Future priorities for a climate-friendly transport. A European Strategic Research Agenda towards 2030

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Abstract

Research is a key factor for a successful reduction in greenhouse gas (GHG) emissions from transport. This paper summarizes the main results of REACT, a project co-financed by the European Commission, which aimed to develop a European Strategic Research Agenda for low GHG transport. A literature review and a multi-stage expert consultation process were used to map technological and non-technological research areas and evaluate them according to different criteria (i.e., GHG emissions reduction, cost-efficiency, feasibility, timeframe of research stages). We consulted the research agendas of the European Technologies Platforms on transport and current EU research programs. Expert opinions were collected through web forms, interviews and participation in structured workshops. The REACT Research Agenda identified the following research priorities for a more climate-friendly transport system by 2030: (a) in the short term, cost-effective solutions consist of (1) more efficient, lighter vehicles with advanced internal combustion engines, (2) reducing road transport demand and (3) fostering GHG emission legislation; (b) in the medium/long-term, the focus shifts towards (1) electric vehicles and

hydrogen, (2) Intelligent Transport Systems, and (3) spatial planning and economic and social measures to reduce transport demand. In addition, one of the main findings identified strong links between technology research and planning, social sciences and economy.

KEYWORDS: strategic research agenda, greenhouse gas emissions (GHG), consultation, climate-friendly transport.

INTRODUCTION

In 2011, the European Commission (EC) reiterated its commitment to low-carbon transport in its new transport strategy (EC, 2011). The strategy outlines the Commission's ambition to cut carbon emissions from transport by 20% by 2030 and by 60% by 2050, through the promotion of low-carbon technologies and modal shift. Forty concrete initiatives have been outlined to reach the target and will require significant investment in Research and Development (R&D) on both technical and social/institutional fronts (EC, 2011) from the public and private sectors.

At the European level, the EC has been providing funding for low-carbon transport R&D (EC, 2001), in order to identify and measure the impacts of transport on climate and to develop technological and behavioural solutions to rising emissions associated with transport (TRKC, 2009). R&D funding at the national level is less consistent (TRKC, 2009; Whitmarsh et al., 2011) and shows great variation across Europe with respect to availability and focus of funding for low-carbon transport research. This is likely to be one of the reasons for the failure of certain European countries to make progress towards their individual Kyoto targets to cut emissions (EEA, 2009).

Comparing the EC's transport research agenda with those of Member and Associated States, there is a reasonable alignment in terms of priorities, such that *environmental* (climate change, air pollution), *economic* (competitiveness, efficiency) and *social* (primarily safety) criteria are important at both national and EU levels (Whitmarsh et al., 2011). The low attention given to other social criteria - such as accessibility and equity - in funding schemes is coherent with other research which has found these criteria to be given less importance by stakeholders in their understanding of sustainable mobility (Whitmarsh et al., 2009a,b) than is warranted according to comprehensive analyses of transport socio-technical systems (SUMMA, 2005). Within the aforementioned funding schemes, there is significant preference for technological research over social research, despite evidence of the critical importance of behavioural and institutional measures to reduce transport emissions (Grubler and Riahi, 2010; Hickman et al., 2010; Schwanen et al., 2011). It is clear, however, that the complexity of transport problems and socio-technical systems warrants a wide-ranging response that includes both 'social' (e.g., planning, behavioural, governance, financial) and 'technical' innovation – even if the former may be politically less attractive and rely more on publicly funded than industrial R&D (Kemp and Rotmans, 2004; Geels, 2005; Gilbert and Perl, 2010; Sperling and Gordon, 2009).

To address the need for a consistent and comprehensive set of priorities for research on climate-friendly transport, the European Commission co-financed REACT[1], a project that involved nine partners from Croatia, Cyprus, Germany, Greece, Italy, Serbia and the United Kingdom. The primary focus of this project was to provide the EU with strategic roadmaps for research to achieve a future vision of a climate-friendly European transport system as defined in the EU 2020 strategic transport strategy (EC, 2001; EP, 2009). A broad picture about the priorities for technological and non-technological research areas may play an important role both at European and national decision levels: it guides and shapes funding strategies according to key factors to improving the European competitiveness, welfare and economic growth. The strategic tool to achieve that vision is a Strategic Research Agenda (SRA). While SRAs have been developed for specific transport modes or technologies (e.g., ERTRAC, 2009; ERRAC, 2007), no attempt has yet been made to develop a comprehensive SRA for climate-friendly (i.e., low GHG) transport. Yet, as suggested above, fragmentation and gaps in existing European research portfolios indicate a need for a holistic vision that cuts across modes, technologies and disciplines. This paper describes the methodology and main findings resulting from the development of a SRA for climate-friendly transport.

This paper is divided into four sections which describe: (a) the methodology used to develop the SRA; (b) the classification of research areas for climate-friendly transport in

[1]The REACT project (grant agreement n° 233984) was co-financed within the Seventh Framework Programme project (www.react-transport.eu). This paper reflects the authors' views, which do not necessarily represent the opinion of the European Commission.

a hierarchical tree structure; (c) the outcome of the assessment of these research areas; and (d) a summary of the assessment and priorities for future research.

1. GENERAL FEATURES OF THE REACT STRATEGIC RESEARCH AGENDA (SRA)

Since the primary REACT objective was to articulate a long-term vision and European research agenda for transport, the REACT SRA followed the EU targets for carbon reduction and considered all research areas in transportation that pursue these targets. Consequently, the core of the REACT SRA was represented by the *main research areas*, classified and organized in a hierarchical structure. Two grouping pillars were created in order to introduce a primary subdivision of the whole spectrum of research areas: *Engineering and Information and Communication Technology (ICT)* and *Planning, Social Sciences and Economy*. Under each pillar, further subdivisions were provided (see Section 2).

The development process of the REACT SRA was constructed around focused consultation activities. Because of the complexity of the matter and the span of research areas involved in the evaluation process, we involved experts of diverse backgrounds and different environments (academia, industry and policy). This also aimed at avoiding possible biases and conflict of interests.Within the first and second rounds of the consultation, seventeen European countries were represented; most of the participants came from the academic world and were complemented by a large minority of consultants, industry representatives and policy makers. Around 60% of the experts came from EU Member States whilst the remaining were from Associated Countries in Southeast Europe.This consultative approach was based on the assumption that the larger the pool of stakeholders engaged in setting up the agenda and the more diverse the views explored, the more reliable and robust the conclusions of the SRA (Dietz and Stern, 2008).

The objective of the consultation was, firstly, to establish the internal coherence of the hierarchical classification proposed (i.e., correctly establishing relationships among research areas and classification levels), and the completeness of the classification (i.e., checking whether research themes were missing or were unnecessarily duplicated); and secondly, to evaluate, for each research area included in the SRA, the priority in relation to the objectives of the vision, previously described. Specifically, the development process embraced different consultation activities (Bresciani et al., 2011):

(1)*Literature review*. A preliminary desk-based analysis was undertaken in order to gather inputs for setting up the agenda. Many SRAs and their relative development processes were compared, starting with the European Technologies Platforms' (ETPs) SRAs on transport. ETPs, supranational organizations developed as a result of the Lisbon European Summit in 2000, aim at making Europe "the most dynamic and competitive knowledge-based economy in the world capable of sustainable economic growth". Each ETP periodically publishes its own SRA to define medium- to long-term research and technological development objectives: ACARE for aeronautics (ACARE, 2004), ERRAC for rail (ERRAC, 2007), ERTRAC for road (ERTRAC, 2009; 2010) and

WATERBORNE for water transport (WATERBORNE, 2011). Note that each SRA deals only with the focus of the respective ETP (i.e., aeronautics, rail, road, and water). In addition, significant information was collected through academic literature review and analyzing current calls for funding of research in Europe (e.g., Seventh Framework Programme). These activities led to a first draft of the hierarchical structure of the REACT SRA.

(2)*Expert Consultation.* Initially, a panel of approximately 50 experts was asked to comment on and amend the classification adopted, completeness of research areas and consistency with the vision. Afterwards, a more focused consultation activity asked experts to prioritise, according to their expertise, each specific research area. Opinions were collected either through participation in structured workshops or via web forms.

*Open Consultation.*This aimed at broadening the consultation to embrace a wider public (Cisic, 2011). Around 200 participants were included; the spectrum of experience of participants varied from transportation doctoral students to experienced research directors. The Open Consultation phase was used to understand whether there was agreement between high level experts and the wider public and to look at research topics from different perspectives. This is in accordance with contemporary trends in governance, which call for early and meaningful public engagement in transport policy-making (e.g. Xenias and Whitmarsh, 2013).

(3)*Interviews with key experts* were carried out to enhance the consistency of the preliminary outcomes that resulted in priorities and scores assigned to the specific research areas. Fifteen interviews were carried out and provided useful insights regarding the experts' evaluations and a wider view on the SRA. Together with the Open Consultation, interviews allowed us to carry out a transversal analysis of the topics addressed by the Expert Consultation.

2. THE HIERARCHICAL STRUCTURE OF THE SRA

The structure of the REACT SRA (Figure 1) encompasses the research areas to consider and the criteria for prioritizing each research area within European funding schemes. Each research topic is categorized according to a logical and hierarchical tree-structure. Each branch is divided into sub-branches (pillars, sectors, research approaches and main research areas) and the leaves of the tree, the most detailed level, correspond to specific research areas.

2.1. Pillars

All information in the Engineering and ICT pillar was derived mainly from ETPs' documentation and the literature review. Each of the four transport modes included in the first pillar was further studied in depth by means of a desk analysis (Schäfer et al., 2009; Uherek et al., 2010; Rothengatter, 2010; Cascetta, 2001).

The second pillar was established using different sources (Banister, 2005; IHT, 1997) and includes research areas related to policy (e.g., planning and analysis tools), economy and multimodal or non-motorized means of transport (i.e., cycling, walking).

2.2. Sectors And Research Approaches

The second level of classification pertains to sectors. For the *Engineering and ICT* pillar, sectors correspond to transport modes: road, rail, water and air. Each of such sectors has been subdivided according to different *Research approaches*, i.e. categories representing the possible targets of research: driver, vehicle, and infrastructure. For the *Planning, Social and Economy* pillar, sectors refer to different policy measures applied to urban space, behaviour or economics: Planning and Systems, Social and Behavioural measures, Industry and Economy.

2.3. Main And Specific Research Areas

Two further levels of classification, not displayed in Figure 1, were provided: "Main research areas" and "Specific research areas". The "specific research area" is the most detailed classification within the REACT SRA structure.

3. ASSESSMENT OF THE RESEARCH AREAS FOR A CLIMATE-FRIENDLY TRANSPORT SYSTEM

The main objective of the REACT SRA was to prioritise research areas relevant to certain technologies or policies. Clearly, there is a correlation between priority and the expected contributions of such technologies or policies to the reduction of GHGs. For instance, a technology that is expected to deliver low GHG reduction will not receive a high priority. However, and this is an important point, the focus of the SRA was on *research*, and we took into account the discrepancy between the present situation and what could be achieved if a specific research area is properly funded. For example, a technology that is expected to deliver high GHG reduction may not deserve high priority if the associated research has reached maturity. Moreover, given the strategic level of assessment of the REACT SRA, we did not include quantitative estimates of potential GHG reductions for each of the research areas.

The REACT SRA inherited from the ETP SRAs the use of criteria and indicators to describe the research areas. Through the consultation process, experts and stakeholders used criteria and indicators to express their evaluation and prioritization of research areas. Since the focus of the REACT SRA was primarily on GHG effects, the primary criteria chosen to assess and rate the specific research areas were:

•*Overall priority*—a general assessment of the priority of a specific research area in terms of its importance for climate-friendly transport research.
•*Contribution to reducing GHG emissions*—an evaluation of how much a specific research area can be effective in reducing GHG emissions.
•*Research demand*—the timeframe of research stages (basic or applied research) and implementation stages, until 2030.

Moreover, three secondary, cross-cutting criteria were selected:

•*Cost-efficiency* considers the amount of GHG savings per financial unit: the higher the ratio of GHG savings to costs, the higher the criterion value.

•*Other effects* evaluates other important impacts of a specific research field or its application, for example, social equity or job creation.

•*Feasibility* evaluates the possibility of a specific research area overcoming social and/or political obstacles (e.g., it is socially unacceptable or politically inconvenient) to its development.

Experts assessed every criterion using two evaluation scales, either from 0 to 5, where 0 stands for "I'm not sure", 1 represents very low impact (or feasibility) and 5 represents very high impact (or feasibility), or from -5 to 5 where -5 represents very negative, and 5 very positive impact. The range of values available for each question posed to experts was normalised into a 0 to 1 scale. The research demand criterion was defined on a year-based scale, indicating how long each research stage (basic, applied, implementation) was expected to last within the time horizon of 2030. Different multi-criteria methods, namely the Analytic Hierarchy Process (Saaty, 1980) and TOPSIS (Hwang and Yoon, 1981; Hwang et al., 1993), were used to combine indicators and to produce composite ranks. A more detailed description is available in Bresciani et al. (2011) and in REACT (2011).

In Figures 2, 3 and 4 only the primary criteria (i.e. overall priority, GHG reduction and research demand) are displayed. The specific research areas are cited in the text (in brackets) using the relative ID number displayed in the figures.

3.1. ICT And Engineering Pillar

3.1.1. Air Transport

Research on methods and technologies for reducing the environmental impact of operating, maintaining, manufacturing and disposing of aircraft and associated systems (ACARE, 2004) was identified as a challenge, both by the ACARE SRA and the consulted experts. Moreover, there was agreement that research should concentrate on more efficient low-emission aircraft and on combining routes into shorter stage lengths for intercontinental journeys. Also, research needs on reducing cruise speeds and optimizing circling and taxiing times were identified (Lee et al., 2009; Browning et al., 2010).

Experts identified aerodynamic improvements, weight reduction (A5) and fuel-efficient engines and systems (A10)(A11)(A12)(A13) as the most promising research areas for reducing emissions. Novel aircraft concepts, such as adaptive airframe structures and Blended Wing Body (A14)(A4), are breakthrough innovations that may provide significant progress in the field. For jet engines, apart from improving their efficiency, new propulsion concepts, including alternative fuels (e.g., liquid hydrogen, biofuels, synthetic fuels, Liquefied Natural Gas - LNG) or power sources (e.g. fuel cells)(A15), should be studied. Alternative fuel power generators could provide aircraft with the energy needed for on board systems (e.g., air conditioning). Regarding ICT, Air Traffic Management systems could introduce new concepts for more efficient flight routes and flight phases (A1)(A2)(A3).

3.1.2. Rail Transport

The REACT SRA attributed the highest potential for reducing GHG from trains to research on reducing weight and improved aerodynamics (Raghunathan, 2002) (A20), regenerative braking systems (A21) and alternative technologies (A22). The alternative propulsion research area (A23) was considered as less important, mainly because existing electric propulsion supplied by a clean energy mix would provide clean trains without the need to invest in new engines. The reduction of air pollutants from diesel-fuelled trains was considered as having a low impact on reducing GHG emissions; a shift to electric trains was seen as more necessary. Regarding timing, the specific research areas that most need basic research were design of lightweight materials (A20), alternative technologies (A22) and alternative propulsion systems (A23). Research on new forms of low-carbon energy supply was deemed as important for all necessary technological improvements, and able to influence future developments and diffusion of new technologies in the market (Givoni et al. 2009).

ICT technologies were expected to influence the development of high-quality services and the implementation of overall intelligent mobility concepts involving customer information, improved accessibility and availability. This was seen as a necessary pre-condition for modal shift, from road and air to rail. In fact, the specific research area of ICT applied to traffic flows and railway networks (A18), which is entering the applied research phase and will be fully operating by 2020, scored highest in terms of overall priority.

In summary, the highlights regarding the Rail sector, along with the ERRAC (2007) SRA, emphasize the importance of energy efficiency and of environmentally-friendly, innovative technologies. These technologies included fuel cell and levitation technology, solar panels for on-board services (air conditioning, lighting, pantograph raising and electric locking) and alternative propulsion systems (eco-diesels and hydrogen). The dominant common themes, though, were weight reduction (e.g., a modular structure can be used to reduce the weight of coaches and can be sourced from renewable materials) and regenerative braking. Finally, particular attention was given to the use of recycled materials in new and refurbished vehicle components.

3.1.3. Road Transport

The preeminent research areas for the road sector mainly related to alternative fuel vehicles: fuel cell, hybrid and electric vehicles (A32)(A33)(A38) that require further basic research. Although Internal Combustion Engines (ICEs) will probably remain the dominant propulsion technology until at least 2030, the use of electricity, biofuels, liquefied petroleum gas (LPG) and compressed natural gas (CNG) will increase from 10% to 20% and such technologies are supposed to replace fossil fuels by 2050 (ERTRAC, 2010; EC, 2011). Experts attributed their lowest priorities to biomass derived fuels (A28) and new combustion concepts (A27). Finally, particular attention was given to manufacturing materials, minerals and design (A30); indeed, weight has been increasingly contributing to emissions in recent decades, despite increased engine efficiency and reduction of emissions from combustion (Knittel, 2011).

3.1.4. Water Transport

The overall most prioritised research areas for water transport were Port operations (A51), Alternative propulsion systems (A48) and Innovative and hydrodynamic vessel concepts (A49). The first implies optimization of current procedures and machinery, to decrease emissions of shipping and port activities (Eyring et al., 2010) and to improve the conditions of the populations living nearby (Corbett et al., 2007). The second and third ranked research areas related to development of energy supply for vessels. According to the latest Waterborne SRA (Waterborne TP, 2011), future oil shortages will foster the search for new energy sources and propulsion systems. Apart from an increase in the use of LNG powered fuel cells, renewable energy systems will become more attractive, especially as supplementary power sources. Other innovative energy harvesting methods (ocean thermal energy, wave energy) are still distant options for onboard use, but remain under consideration. Advancements in design techniques and materials (A49) (e.g., new hull forms) offer the potential for major improvements in propulsion efficiency. Also, for the water sector, the use of electricity for propulsion represents the future although further optimization of cost, size and weight of equipment is required.

3.2. Planning, Social Science, And Economy Pillar

Apart from technological advances - mainly covered in section 3.1 - achieving sustainable mobility requires an integrated approach comprising planning measures, behaviour change, industrial, and economic measures, along with technological advances (e.g., Whitmarsh et al., 2009b; Xenias and Whitmarsh, 2013). The present section concentrates on broader, cross-cutting topics.

3.2.1. Planning And Systems

The SRA "Planning and Systems" sector comprises research areas dealing with systematic aspects of transport infrastructure and with policies and planning for reducing transport or for modal shift. These specific research areas are aiming at carbon reduction on the level of the whole transport system – e.g., by raising the share of lower-carbon modes of transport, or by reducing distances travelled. By contrast, technological research areas mostly focus on carbon reductions from vehicles. The planning and systems research areas mostly address governments and other political decision-makers, in contrast to technology research, which mostly addresses industry.

Experts underlined the importance of this SRA sector as the basis on which other successful measures can be applied. The importance of this area also depends on the long lifetime of spatial planning and transport infrastructures (A55) (A58). Moreover, research should focus on the political and institutional constraints that often obstruct coherent implementation of measures (Cavenago and Trivellato, 2010). The importance of research on restrictive policies (A56)(A61); planning for road transport and public transport (A60); (e.g. the installation of bus lanes); and non-motorised transport (A59) (e.g. bike-sharing services) were also stressed. Regarding logistics systems (A63)(A64), the European Intermodal Research Advisory Council (EIRAC, 2005) pointed out that *interoperability between modes* could lead to a modal shift towards rail and water. Regarding freight transport, experts highlighted the importance of optimization, e.g., Yamada et al. (2009) and Aringhieri et al. (2004).

3.2.2. Social And Behavioural Measures

Within transport policy, a distinction is often made between 'hard' (infrastructural) and 'soft' (information, incentives, etc.) measures (House of Lords Select Committee on Science and Technology, 2011). In general, both are required in order to change transport behaviour, but recent years have seen increased interest in 'soft' measures because they are low-cost and can produce immediate effects. In contrast, planning and many technological changes are likely to have more effect in the medium to long term (Köhler et al., 2010; House of Lords Select Committee on Science and Technology, 2011).

This timescale issue was emphasized in our experts' comments collected by interviews: the implementation of social and behavioural measures (A65)(A66) to reduce vehicle kilometres is needed in the short term to achieve national carbon emission targets. Some NGO representatives within the consultation pointed out the importance of research on specific conditions of behaviour change (e.g., a change in mobility culture and image of different transport modes) and on effects of different behaviour change measures (e.g., education, campaigning, incentives or fiscal measures). Research is also important on specific impacts of political measures: decisions on taxation could be made on a more transparent basis if detailed studies on the behavioural effects of fiscal measures were available. The consultation results revealed that priorities for R&D within the behavioural/social domain include shifting from products to services (Roy, 2000; Luè et al, 2012) (A65), workplace/school travel planning (Luè and Colorni, 2009) (A72), eco-driving (A73) and education (A71). Motorway pricing (A68) was given the lowest priority, and was seen as offering fewer co-benefits than other measures. Economic policies (e.g., fuel taxation, congestion charging) were rated as somewhat less feasible than other measures, perhaps reflecting their lower public acceptability pre-implementation (Schuitema et al. 2010). All areas were considered to reach full implementation in the next few years.

3.2.3. Industry And Economy

While "Social and Behavioural" research areas focused on measures to shape the mobility decisions of transport users, the "Industry and Economy" section deals with the impacts of measures and instruments on business actors, including vehicle manufacturers and transport service providers. Some interviewees pointed out that applying regulatory measures that affect business models and profit margins would make lobbying pressure even harder than it is now. Still the experts mentioned that there is a need for studies on the effects of different types of measures and policy instruments (A75)(A77), which can inform decision-makers about the most effective regulation (Raux, 2004; Greene et al. 2011).

4. SUMMARY OF THE ASSESSMENT

This Section combines the quantitative evaluations within the consultation phases and the qualitative results of formal interviews and informal discussions with experts to summarize the results of assessing different research areas.

The consulted experts expressed difficulty in predicting what would be the leading technology or strategy in the long term: because of many interdependencies, several options were prioritized. Experts broadly agreed that a long transition period would occur where several technologies and strategies would co-exist.

According to expert opinions, in the **short term**, cost effective solutions may consist of three main research areas:

1)*investing in more efficient vehicles with existing technologies, making smaller, lighter vehicles and advanced Internal Combustion Engines (ICEs)*. ICEs do not need further EU support: they are already on the market and research is basically self-financed by the automotive industry. This kind of expertise, moreover, will inevitably be replaced in the long term. This is evidently true for the road sector but also aeronautics is beginning to look at alternative energy suppliers (hydrogen and fuel cells) starting with onboard powering systems. For the rail sector, efficiency would mean combining increased capacity and reduced costs, in other words, the concept of "compact train": to fit as many passengers (or goods) per meter of train, as it is possible without compromising comfort or safety. A large cross-cutting theme for the technological pillar of the SRA (air, rail, road, water) is research on aerodynamics, drag reduction, eco-driving and lighter vehicle materials. Basic research on lighter vehicles appears to be important both for rail and air mode: lighter short-distance (stop and go) trains, composite materials, aerodynamics of the fuselage and totally new concepts of aircraft frames.

Reducing overall road transport demand. Reduction of road transport demand is achievable through social and behavioural measures, leading to an overall reduction of distances travelled (Rentziou et al., 2012) or modal shift to less carbon-intense modes. There are diverse examples of measures, such as car sharing incentives, motorway and congestion charging, public transport system improvements, awareness raising campaigns to encourage cycling, and so on. In this field, research is needed in order to understand how to overcome cultural and behavioural barriers.

Fostering CO_2 emission reduction legislation. Voluntary agreements have not worked as expected in the past. It is known that competition takes a long time to deliver results (and often at a lower standard than expected). Therefore, efforts have to be made to ensure that countries respect current legislation and foster market changes. Moreover, there is a need for further research on the implementation and effects of regulatory and fiscal measures.

In the **medium/long term**, priorities for research are in the following areas:

1)*Electric vehicles and hydrogen*. Electric car implementation and market diffusion largely depend on battery development. According to our experts, research on batteries is both (a) a key factor for the success of electric cars and (b) in economic competition with non-European manufacturers: importing batteries is cheaper than financing R&D research on them, at least in the short-to-medium term. Hydrogen is long-term potential solution which, needs funding to continue improving, and will not give tangible results for a few decades. In this regard, the EU promoted public-private partnerships, such as

The Fuel Cells and Hydrogen Joint Technology Initiative[2] and the *Green Car Initiative*[3], both launched in 2008.

It was largely agreed that both electric and hydrogen fuelled vehicles depend upon the provision of clean electricity; in other words, none of the above measures is meaningful if energy provision still heavily relies on fossil fuels. Although the shift to electricity offers advantages on its own, lowering emissions depends on how the production and distribution of electricity is planned, implemented and managed (EC, 2011).

2)As a consequence of new propulsion systems, vehicle architecture will have to be re-adapted (e.g., smaller, more compact) and distribution infrastructures reviewed (e.g., smart electric grid). Regarding biofuels, experts' opinions diverged. Some experts thought they would not be more than a short- to mid-term solution: mass biofuel production would cause long-term damage to the environment and society.

Other experts believed that the use of biomass-derived fuels is expected to increase in the next few years, not least because it is promoted by the EU (EP, 2009). Yet they acknowledged that certain production-types of biofuels can impact food prices, biodiversity and deforestation. At the moment, second and third generation biofuels are a subject of R&D (EBTP, 2011). Another example of divergent opinions regarded congestion charging: some pointed out that there is little doubt about the effectiveness of the measure, whilst others state that the impact on total travel demand is limited and the main result is a shift of car use from rush hour to non-rush hour.

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[2] http://www.fch-ju.eu/

[3] http://ec.europa.eu/research/transport/road/green_cars/index_en.htm

One of the major debates focused on electric versus hydrogen solution for propulsion: most experts preferred electric, citing hydrogen production methods and distribution infrastructure as barriers. Finally, plug-in and full hybrids have already been selected for prioritization by the industry. This means that such research areas do not need EU support, but must instead focus on demonstrating commitment (e.g., the “Plugged in Places” programme[4]), which will lead to the creation of “niches” in the market and society.

Intelligent Transportation Systems (ITS). This research area was one of the most highly prioritised topics: ITS solutions could optimise vehicle trips, decrease consumption, avoid collisions, and encourage modal shift. Such opinion was confirmed by recent EU legislation efforts (EP, 2010) to accelerate and coordinate the deployment and use of ITS applications and services, and by the results of the 2DECIDE project (2DECIDE, 2011).
3)*Spatial planning, economic and social measures to reduce transport demand*. Experts agreed on the fact that research on spatial planning is the basis on which other successful measures should be applied. This is the case both for passengers (e.g., good connections with public transport modes and car-sharing) as well as for goods (more efficient long-distance transport and local distribution to customers).

It was also agreed that a modal shift to less polluting modes largely depends on social change. Such a shift can be achieved by continuing to communicate evidence and elevate niche market players as primary actors in bringing about change (Geels, 2005). As the

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[4] https://www.gov.uk/government/publications/plugged-in-places

White Paper suggests, "*EU research needs to address the full cycle of research, innovation and deployment in an integrated way through focusing on the most promising technologies and bringing together all actors involved*" (EC, 2011, p. 10). In addition, a general, important and long-term challenge consists of educating society to abandon the dominant model of infinite growth and consumption and changing people's habits. This emphasizes the value and urgency of research on non-technological measures geared towards climate-friendly transport: "*'Growing out of oil' will not be possible relying on a single technological solution. It requires a new concept of mobility, supported by a cluster of new technologies as well as more sustainable behaviour*" (EC, 2011, p.12).

Some **transversal topics** have been identified that underline the cross-cutting issues raised by the consultation; in particular, the contribution of energy sources and vectors to reducing emissions from the transport system as a whole. According to our experts, the most promising source of energy is solar and the most promising energy vectors are fuel cells/hydrogen and electricity. In 2005, 14% of the EU Gross Electricity Generation (3,300 TWh) came from renewable energy sources while more recently (EC, 2011) it is estimated that 35 to 40% of the total electricity has to come from renewable energy sources in 2020 to meet the "20-20-20" target (i.e., 20% reduction in GHGs, 20% of energy production from renewables, and 20% improvement in energy efficiency). In relation to transport, the use of solar energy primarily relates to charging the batteries of electric vehicles (Connors, 2007). The results obtained by research on fuel cells and electricity confirm experts' opinions that this is a priority for research. Finally, the consultation underlines the need for an upgraded distribution grid both for electricity

(Shinnar, 2003; Ipakchi, 2009) and hydrogen (Putrus et al., 2009), which represents a major challenge and may influence the forecasted increased use of non-fossil energy supplies for vehicles.

5. CONCLUSIONS

This paper summarizes one of the main outcomes of project REACT: a European Strategic Research Agenda (SRA) for climate-friendly transport. Several research areas were mapped and evaluated, drawing on current EU research programs, research agendas of the European Technologies Platforms and an extensive consultation process. As a general feedback from the consultation process, several experts stressed the need for a comprehensive SRA on climate-friendly transport as a reference point for the European research community and policy-makers.

Collecting and classifying all the research areas linked to climate-friendly transport is an ambitious task. Of several possible approaches, our adopted SRA highlights the difference between "technological" and "non-technological" research. However, it does not directly stress the differences between research areas related to the transport of passengers and goods. Moreover, the top-down hierarchical structure of the classification does not emphasise cross-cutting themes: some research areas are replicated in different sectors (e.g., design and materials). Technology itself does need social acceptance and behavioral change, and vice versa. Other aspects that are not stressed are the prerequisites for one research area with respect to another (e.g., a research area may require further basic research in another area to fully develop) and the impact of an area on another (e.g., the development of hydrogen fuel cell engines may affect research on biomass-derived fuels).

The present SRA structure, and the classification of research areas, was chosen together with the experts, and represents a pragmatic compromise between the need for completeness and the need to practically manage the breadth of possible research topics. The ambition lies not only with the chosen structure, but also with the main objective of the SRA, i.e. attributing a priority to research areas—there is high uncertainty in the estimation of the effects of certain technologies or policies. For instance, Yang et al. (2010) discuss that the available evidence on the benefits of interventions to promote cycling is of limited quantity and validity. Similarly, Möser and Bamberg (2008) argued that it is hard to draw reliable conclusions on the effectiveness of policy measures due to the lack of good quality available data. Such uncertainty is amplified while estimating the benefits of *research* on such technologies or policies. Therefore, the validity of prioritising the research areas given in the REACT SRA depends greatly on the expertise of the people involved in the consultation. For this reason, we employed a wide variety of experts in this exercise from as many areas as possible.

The output of the REACT SRA assessment is represented by a priority level for each considered research area, along with composite indicators. Specific indications on certain areas were compiled by means of interviews and during the consultation. However, future research should analyse more deeply the most promising areas, identifying in more detail the gaps to be filled and the specific research topics to be funded.

Moreover, R&D is only one of the elements of a comprehensive strategy needed to reduce transport GHG emissions, which comprises other improvements, such as infrastructure investment, urban planning, public attitudes, and the governance of companies and public bodies.

One of the main emerging themes from this exercise, was the increasing need for research that links the two main pillars (i.e., technology; and planning, social sciences and economy). Technology alone will be insufficient to achieve the necessary reductions in carbon emissions to effectively tackle climate change (e.g., House of Lords Committee on Science and Technology, 2011; EC, 2011). Integrated research on 'soft' and 'hard' solutions, which complement each other, is necessary. For instance, technological improvements may offer significant GHG reduction potential, but strong interventions in policy schemes (e.g., emission trading schemes) would be needed since markets do not initiate the necessary relevant changes (Rajan, 2006).

Moreover, the tendency to focus on long-term technological solutions cannot be treated independently from the short-term behavioural change that becomes crucial if the benefits of new technology are to be fully realized (Chapman, 2007; Skippon et al., 2012). In addition, since behavioural and social change have been recognized as paramount (e.g., Grubler and Riahi, 2010) for the success of any GHG-related policy or technology measure, timing would be critical: for the greatest impact, behaviour change policies and interventions would need to be applied early, deeply, and consistently. As Urry (2012) asserts, “there is little doubt that future ‘low-carbon innovation’ will also require ‘consumer communities’ coming to highlight, advocate, develop, make fashionable and synchronise actions and objects across diverse scales and socio-economic practices”: participation is not a fashionable method but a necessary step towards a low-carbon scenario. Future research should thus prioritize examination of how behavioural and institutional interventions should be implemented in relation to technical innovations, as well as unpacking notions of social and political ‘feasibility’, by drawing on socio-technical transitions, social practices, psychology, innovation, governance and related literatures (Schwanen et al., 2011).

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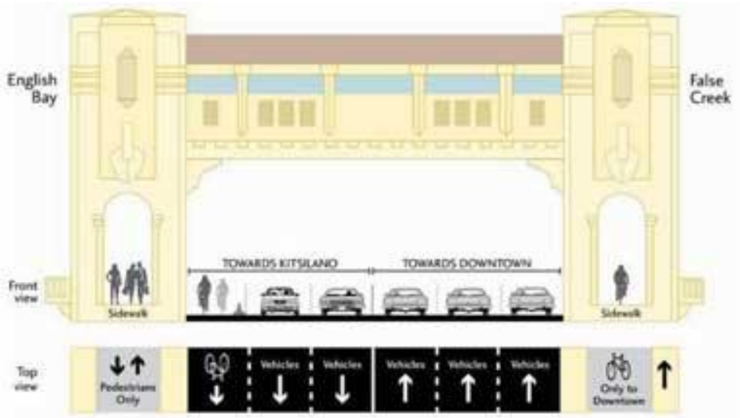
Figure 1: the higher levels of the hierarchical tree structure of the SRA (i.e., Pillars, Sectors, and Research Approaches). Sectors have been subdivided according to the same Research Approaches (i.e., driver, vehicle, and infrastructure).

Figure 2: assessment of the specific research areas for *Aeronautics* and *Rail* sectors.

Source: Pricetags blog, 2 July, 2012 (photo used with permission)

Figure 3: assessment of the specific research areas for *Road* and *Water* sectors.



Source: Advertisement run in the *Vancouver Courrier* (City of Vancouver 2009c, used with permission)

Figure 4: assessment of the specific research areas for the *Planning*, *Social Science* and *Economy* sectors.

Source: photo by Steven Godfrey (used by permission)