices are much more moderate due to much lower tensions on oil markets).

Consumption of energy in the road transportation sector also diverges when looking at the REF and the F4 scenario. Although mobility levels are maintained for the period, we do see a marked decline in energy consumption in the F4 scenario (Figure 4). Indeed, the gains in energy efficiency from the REF to the F4 scenario are of the order of 20 % by 2030. Over the same period, we see declines in the consumption of petrol and diesel but see the alternative technologies (electric, hybrid and direct hydrogen) increase in importance. This trend is particularly marked in the period after 2035. Once the effect of vehicle fleet inertia begins to fade (i.e., the fleet is renewed with newer models that are better adapted to the changed conditions facing consumers), we notice a sharp divergence between the two scenarios. This reflects the longer-term flexibility in the energy consumption of LDVs. In the presence of such strong price signals we see energy consumption decline markedly in the F4 scenario compared to the REF scenario. The trends also reflect the larger
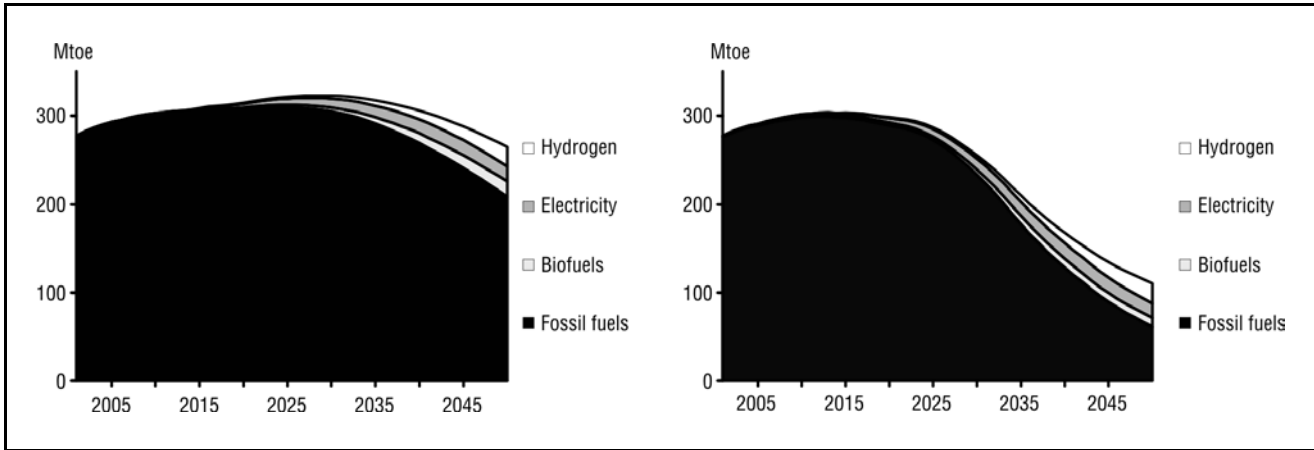
Figure 4. End-use energy consumption of road transportation, REF (left) vs. F4 (right) scenario. The units on the y-axis are Mtoe, million tonnes of oil equivalent. 1 toe = 41.87 GJ.
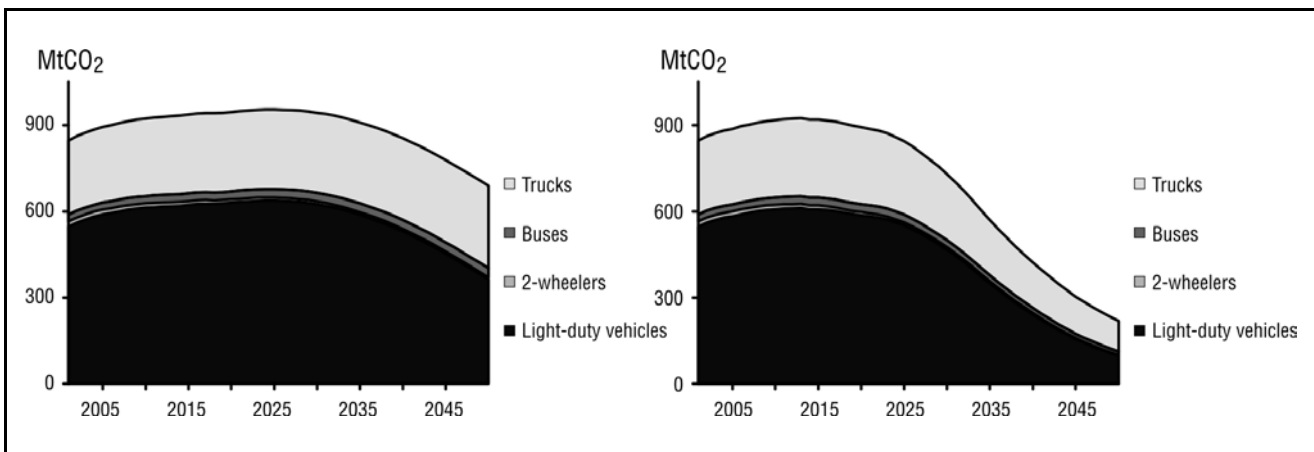

Figure 5. Tailpipe CO_2 emissions of road transportation, REF (left) vs. F4 (right) scenario

share for the alternative technologies towards the end of the period. As regards the truck, bus and two-wheeler sectors, we see similar improvements in energy consumption (in the case of two-wheelers, much tighter regulations are introduced).

In total, we find that in the presence of the stringent carbon scenario, significant reductions in CO_2 emissions from road transportation are achieved. The reduction in such energy consumption between the REF scenario and the F4 scenario grows to 23 % by 2030 (Figure 5). LDVs show a significant decline in emissions of CO_2 (primarily because of the gains in energy efficiency and the increasing share of cleaner technologies in the market). The second biggest contributor of emissions, trucks, also sees a decline in its share (albeit more modest).

These graphs show that the divergence between the REF and F4 scenarios takes place primarily after 2015 and the gap widens as we approach 2030. In the REF scenario emissions do not peak until nearly 2030 while in the F4 scenario, emissions begin to decline before 2015. However, by 2050, the divergence between the two scenarios is stark. The gap in emissions is now in excess of 60 %, very much in line with the overall F4 objective. This again suggests that the benefits of climate change mitigation are spread over a long time horizon and are

slow to be manifest in the short run. Additionally, a focus purely on long-run overarching targets may not necessarily result in the simultaneous attainment of short-term objectives. To investigate this concept further, we introduce a number of key interim transport policy objectives outlined by European policy-makers and test the likelihood of these targets being met under the two different scenarios.

Below, we present five targets covering two policy areas in the transport arena that are outlined in the SDS. The targets have been set by the EU not as desirable objectives in themselves but with the aim of reducing emissions of CO_2 and ultimately to aid in climate change mitigation. The first policy area relates to the penetration of biofuels in the market for transport fuel and targets are set for 2010, 2015 and 2020[22]. The second relates to emissions of CO_2 from the average new car fleet (here captured as the LDV class). We find that under both scenarios, all the outlined targets are missed, and missed by considerable distances. For instance, the target of biofuel penetration rising from a target of 5.75 % in 2010 to 10 % by 2020 is missed by approximately 90 % in the REF scenario. It fares only marginally better in the F4 scenario. The objective of reducing average new car fleet emissions of CO_2 to 120 g/km and to 95 g/km by 2012 and 2020

Table 4. Status of transport objectives under the two scenarios

Target	Year	Objective	REF scenario		F4 scenario	
			Achievement	Off by	Achievement	Off by
Share of biofuels	2010	5.75%	0.82%	86%	0.81%	86%
Share of biofuels	2015	8%	0.92%	88%	0.94%	88%
Share of biofuels	2020	10%	0.98%	90%	1.04%	90%
LDV CO_2 emissions, vintage average	2012	120 g/km	148	23%	146	21%
LDV CO_2 emissions, vintage average	2020	95 g/km	136	43%	130	37%

respectively is also missed by significant amounts. For the REF scenario, CO_2 emissions are 23 % higher than targeted in 2012 and almost 40 % higher than targeted in 2020. The performance of the policy scenarios vis-à-vis targets is no better in the F4 scenario[23].

These findings point once again to the importance of inertia in the fleet structure in the face of policy changes and how this is likely to undermine the achievement of ambitious short-term policy initiatives. Even in the F4 policy scenario, in which stringent actions are undertaken by policy-makers with the aim of fulfilling an overarching policy objective, there is no guarantee that interim policy targets will be attained. The biofuel and energy efficiency policy objectives are goals, and require additional policy initiatives in order to be achieved. As a result, we reject the hypothesis that the presence of such a long-range target will "dominate" specific interim measures. The reason for this is clear from looking at the long-term trends in our research. By 2050, the F4 scenario – in which we hypothesise the meeting of the climate change objective – diverges significantly from the business-as-usual alternative. This trend is repeated when we look at specific elements of the market (i.e., the composition of the LDV fleet, etc.). However, these trends only begin to assert themselves after a considerable lag. Inertia in the replacement and substitution of vehicle fleets militates against a quick response to even significant price signals for carbon. We find that even in the F4 scenario, in which there is an accelerated turnover in vehicle type and composition, emissions only diverge gradually from the REF case. By 2050, the divergence is significant but an analysis to 2030 shows very little difference between the two scenarios. We find this trend once again when we investigate how the presence of such a long-term ambitious target impacts on shorter-term sub-targets. Given the short time horizon for these targets and the inertia in the fleet of vehicles, all the targets are missed. The F4 scenario has only marginal impact. This presents policy-makers with significant challenges in formulating policy targets in the short run and in the long run.

6. Conclusions

This paper has set out to investigate the impact of stringent long-term climate change mitigation targets on the shorter-run trends in the transportation arena. To do this, we have investigated the impact of the overall objective of reducing emissions of CO_2 by between 60 and 80 % by 2050 on some transport objectives outlined in the SDS. We have employed a scenario-based approach over the time horizon of 2001 to 2050 and explored a business-as-usual reference scenario and a scenario with an ambitious carbon pricing assumption. Both scenarios are harmonised projections of the global dynamic recursive computable general equilibrium model IMACLIM-R, and of the POLES model of global energy markets, thereby guaranteeing full consistency between the macroeconomic and energy balances. At the outset, we hypothesise that reaching the ambitious target of a 60 % to 80 % reduction in CO_2 by 2050 will "dominate" other targets specifically related to the transport sphere. To do this, we introduce a number of targets outlined in the SDS. In fact, we find that the hypothesis that we tested can be rejected. We see that under both the REF scenario and the scenario in which strong carbon price signals are given, the interim transport policy targets are not met. This is a stark finding and one that should be of concern to policy-makers. It indicates that the presence of a long-term target for climate change mitigation (even one that is acted upon) does not guarantee that short-run transportation sub-targets will be met. We conclude that the structure of the market forbids immediate reactions to price signals (even very significant ones).

In addition to the above, we have seen that the imposition of the carbon price signal does have some impact on economic growth. This is especially the case for Europe. We find that projected economic growth is reduced by the introduction of a pricing signal for carbon; however, the impact reduces over time. Worryingly for policy-makers, this implies that while the benefits are spread over the whole period, the negative impacts are focused within a shorter time horizon. This again reflects the inertia existing in the vehicle fleet market and the resultant lag in response to policy initiatives. Despite this, we do see that the impact of the carbon pricing strategy is significant. We find that in our REF scenario in which moderate actions are undertaken, European emissions of CO_2 rise by 35 % over 1990 levels up to 2030 and continue to 43 % over 1990 levels by 2050. In contrast, the F4 scenario projects emissions in Europe to fall to 67 % of 1990 levels by 2030 and 37 % by 2050. This seems to indicate that reaching the F4 objective necessitates significant policy measures which are likely to have massive

impacts. In the F4 scenario price signal, a tonne of CO_2 rises to \$ 248 in Europe and in the other industrialised countries (OIC). In China, India and the rest of the world, we see the price signal per tonne of CO_2 climb to a more modest but still substantial \$ 74. The scenario as it stands is somewhat conservative as it does not hypothesise induced changes in lifestyles, location and urbanisation choices. It would be reasonable to assume that such behavioural changes would allow for even more radical changes.

When estimating the impact of our policy agenda on transport mobility (expressed as vehicle-kilometres), we found – in common with other studies – that light-duty vehicle mobility is inelastic to even large price signals for carbon. We do, however, see a significant impact on the composition of the fleet (in the medium to long run). In the F4 scenario high carbon prices act as a signal and the market shares of less emitting technologies are boosted. By 2030, the share of electric and hybrid vehicles increases from 11 % in the REF scenario to 17 % in the F4 scenarios. By 2050, the share for these cleaner technologies is 36 % and 41 % respectively, the relative similarity being accounted for by higher oil prices by mid-century. This seems to imply that while mobility is not affected by the carbon pricing strategy, the composition of the fleet undergoes some significant changes.

A similar trend is seen in the area of energy consumption. Energy consumption is reduced significantly in the F4 scenario over the REF case by 2050; however, the divergence between the two scenarios only begins to become apparent after 2020. This results in the light-duty vehicles showing a significant decline in emissions of CO_2 (primarily because of the gains in energy efficiency and the increasing penetration of cleaner technologies in the market). The second biggest contributor of emissions, trucks, also sees a decline in its share (albeit more modest).

As we have seen in the previous sections, the impact of the stringent policies aimed at reducing carbon dioxide emissions only begins to take effect in the medium to long term. We propose that the key explanation for the lack of divergence between the two scenarios in the short term is the structure of the vehicle fleet market. The inherent inertia in fleet turnover and substitution hinders short-term responses to policy actions; yet by 2050, we see a significant divergence in the transportation trends (with the exception of overall mobility) under the two scenarios. Emissions from transport now contribute over a quarter of all CO_2 emissions in Europe. Despite this short-term inertia, we find that in the presence of significant pricing signals, the transportation trends do begin to diverge (due primarily to the penetration of cleaner technologies in the medium to long run). This is an important finding for policy-makers. Given that transportation is amongst the most rigid of all sectors in relation to emissions of CO_2, the long-term findings are encouraging. Despite finding that the presence of a long-term overarching climate change mitigation objective does not guarantee the achievement of interim related goals, the sector does

react to the pricing signals in the longer term. The evident short-term inertia should not hinder policy-makers who wish to initiate policies aimed at reducing emissions from this sector. ∎

Notes

1. http://www.europarl.europa.eu/facts/4_5_1_en.htm (accessed 1 July 2007).

2. Congestion occurs because the motorist's private marginal costs diverge from the cost he/she imposes on society. The externalities can manifest themselves as delays in business transactions, excess business and private time lost to congestion, etc.

3. For instance: severance impacts on ecosystems or communities arising from the construction of a motorway.

4. The treaty, signed by more than 165 countries and ratified in February 2005, commits the countries listed in its Annex 1 to an overall 5.2 % reduction on 1990 levels by 2008-2012, cf.
http://unfccc.int/essential_background/kyoto_protocol/status_of_ratification/items/2613.php (accessed 17 June 2007). The EU ratified the treaty in May 2001, committing itself to an 8 % reduction over the period.

5. In 2006 the EU published a mid-term review of the White Paper on European Transport Policy for 2010 [CEC, 2006]. As part of this review, Transport and Mobility in the Catholic University of Leuven developed scenarios to run its TREMOVE model on. This had two aims: firstly, to assess the conformance of the transport implementation activities with the original White Paper over the period 2001-2005; and secondly, to assess whether the objectives were still feasible given policy and trend developments. An analysis of these 60 objectives is beyond the scope of this research but interested readers are directed to Annex 1 of the 2001 White Paper on Transport [CEC, 2001a]: http://ec.europa.eu/transport/white_paper/documents/doc/lb_texte_complet_en.pdf.

6. A global dimension has also been added to the policy-making process with the adoption of the 2002 strategy on establishing a global partnership in sustainable development [CEC, 2002]: http://europa.eu/eur-lex/en/com/cnc/2002/com2002_0082en01.html.

7. This strengthened the commitment in the original SDS, outlined in relative terms only: to reduce atmospheric GHG emissions by an average of 1 % of 1990 levels per year up to 2020.

8. 40-plus countries of geographical Europe, not the EU strictly speaking.

9. Following "Zahavi's law", establishing that the daily time spent in transportation is quite stable across time and regions of the world, regardless of the transportation mode – and hence of the distance covered.

10. Fossil fuel production is simulated by a detailed discovery process model for the main producing countries and a more compact model for the minor ones. Production is maximum for all regions ("fatal" producers) except major producers (e.g., the OPEC for oil), which adjust their own production to cover excess demand. The reserves to production ratio of major producers drives the international prices.

11. Note that, for comparison purposes, the growth of European labour productivity was specifically adjusted to allow the computed GDP growth to reach the same level as envisaged in the ASSESS assessment of the first White Paper [CEC, 2001a]. The value typically used in IMACLIM-R scenarios (based on [Maddison, 2001]) is annually ~0.6 percentage points lower, leading to a significantly lower GDP growth.

12. ASSESS was run by Transport and Mobility in the Catholic University of Leuven.

13. Annex I parties include the industrialised countries that were members of the OECD (Organisation for Economic Cooperation and Development) in 1992, plus countries with economies in transition (the EIT parties), including the Russian Federation, the Baltic states, and several central and eastern European states. For a complete list, see http://unfccc.int/parties_and_observers/items/2704.php.

14. These are the 36 industrialised countries and economies in transition listed in Annex I of the United Nations Framework Convention on Climate Change.

15. A provision of the Kyoto Protocol encouraging Annex I countries to finance GHG abatement projects in non-Annex I countries.

16. These development trends are explicitly modelled in IMACLIM-R and POLES.

17. A concentration level compatible with the EU objective of capping temperature increases at +2º C over pre-industrialised levels.

18. The scenario is indeed named after the latter objective, which approximately requires cutting down emissions by a factor of 4 from their baseline level. See [Weizsäcker et al., 2001] for a general discussion of the "Factor 4" objective.

19. IMACLIM-R's "Europe" aggregates POLES's "Rest of Western Europe" (mostly Iceland, Norway and Switzerland), "Rest of Central Europe" (the Balkan states) and "Turkey"

regions to the 27 European Union countries it details.

20. Pick-up trucks, however little used in Europe, are included in the LDV category.

21. Among these, POLES projects the penetration of thermic hydrogen-powered cars. The same as the much discussed hydrogen fuel cells, the underlying technology is a convenient way of concentrating carbon emissions at hydrogen-producing facilities, where these emissions can be captured and stored; however, it has the advantage over the fuel cell to be but an extension of the current conventional internal combustion engine (cf. the already running BMW vehicles), thus partially benefiting from its century of R&D.

22. The last of these targets has only been formulated in 2007. See [CEC, 2007], *Energy for a Changing World: An Energy Policy for Europe – The Need for Action,* http://ec.europa.eu/energy/energy_policy/doc/2007_03_02_energy_leaflet_en.pdf (accessed 2 July 2007).

23. In addition, while not reported in detail in this research, we find that the EU-27 target for the first Kyoto Protocol implementation period (2008-12) is overshot by 11 % in the F4 scenario (i.e., emissions for the implementation period are 11 % above permitted limits) and by 14 % in the REF scenario.

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