Navigating the Roadmap for Clean, Secure and Efficient Energy Innovation

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Executive Summary

Despite having a very innovative transport industry investing a lot in research and development with policies designed to foster the shift towards energy efficient and renewable energy carriers, the transport sector is still strongly based on fossil fuels. The EU Roadmap for moving to a competitive low-carbon economy sets the target to reduce emissions from transport compared to 1990 by -54% to -67% in 2050. Analyses show that transport is likely to miss this target by far without major changes in the policy framework.

In this case study, ambitious policy scenarios were analysed to achieve a CO₂ emission reduction in the transport sector of 60% to 65% by 2050 compared to 1990. The major strategies for decarbonising the transport sector are (1.) shifting to more efficient transport modes, (2.) diffusion of low/zero-emission technologies, and (3.) bio & synthetic fuels. The case study differentiates two ambitious policy scenarios due to two promising technologies for road freight transport: (1.) Direct electrification achieved by hybrid-trolley trucks on motorways, and (2.) Power-to-Hydrogen based fuel cell electric vehicles. These transition scenarios include several strong policy measures.

The main model used in this case study is ASTRA (ASsessment of TRAnsport Strategies), an integrated assessment model applied since more than 20 years for strategic policy assessment in the transport and energy field. With ASTRA, policies cannot only be simulated by single transport measures but as whole transport policy bundles. Technology diffusion is based on an adapted total cost of ownership approach. New low-emission powertrain options were added within the SET-Nav project and the scope of the model was expanded to EU28 countries.

The results show that all three strategies for decarbonisation have to be combined. The shift to more efficient road modes is partly restricted by limited capacities of public transport and railways, and depends a lot on behaviour change that is hard to achieve and is influenced by various factors. The new powertrain technologies offer huge potentials for decarbonisation, however, due to high production costs at market entry level, a lack of infrastructure in many countries and low acceptance, the diffusion of these technologies has to be pushed with diverse measures including stronger R&D, subsidies, deployment of the filling and charging infrastructure and increased CO₂ emission standards. Even phase-out decisions of pure internal combustion engine vehicles should be considered. After having achieved a certain diffusion level, price decreases and range increases due to technological learning and higher acceptance due to familiarity with the alternative options are expected to accelerate the diffusion. As sustainable biomass is limited and the efficiency of synthetic fuels is low, both options should mainly be considered as supplement for transport modes for which low-emission alternatives will not be available in the upcoming decades. As sector coupling is key to achieve the overall energy system transformation, technological options have also to be assessed on their flexibility potential that they provide for the electricity sector and on the overall efficiency.

The analysed ambitious scenarios reflect a radical change to be achieved within three decades only. Policies need to be in place soon to drive this transition. Intensive discussions are required on the best policy mix on European and national level as well as on further required framework conditions.
1 Introduction

In 2015, the transport sector accounted for around 28% of the European greenhouse gas (GHG) emissions. The EU Roadmap for moving towards a competitive low-carbon economy sets the target to reduce GHG emissions from transport\(^1\) compared to 1990 by -54% to -67% in 2050 in order to achieve an overall reduction of 80% for all domestic emissions across sectors. Analyses show that transport is likely to miss this target by far without major changes in the policy framework and the adoption of new technologies.

Despite having a very innovative transport industry investing a lot in research and development with policies designed to foster the shift towards energy efficient and renewable energy carriers, the transport sector still strongly depends on fossil fuels. Efficiency increase of conventional technologies is countered by a strong increase in transport activity both for freight and for passengers due to GDP growth and higher incomes of the population. In 2005, the transport sector showed even an increase of +30% compared to the base year in contrast to all other sectors that were able to decrease GHG emissions. The EU Reference Scenario 2016 shows that based on current policies the European transport sector would still be strongly fossil-fuel-based in 2050 with over 80% of final energy demand met by refined oil-products. Thus, substantial efforts are needed to reduce the use of fossil fuels in the next decades.

In 2015, European transport GHG emissions mainly stemmed from road transport (84%) and from aviation (15%). The decarbonisation potential varies between transport modes. Ships and aviation are difficult to decarbonise in particular due to the long operating life of aircrafts and vessels up to 50 years with low substitution rates and lack of profound technological alternatives. Thus, heading for a 60% cut of GHG emissions in transport until the year 2050 requires land-based transport to be comprehensively decarbonised by 2050. Today, road transport emissions are mainly caused by passenger cars (61%), by heavy duty trucks and buses (26%) and by light duty vehicles (12%). Due to the significance of road transport for reducing GHG emissions of the transport sector, the main focus of this case study will be on required policies and measures to achieve the transition towards low- and zero-emission road vehicles.

2 Strategies and policies to decarbonise transport

Strategies to decarbonise transport

There are several options to reduce GHG emissions in the transport sector. They can be differentiated into technological and behavioural options. The so-called ASIF scheme originally developed by the IEA on behalf of the World Bank (Schipper et al. 2000) describes the various options in a simple equation:

\[
\text{GHG emissions} = \text{transport Activity} (A) \times \text{modal Share} (S) \times \text{energy Intensity} (I) \times \text{carbon intensity of Fuel} (F)
\]

Reducing transport activity (A) in terms of vehicle-km driven is the first option in this scheme contributing to a decarbonised transport sector. Vehicle-km can be reduced by avoiding passenger trips or freight volumes, by reducing average distances of transport and by optimising load factors, empty runs and occupancy rates. Shifting (S) transport activity towards more energy efficient and less carbon intensive transport modes is the second option that can be achieved by improving the

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\(^1\) including international aviation, excluding international maritime shipping
competitiveness of these transport modes. The third option consists in the improvement of energy intensity (I) of transport means. This can be achieved by optimising energy efficiency of conventional transport technologies or by a transition towards more energy efficient fuel options. Finally, reducing the carbon content of transport fuels (F) is the forth option in the ASIF scheme.

The EU Transport White Paper from 2011 (European Commission 2011) has set several targets to reduce GHG emissions from transport in the EU until 2050. According to the White Paper, the key goals or strategies to decarbonise the transport sector until the year 2050 are:

1) Shift to more efficient transport modes: More than 50% of road freight transport above 300 km distance should be shifted towards rail and ships.
2) Diffusion of low/zero-emission technologies: The share of conventionally fuelled cars in cities should be halved until 2030 and completely set to zero by 2050.
3) Alternative fuels - biomass and synthetic: Sustainable low carbon fuels for aviation should achieve a share of 40% in the year 2050.

Shifting transport towards more efficient transport modes like public transport, trains or non-motorised modes (cycling and walking) is difficult. The modal split in many European countries kept constant over decades or a shift towards motorised road transport was even observed. Nevertheless, there are measures and incentives to achieve such a modal shift. The combination of

- financial measures like smart pricing, road infrastructure or congestion charges in cities,
- measures to improve the infrastructure of public transport, cycling and walking pathways,
- measures to improve the accessibility and the use of multi-modal transport, bike-, car- and ridesharing services by better applying digital technologies and
- regulatory measures like lower speed limits for passenger cars, prioritised traffic flows of non-motorised modes and public transport on crossings and high parking fees

can be powerful instruments to achieve a modal shift at least in urban areas.

A powerful instrument to force efficiency increases of road vehicles is setting stricter CO₂ standards. Those standards have the potential to enforce the manufacturers and suppliers of road vehicles to further improve fuel efficiency of fossil fuel based drivetrains. Furthermore, they can lead to an accelerated diffusion of alternative fuel vehicles like battery, plug-in hybrid or fuel cell electric vehicles. Unfortunately, alternative fuel options to reduce GHG emissions do not exist for each transport mode due to technical limitations like energy capacity, range or economic limitations like high investment costs. The following list names promising alternative fuel options from a feasibility and cost-efficiency perspective by mode that could contribute to a decarbonisation of the transport sector:

- Cars and light duty vehicles: Electrification in terms of battery electric (BEV) and plug-in hybrid vehicles (PHEV) for general use as well as fuel-cell electric vehicles (FCEV) for specific uses related to long-distances like for taxis.
- Heavy duty vehicles: Electrification with FCEV or hybrid-trolley trucks for long haul transport and battery electric trucks for urban or last mile delivery.
- Buses and coaches: BEV or trolley systems for urban busses and FCEV for coaches.
- Train: Further electrification of railways.
- Ships: Improvement compared to diesel with LNG and its biofuel and synthetic fuel alternatives (PtX).
- Aviation: Bio-kerosene and synthetic kerosene.
The big advantage of biofuels and synthetic fuels is that they can be applied without the need of substantial additional investment in new vehicles and filling station infrastructure. Nevertheless, limitations exist for both options. **Biofuels** should be limited despite their renewable character due to competition with other needs of land use. Only sustainably produced biofuels should be allowed. As biomass is also used by other sectors for decarbonisation, quantitative limits have to be taken into account. What concerns **synthetic fuels**, it is foreseen that they are produced via electrolysis with electricity from renewable energy sources (RES-E). However, they will be most probably more expensive in the production than fossil fuels - even when the development of large scale production sites is assumed. Therefore, these alternative fuels could be used in particular for modes for which no promising technological alternatives are available so far. While ships might at least partly switch from diesel consumption to liquefied methane, aircrafts will continue to use kerosene at least until the year 2050. Considering also the long operating life of aircrafts and vessels, alternative fuels could be dedicated in particular to maritime and inland waterway ships as well as to aviation.

All three strategies have to be applied to a certain degree in order to achieve the GHG reduction targets of the transport sector in 2050. These strategies will only be successfully implemented, when several transport policy measures are combined.

**Policies and framework conditions**

Regulatory measures like setting CO\(_2\) standards for new registered vehicles in Europe might be powerful measures to contribute to the decarbonisation of the transport sector. However, their impact strongly depends on the level of ambitiousness. The draft of the enforcement of CO\(_2\) standards for passenger cars and light duty vehicles of the EU from November 2017 proposing a further reduction of CO\(_2\) emissions of 30% until 2030 could lead to a stagnation of efficiency gains (Mock 2018) for ICE vehicles. As average lifetimes of passenger cars in Europe are increasing, a significant share of inefficient ICE vehicles could still be in vehicle stocks around Europe avoiding the decarbonisation of road transport. Additionally, few transport policies address the envisaged strong modal shift for road towards rail freight transport until 2050. Even if infrastructure bottlenecks will be reduced by the implementation of the TEN-T networks until 2050, road freight transport will still be more competitive in economic terms in many cases. Similarly, the modal shift from motorized individual transport towards multi-modal, public transport and non-motorized transport requires more effort and suitable policy measures.

The following measures can support the transition to a low-carbon transport system. They intend to accelerate the penetration of low- and zero-emission vehicles while further improving the internal combustion engine (ICE) in the short and medium term and to foster modal shift:

- Stricter fuel efficiency or CO\(_2\) standards until 2030 and beyond resulting in reduced fuel consumption factors of new registered vehicles
- Subsidies for electric vehicles in early market phases to push sales and accelerate price decrease via technological learning
- Vehicle registration taxes steered via bonus-malus systems related to CO\(_2\)-emissions of the vehicle
- Increased energy taxation for conventional fuels and reduced fuel tax for electricity, biofuels, hydrogen and renewable synthetic fuels
- Spreading road charges for trucks, light duty vehicles, busses and passenger cars based on CO\(_2\) emissions (on all roads)
- Banning fossil-fuel based cars from entry into cities
- Regulating a general phase-out of pure ICE vehicles at least for passenger cars
- Support of the development of common electronic multi-modal information platforms and seamless electronic ticketing for all public transport modes (incl. car-sharing)
Decisions required on investments and selection of alternative technologies

The intensity and the speed of diffusion of alternative fuel technologies does not only depend on related direct cost and on more soft factors like driving range, image and perceived reliability and risks, but requires also a sufficient deployment of charging and filling infrastructure. Studies have shown that a certain level of deployment is required for early adopters followed by a further steady ramp-up consistent with the increased vehicle diffusion in order to reduce perceived hurdles of vehicle purchasers and at the same time avoiding unprofitable infrastructure due to a lack of customers.

For road freight transport, battery-electric vehicles are not an option for intermediate and long-distance trucks due to the limited energy capacity and the weight of batteries. From the technical point of view, fuel cell electric trucks and hybrid trolley trucks are the most promising options to decarbonize at least long haul freight transport in Europe. Both technologies are still under development. Hybrid trolley truck systems are already tested at least in some field tests in different European countries. Overhead power lines are erected along motorways similar to those used in cities by trolley buses and trams. The system enables diesel-electric hybrid trolley trucks to operate in electric mode when connected via overhead pantographs. For distances without overhead power lines, diesel is used. Starting with diesel-electric hybrid trolley trucks, diesel could be replaced by batteries in new vehicles as of 2030 in order to achieve a complete electrification of the hybrid trolley trucks. While fuel cells and trolleys constitute promising decarbonisation options for trucks operating on long haul distances, there are several experts claiming that an introduction of both technologies in parallel would be too expensive due to the investments in two completely different infrastructure systems. It is not yet clear which technology will prevail. The decision for a deployment of a trolley infrastructure on motorways for trucks that are driving long-distances and often cross national borders might depend on a joint decision of several European countries to rely on this technology.

For synthetic fuels, decisions must be taken on the expansion of production capacities in Europe versus import agreements from Non-European countries. Synthetic fuels like Power-to-Liquid (PtL) or Power-to-Gas (PtG) can be produced using renewable electricity, water and CO₂ from the atmosphere or industrial processes in electrolysis and further synthesis processes. The production is very energy-intensive. Hence, the energy efficiency from the basic renewable electricity to the final synthetic fuel is low which would require substantial additional renewable electricity capacities in Europe. It seems improbable and not cost-efficient that additional renewable energy capacity will be installed in Europe only to produce these synthetic fuels because the demand for electricity from renewable energy sources is already high and might further increase. An option discussed among experts is the strategy to import synthetic fuels from countries with higher economic potential of renewable electricity (e.g. from Algeria with renewable wind and photovoltaics power). As the production varies according to the fuel type, different strategies might be applied. While hydrogen is produced within one electrolysis step, the production of synthetic methane and kerosene including diesel and gasoline requires two energy-intensive steps. This implies a higher consumption of electricity for the production. In addition, the liquefaction of methane to LNG and the refinement process for kerosene are also energy-intensive processes.

The probable scenario is to produce LNG, kerosene, diesel and gasoline in non-European countries at locations where renewable electricity can be produced at lower cost due to better conditions. However, the less-energy-intensive electrolysis-based hydrogen production might be a reasonable option in Europe, in particular in times of electricity oversupply. This could even constitute a flexibility potential for the renewable energy system that is challenged by fluctuations from solar and wind power generation.
3 Scenario definition to achieve CO₂ reduction targets and methodology for analysis

3.1 Scenario definition

To identify and describe potential decarbonisation pathways up to 2050, we conducted a model-based analysis of three different scenarios:

- A Reference scenario, which reflects the effects of current policies and serves as a benchmark to compare the more ambitious scenarios.
- Two ambitious Policy scenarios that aim at achieving GHG emission reductions of 60% to 65% by 2050 compared to 1990 and are mainly differentiated by infrastructure decisions:
  1) Direct electrification: Hybrid trolley truck infrastructure is deployed in all European countries on highly-used motorways.
  2) Hydrogen scenario: Hydrogen fuelling infrastructure is expanded comprehensively and market entry supported.

Table 1 provides an overview on the key policies and measures for the three scenarios. The interventions for the policy scenarios are considered to be additional to the existing measures in the reference case.

3.2 Methodology

The main model used in this case study is ASTRA (ASsessment of TRAnsport Strategies), an integrated assessment model applied since more than 20 years for strategic policy assessment in the transport and energy field. ASTRA is a system dynamics model covering the transport, economic and environmental system by European country. It simulates the development of passenger and freight transport per mode with an adapted classical four stage modelling approach.

With ASTRA, policies cannot only be simulated by single transport measures but as whole transport policy measure bundles. Within the SET-Nav project, the scope of the model was expanded to EU28 countries by adding Croatia. New low-emission powertrain options were added in particular for the freight road modes and for buses. Technology diffusion is based on an adapted total cost of ownership (TCO) approach. Besides the associated costs, an important issue of the diffusion of new technologies is the deployment of charging and filling station infrastructure and the development of ranges of alternative fuel vehicles. Therefore, ASTRA was linked to the ALTERMOTIVE model providing the technological development of storage capacities and consumption factors for batteries and fuel cell stacks as input for ASTRA.

In addition, as the ASTRA model simulates the demand side for electricity, hydrogen and gas consumption from transport activities, it is coupled with the energy supply models Enertile and Empire. The modelling work will be described in more detail in the case study report. A more detailed description of the ASTRA model can be found in Schade (2005), Krail (2009), Fermi et al. (2014) or on the ASTRA website (www.astra-model.eu).
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<th>Policies for the diffusion of low/zero-emission technologies and alternative fuels</th>
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<td>Subsidies and R&amp;D initiatives for market entry of FCEVs</td>
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<td>Increased energy taxation for conventional fuels and reduced fuel tax for electricity, biofuels, hydrogen and renewable synthetic fuels</td>
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<td>Phase-out of new pure internal combustion engine vehicles for urban buses as of 2030, for cars and light duty vehicles as of 2035</td>
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<td>Renewable Energy Directive 2009/28/EC (10% share of renewable energy in the transport sector final energy demand)</td>
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<td>Filling and charging stations for alternative fuels</td>
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4 Results and implications of the scenarios

4.1 Transport sector

4.1.1 CO₂ emissions in EU28 until 2050

The development of the CO₂ emissions for the three scenarios is depicted in Figure 1. The Policy Scenarios exceed the current European reduction targets for the transport sector in 2030 and in 2050 and meet the aimed reduction of 60% to 65%. Two main drivers of the achieved CO₂ emission reduction are the diffusion of alternative fuel vehicles for road transport and mode shifts in particular for passengers. They will be described in more detail in the following sections.

![Figure 1: CO₂ emissions by transport mode in EU28 until 2050 in Mt CO₂-equivalent](source: ASTRA)

4.1.2 Development of the share of alternative fuel vehicles in the vehicle stock

Figure 2 shows the development of the powertrain technologies in the European car fleet for the three scenarios. In the Reference scenario, pure diesel and gasoline-fuelled vehicles still constitute around 70% of the European car fleet in 2050, while battery electric cars (BEV, PHEV) represent a quarter of the fleet. The development is driven by a planned increase in charging stations as well as by decreasing prices and longer ranges due to technological learning. Learning effects in the first years result mainly from countries like Norway, the Netherlands and China where electric cars already have a remarkable market share today. In the Policy scenarios, pure gasoline, diesel, LPG and CNG cars were phased out as of 2035. This leads to more than 90% electric cars in 2050, therein around 30% pure battery-electric vehicles. The two Policy scenarios show only minor differences for the car fleet. In the Hydrogen policy scenario, the fleet constitutes of some more fuel cell electric vehicles (FCEV) that substitute PHEVs for cars driving long-distances in comparison to the Direct electrification scenario.
Figure 2: Car fleet composition by technologies in EU28 until 2050

Figure 3 depicts the fleet composition of the light duty vehicles (LDV). In the Reference scenario, BEVs diffuse continuously to around 15% by 2050 mainly driven by the increasing fleet of CEP (courier, express mail and parcels) operators delivering parcels in cities. In the Policy scenarios that incorporate also a phase-out of pure gasoline, diesel and CNG LDVs as of 2035, the share of BEVs and PHEVs increases to more than 95% in the Direct electrification scenario in 2050. In the Hydrogen scenario, the BEV and PHEV share is lower with both representing together ~80% of the LDV fleet in 2050, but are supplemented by a significantly higher diffusion of FCEVs.

Figure 3: Light Duty Vehicle (LDV) fleet composition by technologies in EU28 until 2050

Figure 4 shows the technology diffusion in the truck fleet over time. While diesel trucks dominate in the Reference Scenario with less than 3% alternative powertrains in 2050, diesel trucks decrease in the Direct electrification scenario to a share of 53% in the fleet and in the Hydrogen scenario to even 44%. Assuming a deployment of the trolley truck overhead cable infrastructure as of 2020 in the direct electrification scenario, trolley technology starts diffusing from this time onwards for the
road tractors and long-distance trucks. Market penetration of fuel cell electric trucks in the Hydrogen scenario starts later due to challenges related to the technology, the hydrogen production and its distribution to refuelling stations. Despite this later start, the fleet composition shows a higher share of FCEVs in 2050 compared to trolley trucks in the Direct electrification scenario because fuel cell technology is used for all truck weight classes not only for the long-distance trucks.

![Figure 4: Truck fleet composition by technologies in EU28 until 2050](image)

The bus fleet presented in Figure 5 comprises urban buses and coaches. Diesel stays the main technology in the bus fleet of the Reference Scenario because the CNG technology does not seem to provide emission-related advantages anymore and alternative options are much more expensive and require high investments. BEVs are mainly chosen by cities that aim at reducing their high emission levels. Ambitious policies including a phase-out of internal combustion engine buses in cities lead to a higher share of BEVs in the bus fleet in the policy scenarios. In addition, the number of urban trolley buses increases in the Direct electrification scenario in particular based on infrastructure extensions and for bus lines with high demand; however, their share in the urban bus fleet stays minor compared to other technologies due to lower acceptance of the required infrastructure within the cities and higher initial investments. With a deployment of overhead power lines on motorways for trolley trucks, trolleys might become also an option for coaches. In contrast, the Hydrogen scenario results in a third of the bus fleet being FCEVs due to technological learning and due to an extension of the hydrogen fueling infrastructure that is important for coaches.
4.1.3 Modal shift

Current measures in the Reference scenario already result in a shift from car use to trains for passenger transport. In the Policy scenarios an even stronger shift is achieved assuming further improvements in public transport in combination with higher costs for driving a car due to policies like higher taxes on conventional fossil fuels (see Figure 6).

4.1.4 Limitations of the scenarios

Besides uncertainties in the prediction of cost developments and the effectiveness of policies, the policy scenarios have further limitations:

**Changes in behaviour** that are not mainly cost-driven are hard to achieve and predict and might depend on other factors including societal trends and the perceived attractiveness of more efficient...
alternatives. In order to shift to other more efficient modes, the perceived benefits must exceed the disadvantages and sense of loss. For example, car-sharing users have currently a distinctive socio-economic profile (mainly well-educated, male, young adults, middle/upper income ...). Upscaling car-sharing usage to further groups might also depend on the degree of development towards a sharing-economy and/or the perceived benefits like flexibility and reduced effort for car maintenance compared to owning an individual car. Reduction of transport activity via complete avoidance of certain trips is not considered in the policy scenarios.

**Fully automated vehicles** were also not included in the scenarios. Their market entry is not expected before 2035 (Krail et al. 2018). According to recent studies their share in private vehicle fleets will still be low due to high production costs until 2050. Fully automated vehicles have a higher fuel efficiency of 15-18%. However, overall effects on emissions will depend a lot on related regulations. As part of public transport bridging the 'last-mile' in particular in less-urban regions, public transport could gain users and increase overall transport efficiency. In contrast, fully automated cars in individual private ownership could increase transport activity strongly due to additional empty trips when driving family members to their various destinations and due to increased travelling as driving time can be used for other activities. Fully automated trucks and busses might diffuse faster after market entry due to higher savings with the elimination of driver cost and increased fuel efficiency gains.

### 4.1.5 Required investments and expenditures

Investments in the infrastructure can only be roughly estimated within this case study.

The Direct electrification scenario assumes that a cost-efficient deployment of trolley truck infrastructure is achieved when a third of the European motorways is provided with overhead cables for trucks. This third of motorway roads should be the distances that are most highly frequented and thus represent towards 2/3 of the distances driven on motorways by the trucks. This assumption is based on a study for deploying motorways in Germany with a sufficient trolley infrastructure (Wietschel et al. 2017). Assuming a required infrastructure investment of 2 Mio EUR per kilometer, total investments would add up to 51 billion Euros for EU28.

Setting up a hydrogen filling station infrastructure including a hydrogen distribution network would be costly as well. Investments for the filling stations depend on the foreseen size of the single stations and on the decision if hydrogen is produced in larger production sites or directly at the filling stations. According to experts, investments for smaller hydrogen filling stations would be around 1 million Euro. Due to the different tank capacities of passenger cars and long-haul trucks, hydrogen filling stations for trucks could require investments of 10 to 20 million Euro per filling station. In this case, the deployment of a European network of 2.500 up to 5.000 hydrogen filling stations would lead to the same infrastructure investments of around 50 billion Euros. According to Gnann et al. (2017) there are still some open issues on the hydrogen distribution network to be considered as the distribution of hydrogen via semitrailer trucks from the production site to the filling station would not be sufficient for large and frequently visited hydrogen filling stations by long-haul trucks. In this case, additional investments could be necessary.

While investments for the zero- and low-emission vehicles are higher at first, lower energy prices and lower maintenance cost in addition with policy-driven advantages, like lower registration taxes and road charges, will partly compensate higher vehicle prices over time. In addition, vehicle prices of new technologies decrease with higher production numbers and technological learning.

Financing solutions have to be discussed in particular for the infrastructure. Investments by the private sector might be preferable, only supported by governmental subsidies where needed.
Decisions and regulations on national and European level towards a specific technology and infrastructure would reduce investment risks and thus support private investments.

Governmental subsidies and tax reductions, e.g. for supporting R&D and reducing alternative fuel prices, seem required for the market penetration of low-emission vehicles.

To conclude, a mix of governmental expenditures and private investments is needed to achieve the decarbonisation according to the two analysed policy scenarios.

4.2 Link to the power sector and overall efficiency

The investigated decarbonisation options for transport are strongly linked to the power sector. First, the real emission reduction potential through low-emission technologies and synthetic fuels depends strongly on the share of renewable electricity in the European grids. Secondly, alternative fuel technologies provide further flexibility options for an energy supply system that depends to a large degree on volatile renewable energy sources.

The flexibility potential is determined by the electrification type and the acceptance of load shifting. While trains, trolley trucks and trolley busses that are powered by overhead wires will increase electricity consumption directly at the time when the transport activity takes place, BEV, PHEV and the production of hydrogen and further synthetic fuels via electrolysis as PtG or PtL provide a certain flexibility potential due to their storage options.

Load shifting of BEV and PHEV can be incentivised by a reduced electricity price but might also depend on familiarity with demand side management from other sectors like home appliances. What concerns the flexibility potential of synthetic fuel production, it is dependent on where the fuels will be produced. Most probably, only the less-energy-intensive PtG-Hydrogen production will be available as flexibility option in Europe while the other fuels might be imported (see arguments for decisions on page 4).

There is a tendency that the higher the flexibility potential the lower the overall efficiency: The best overall efficiency can be achieved by direct electrification with power generation from renewable energy sources either as battery-electric vehicles or as powered overhead-cable solutions. BEVs can achieve an overall efficiency factor of more than 70%, FCEVs achieve only around 30%.

Figure 7 and Figure 8 show the electricity and hydrogen consumption by scenario. The respective quantities provide an indication on the higher efficiency in the Direct electrification scenario and the higher flexibility potential in the Hydrogen scenario.

Figure 7: Electricity consumption in TWh in EU28 in 2050 by scenario and mode

Source: ASTRA
For a cross-sector optimisation, flexibility should only be a relevant criteria as long as it supports a secure and cost-efficient energy system, but above this level, overall efficiency should be a main decision criteria. In the SET-Nav project, it will be investigated across sectors for several transition scenarios how the electricity mix develops and how much flexibility is needed for a secure and cost-efficient energy system.

5 Conclusions

The major strategies for decarbonising the transport sector are (1.) shifting to more efficient transport modes, (2.) diffusion of low/zero-emission technologies, and (3.) bio & synthetic fuels. In this case study, ambitious policy scenarios were analysed to achieve a CO₂ emission reduction in the transport sector of 60% to 65% by 2050 compared to 1990. The case study differentiated two ambitious policy scenarios due to two promising technologies for road freight transport: (1.) Direct electrification achieved by hybrid-trolley trucks on motorways, and (2.) Power-to-Hydrogen based fuel cell electric vehicles. These transition scenarios include several strong policy measures.

The results show that all three strategies for decarbonisation have to be combined. The shift to more efficient road modes is partly restricted by limited capacities of public transport and railways, and depends a lot on behaviour change that is hard to achieve and is influenced by various factors. The new powertrain technologies offer huge potentials for decarbonisation, however, due to high production costs at market entry level, a lack of infrastructure in many countries and low acceptance, the diffusion of these technologies has to be pushed with diverse measures including stronger R&D, subsidies, deployment of the filling and charging infrastructure and increased CO₂ emission standards. Even phase-out decisions of pure internal combustion engine vehicles should be considered. After having achieved a certain diffusion level, decreasing prices and range increases due to technological learning as well as higher acceptance due to familiarity with the alternative options are expected to accelerate the diffusion. As sustainable biomass is limited and the efficiency of synthetic fuels is low, both options should mainly be considered as supplement for transport modes for which low-emission alternatives will not be available in the upcoming decades. Moreover, technological options have also to be assessed on their flexibility potential that they provide for the electricity sector and on the overall efficiency because sector coupling is key to achieve the overall energy system transformation.
The analysed ambitious scenarios reflect a radical change to be achieved within three decades only. Policies need to be in place soon to drive this transition. It has to be noted that the European reduction target by 2030 will leave a huge gap to meet the very challenging target in 2050 in only 20 years. The argument for an increasing effort over time is that a wider set of cost-effective technologies will become available (European Commission (2011a)). However, considering the lifetime of vehicles and the accumulation of carbon dioxide in Earth’s atmosphere, policies might rather aim at overachieving the 2030 target. Furthermore, the reduction target for the transport sector of minus 60% in 2050 compared to 1990 was defined in 2011 in the European Low Carbon Roadmap that aims at reducing overall European GHG emissions by 80% across all sectors. The 2015 Paris Agreement calls for countries to pursue efforts to limit global-mean temperature rise to significantly below 2°C, ideally to 1.5°C. Therefore, it is under discussion that the EU should even aspire to reduce overall GHG emissions by up to 95% by 2050 in order to achieve this goal. This could mean even more efforts for the transport sector. To decarbonize transport even further, the bio-fuel share could be increased or PtX-fuels could be used if not enough sustainable biomass is available. In addition, more efforts could be made to achieve behaviour change in order to shift to more efficient or active modes. At the same time, the transition should ensure affordability and inclusiveness of mobility.

Thus, intensive discussions are required on the best policy mix on European and national level as well as on further required framework conditions. Relevant discussion points include the current strategy of technological openness versus a focus on the most cost-efficient technology pathway, the role and appropriate production sites of synthetic fuels and most effective and cost-efficient policy measures.

This issue paper described the main aspects and results of the case study on the decarbonisation of the transport sector. More details on the involved models and the assumptions as well as further results will be published in a comprehensive case study report. The SET-Nav project has the overarching goal of supporting strategic decision making in Europe’s energy sector, enhancing innovation towards a clean, secure and efficient energy system. The transport case study will be the basis for four holistic transformation pathways that will be simulated with the whole SET-Nav consortium to achieve EU GHG reduction targets across all sectors. Each pathway represents specific framework conditions and trends that might evolve in the upcoming decades varying the two key uncertainties degree of cooperation and degree of decentralisation. Results will be available for download on the project website www.set-nav.eu.
6 References


**About the project**

SET-Nav aims for supporting strategic decision making in Europe’s energy sector, enhancing innovation towards a clean, secure and efficient energy system. Our research will enable the European Commission, national governments and regulators to facilitate the development of optimal technology portfolios by market actors. We will comprehensively address critical uncertainties facing technology developers and investors, and derive appropriate policy and market responses. Our findings will support the further development of the SET-Plan and its implementation by continuous stakeholder engagement.

These contributions of the SET-Nav project rest on three pillars: modelling, policy and pathway analysis, and dissemination. The call for proposals sets out a wide range of objectives and analytical challenges that can only be met by developing a broad and technically-advanced modelling portfolio. Advancing this portfolio is our first pillar.

The EU’s energy, innovation and climate challenges define the direction of a future EU energy system, but the specific technology pathways are policy sensitive and need careful comparative evaluation. This is our second pillar. Ensuring our research is policy-relevant while meeting the needs of diverse actors with their particular perspectives requires continuous engagement with stakeholder community. This is our third pillar.

**Who we are?**

The project is coordinated by Technische Universität Wien (TU Wien) and being implemented by a multinational consortium of European organisations, with partners from Austria, Germany, Norway, Greece, France, Switzerland, the United Kingdom, France, Hungary, Spain and Belgium.

The project partners come from both the research and the industrial sectors. They represent the wide range of expertise necessary for the implementation of the project: policy research, energy technology, systems modelling, and simulation.
The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no. 691843 (SET-Nav).

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Navigating the Roadmap for Clean, Secure and Efficient Energy Innovation

Workshop Proceedings Paper on Accelerating the transition towards sustainable transport

SET-Nav Stakeholder Dialogue: 3rd Topical Workshop

Author(s): Eleanor Drabik, CEPS

May / 2018

A report compiled within the H2020 project SET-Nav (work package 2, deliverable D2.6)

www.set-nav.eu

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Work Package Coordinator: Centre for European Policy Studies (CEPS)

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# Agenda

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<td>13:00 - 14:00</td>
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<td>14:00 - 14:35</td>
<td><strong>SESSION I: INTRODUCTION AND KEYNOTE SPEECH</strong></td>
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<td>14:00 - 14:05</td>
<td>Welcome by <a href="#">Eleanor Drabik</a>, Researcher, CEPS</td>
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<td>14:05 - 14:10</td>
<td>Overview of the SET-Nav project by <a href="#">Marijke Welisch</a>, Researcher, TU Wien</td>
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<td>14:10 - 14:20</td>
<td>Keynote speech by <a href="#">Robert Missen</a>, Head of Unit, DG MOVE, European Commission</td>
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<td>14:20 - 14:35</td>
<td>Q&amp;A</td>
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<td><strong>SESSION II: WAYS TO A CLEANER AND SMARTER TRANSPORT SECTOR</strong></td>
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<td>Chair: <a href="#">Christian Egenhofer</a>, Head of Energy &amp; Climate Change, CEPS</td>
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<td>14.35 - 14.50</td>
<td>Presentation of the modelling results on the ways to a cleaner and smarter transport sector: <a href="#">Stephanie Heitel</a>, Scientific Associate, Fraunhofer ISI</td>
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<td>- <a href="#">Patrik Akerman</a>, Head of eHighway Business Developer, Siemens</td>
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<td>- <a href="#">Jorgo Chatzimarkakis</a>, Secretary General, Hydrogen Europe</td>
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<td>- <a href="#">Marie-France Van der Valk</a>, Head of Renault-Nissan Alliance</td>
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<td>representation office in Brussels</td>
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<td>15:20 - 16:25</td>
<td>Open discussion and Q&amp;A</td>
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<tr>
<td>16:25 - 16.30</td>
<td>Concluding remarks by chair</td>
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<td>16:30</td>
<td><strong>END OF THE WORKSHOP</strong></td>
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2 Minutes

2.1 Welcome

This event was used to promote the work done within the case study 5.4 on *Ways to a cleaner and smarter transport sector* to ensure a continuous flow of dissemination activities and to give interested actors the opportunity to bring their views and guide the analytical process within the project.

2.2 Session 1: Introduction to the project and the keynote speech

This session primarily provided an introduction to the topic of sustainable transport by a representative of the European Commission. It also gave an overview and summary of the progress of the SET-Nav project that started in April 2016.

- **Maijke Welisch** from TU Wien, who is part of the project coordinating team, provided an overview of the project to the audience and a brief summary of the progress so far. Marijke informed participants of the three key pillars of the project, the objectives and methodological framework of SET-Nav as well as the upcoming modelling workshops that are planned as part of the project. In particular, Marijke informed the audience of the upcoming “Energy Modelling Platform for Europe 2018”, which will take place in Brussels at the European Commission on the 25th – 26th September 2018.

- **Robert Missen**, who is Head of the research and innovation Unit for sustainable transport at DG MOVE from the European Commission, provided the keynote speech and set the tone of the event. He discussed the legislative processes currently taking place in his unit. He also enlightened the audience that the goal has already been set by the European Commission, for the EU and its industries to become a world leader in innovation, digitalisation and decarbonisation, and that this will be made a reality in the mobility sector.

![Figure 1: Session 1](image)
2.3 Session 2: Ways to a cleaner and smarter transport sector

As opposed to other energy sectors, final energy consumption of the European transport sector has continuously increased over the last decade. Despite having a very innovative transport industry investing a lot in research and development with policies designed to foster the shift towards energy efficient and renewable energy carriers, the transport sector is still strongly based on fossil fuels. With this in mind, the SET-Nav consortium aimed to present a preliminary answer to the question: what measures can be put in place to accelerate the transition of the transport sector towards a low-carbon system that can additionally provide further flexibility option with regards to the energy sector?

In this session, SET-Nav researchers offered potential options and strategies to decarbonise transport that have been previously analysed using different modelling approaches. Following this, comments were provided by leading stakeholders.

- **Stephanie Heitel** from Fraunhofer ISI, part of the SET-Nav team, presented her findings on the Case Study *Ways to a cleaner and smarter transport sector*. The results she presented were from three different policy scenarios. The first scenario observed direct electrification for transport while the second looked at including some elements of vehicles powered by hydrogen. The difference here is the policies that introduce dense hydrogen infrastructure and subsidies for market entry of FCEVs compared to policies that stimulate hybrid trolley-truck infrastructure on motorways. These scenarios were compared with a third scenario, the reference scenario. Using the ASTRA model, she disclosed modelled projections of the reduction in greenhouse gas emissions in the years 2020, 2030 and 2050 for each of the three scenarios. The modelling results show that the direct electrification scenario would result in a marginally lower reduction in emissions than the hydrogen scenario and that both those scenarios would result in lower emission when compared with the reference scenario.

- **Patrik Akerman**, Head of eHighway Business Development from Siemens provided his comments in response to the results presented by the SET-Nav research team. He discussed the key challenges to the decarbonisation of the transport sector and discussed technical concepts for electrified roads for HDVs. This was in relation to the direct electrification of transport scenario presented by Stephanie Heitel. He also explored the cost assessment of such a system and the roadmap to get there. Following some demonstration projects in Sweden, he believes the next step for the development of a trolley truck system in the EU is to hold field trials in Germany and the path forward should focus on the electrification of highly frequented routes.

- **Jorgo Chatzimarkakis**, Secretary General of Hydrogen Europe provided his comments on the topic and the results presented by SET-Nav researchers. He pointed out that hydrogen is key to support the energy transition. It firstly enables large-scale renewable energy integration and power generation, and can act as a buffer to increase system resilience. Secondly, it can help decarbonise transport, industrial processes as well as building heat and power. In regards to heavy duty hydrogen, he stated that it provides a high daily range for vehicles and operational flexibility when compared with electrified transport.

- **Marie-France Van der Valk**, Head of Renault-Nissan Alliance representation office in Brussels also provided her comments on the research presented by the SET-Nav project team. She included an additional element to the discussions, the efficiency of resources related to the circular economy. She spoke about optimizing the environmental impact of EV batteries and integrating a circular economy loop into the system through battery recycling and second-life applications.
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About the project

SET-Nav aims for supporting strategic decision making in Europe’s energy sector, enhancing innovation towards a clean, secure and efficient energy system. Our research will enable the European Commission, national governments and regulators to facilitate the development of optimal technology portfolios by market actors. We will comprehensively address critical uncertainties facing technology developers and investors, and derive appropriate policy and market responses. Our findings will support the further development of the SET-Plan and its implementation by continuous stakeholder engagement.

These contributions of the SET-Nav project rest on three pillars: modelling, policy and pathway analysis, and dissemination. The call for proposals sets out a wide range of objectives and analytical challenges that can only be met by developing a broad and technically-advanced modelling portfolio. Advancing this portfolio is our first pillar. The EU’s energy, innovation and climate challenges define the direction of a future EU energy system, but the specific technology pathways are policy sensitive and need careful comparative evaluation. This is our second pillar.

Ensuring our research is policy-relevant while meeting the needs of diverse actors with their particular perspectives requires continuous engagement with stakeholder community. This is our third pillar.

Who we are?

The project is coordinated by Technische Universität Wien (TU Wien) and being implemented by a multinational consortium of European organisations, with partners from Austria, Germany, Norway, Greece, France, Switzerland, the United Kingdom, France, Hungary, Spain and Belgium.

The project partners come from both the research and the industrial sectors. They represent the wide range of expertise necessary for the implementation of the project: policy research, energy technology, systems modelling, and simulation.

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