Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 14 (2016) 2620 – 2629

Transportation Research Procedia

www.elsevier.com/locate/procedia

6th Transport Research Arena April 18-21, 2016

Transitions and impacts of passenger car powertrain technologies in European member states

Gillian Harrison [a,]*, Jette Krause [b], Christian Thiel [b]

[a]*Institute for Energy and Transport, Joint Research Centre, European Commission*[1] *Westerduinweg 3, Petten, Noord Holland, Netherlands*
[b]*Institute for Energy and Transport, Joint Research Centre, European Commission Via Enrico Fermi 2749, Ispra (VA), Italy*

Abstract

In this paper we seek to understand the relative impacts that policies and incentives focused on e-mobility may have on the technology market shares for passenger cars, and the associated fleet energy requirements and greenhouse gas emissions. We have a European Union (EU) wide focus, and from this deduce what recommendations could be provided for countries intending to encourage e-mobility in the near future. For this task we integrate two in-house models of the vehicle fleet and market developed by the European Commission Joint Research Centre. Our main policy conclusion is that although ambitious policy may lead to great improvements in specific efficiency and emissions, second order effects could lead to increased passenger car activity, limiting the overall emission improvement achieved. Therefore, any policy portfolio requires not only technological policies (aimed at both users and manufacturers), but also would need to address wider mobility patterns in an integrated approach. As such not only do we present findings relevant for policy decision making but also contribute to methodological approaches regarding the use and integration of modelling tools in support to policy design.

Peer-review under responsibility of Road and Bridge Research Institute (IBDiM)

Keywords: electro-mobility; emissions; energy; modelling

---

* Corresponding author. Tel.: +31-(0)224-565465.
E-mail address: Gillian.Harrison@ec.europa.eu

[1] The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

Peer-review under responsibility of Road and Bridge Research Institute (IBDiM)
doi:10.1016/j.trpro.2016.05.418

1. Introduction

As efforts increase to reduce carbon emissions within a world of changing preferences regarding mobility, there is much attention on the transition from conventionally fuelled internal combustion engine (ICE) vehicles towards electro-mobility. To this end, the European Union designs and implements regulations and policies to ensure decarbonisation targets are met. The goal of the European Union's (EU) sustainable transport policy is to ensure that the transport system meets the economic, social and environmental needs of society (EU 2011), envisaging a reduction of road transport emissions by 60% by 2050 versus 1990 levels, alongside the halving of conventional vehicles in cities by 2030. Moreover, in October 2014 the European Council adopted a binding EU target of an at least 40% domestic reduction in greenhouse gas emissions by 2030 compared to 1990. The sectors not included in the EU Emissions Trading System will have to fulfil a reduction target of 30% by 2030 compared to 2005 through a new effort sharing decision yet to be proposed (EU 2014). Road transport currently accounts for around a fifth of total EU emissions (EEA 2014) and is the largest contributor to non-ETS emissions, with a contribution of 34%, and latest estimates expect that this share will be growing in the future if no policy action is taken (EC 2013).

In this paper we present two models that have been developed within the Joint Research Centre of the European Commission and are currently being soft-linked. The aim of it is two-fold. Firstly (and foremost) we aim to present some initial results describing what impact a technology transition scenario may have on the evolution of the passenger car fleet in the EU member states, and what this means for resultant emissions and energy use. Secondly, we discuss the methodological challenges of linking models, but frame this within the context of the benefits of combining approaches for a more comprehensive and relevant application of such policy tools than the usage of a single model, only.

The paper is set out as follows. Firstly we give a brief overview of the two models, though the reader should bear in mind that this research paper does not give detailed insight into the model design or development. Within this we describe the scenarios and the powertrains we consider in this research. We then discuss the similarities and differences of the two models, leading us to highlight the challenges to overcome and synergies to exploit in the soft-linking of the models. After presenting the methodological approach chosen, we then present our results – what our chosen policy and market condition scenario could mean for powertrain technology market shares and EU energy and emissions over the period until 2050. Finally we discuss the results, drawing some conclusions for policy makers regarding market transitions such as electrification of transport, as well as conclusions on model integration.

2. The Powertrain Technology Transition Market Agent Model (PTT-MAM)

The PTT-MAM is a system dynamics based model. It studies the interaction between, and influence of, the market agents of the automobile sector on possible powertrain technology transitions of the light duty road transport fleet (passenger cars and light commercial vehicles) within Europe, up to 2050. These market agents are automobile manufacturers, infrastructure (and maintenance) providers, authorities and users, each represented as one conceptual conglomerate (though certain dynamics are included in recognition of competitive aspects etc.). The strength in the PTT-MAM is the ability to run multiple policy and/or market condition scenarios for detailed analysis of sensitivities of powertrain market shares to input parameters.

System dynamics modelling has long been used to study not only transport, but also specifically the uptake of alternative-fuelled vehicles (Shepherd 2014). Our model expands upon previous models by encompassing a wider array of 16 powertrain types, market agents and all 28 member states of the EU. Thus the main focus and purpose of this model is to gain insights in the key levers and influences on adoption rates of new technologies that can be applied on both supply and demand sides in a policy context, at both an EU and member state level. The principal output is the market shares of new powertrain technologies (on an annual basis) as a result of different policy scenarios. Although there is not the space to go into a detailed description of this model in this paper, there is currently a technical report with more details under development. The model consists of over 1,500 elements with up to 10,000 subscripts (e.g. powertrain type, country) leading to over 700,000 data points at each time step of the model. Within this, there are over 700 simultaneous equations and 300 constant data input parameters. Input data is sourced from publically available sources where possible, such as Eurostat, TRACCS (EMISIA 2013; Papadimitriou et al. 2013) and the EU Reference Scenario (EC 2013), as well as numerous publications and expert judgments.

Despite this complexity, each model scenario runs in only a few minutes, allowing many iterations to be compared in a relatively short period of time. Further detail on this model will be available from a Technical Report that is currently under preparation at the time of writing this paper and is due for release in early 2016.

3. The DIONE fleet impact model

The Fleet Impact Model DIONE was conceived for analyzing scenarios of future European road vehicle fleet composition, vehicle efficiency development, activity patterns, fuel greenhouse gas (GHG) intensities and their impacts on road traffic energy consumption and CO_2 as well as non-CO_2 pollutant emissions up to 2050. The particular strengths of the model are its detailed representation of all road vehicles, its precise energy consumption and emission calculation, and its flexibility to accept user inputs for scenario creation. Main variables can be defined by the user, including vehicle stock, new registrations, survival rates, activity, efficiency, flex-fuel vehicles (FFV) fuel mix, fuel production pathways, and biofuel admixture shares. The user can decide to create scenarios, e.g., for single EU member states (plus Iceland, Norway, Switzerland, Former Yugoslav Republic of Macedonia and Turkey) or pre-defined groupings such as EU28, EU15 and EU12. The model also allows the definition of custom regional entities or vehicle types that are not covered by the pre-settings. The software includes a pre-defined calibrated baseline which users can depart from for creating own scenarios, which is consistent with TRACCS and is taken forward following the trends of PRIMES 2012 baseline scenario with adopted measures. A detailed technical report on DIONE is under preparation. The model calculates energy consumption for these vehicle types and entities, as well as GHG emissions (CO_2, CH_4, N_2O, Black Carbon) and air pollutant emissions (SO_2, NOx, NMVOC, Particulate Matter, CO, Organic Carbon, NH_3). For both energy consumption and GHG emissions, DIONE can provide current and future real world Tank-to-Wheel (TtW) as well as Well-to-Wheel (WtW) results. For CO_2 emissions, NEDC type approval or real world values can be tracked. Real world fuel consumption and emission calculation for combustion engine vehicles is based on the COPERT 4 v.11 road transport emission inventory software. For alternative fuel vehicles, an energy and emission calculation methodology has been developed which takes account of vehicle characteristics, trip lengths and speed distributions. DIONE also includes a cost module which determines additional costs for achieving given efficiency targets for conventional passenger cars.

4. Similarities and differences between the PTT-MAM and DIONE

The link between the two models is fundamentally a simple process: the resultant new registration market share and fleet composition of powertrains for each year that are calculated endogenously within the PTT-MAM are exogenous data inputs into DIONE. However, as the models were developed separately, the translation of data is not so straight forward. The first complication resulted from relative baseline assumptions, such as mileage/activity, growth in fleet size and technological evolution. The PTT-MAM, with its hundreds of exogenous data input points and endogenous feedback calculations, is much more sophisticated requiring many more assumptions than DIONE that has a limited number of generalisations regarding base conditions. DIONE was not designed to account for policy or market conditions endogenously, but focusses on a detailed representation of the road vehicle fleet and accurate emission and energy consumption calculation. It is these relative strengths and weaknesses that mean linking the models allows us to exploit the key advantages of each of them. However, equally due to this, it is not possible directly to match a PTT-MAM baseline with a standard DIONE baseline or input. Secondly, classification of powertrain technologies and vehicle sizes is not directly compatible. Both models contain passenger cars and light commercial vehicles but as the latter has not yet been as sophistically developed in either model, our focus remains on passenger cars only. PTT-MAM operates with 16 powertrain/fuel combinations, of 3 different sizes each, which are roughly considered to be equated to market segments as the user purchase decision is central to the model. These powertrains are characterised by their component parts and improve over time endogenously within the model relative to the R&D decisions of the automobile manufacturer market agent. This is itself influenced by feedbacks from user decisions, authorities and infrastructure development. Conversely, DIONE has a more sophisticated disaggregation of powertrain technologies, with vehicle sizes based on engine size rather than market segment, as well as a detailed age-specific representation of vehicle stock and its consumption and emissions. However, the two models remain to be compatible and these differences were not insurmountable, as described in the next section. Importantly, the source data for both models come primarily from four public sources: EU Reference Scenarios (based on PRIMES), Eurostat, the TRACCS project and the European Automobile Manufacturers Association (ACEA). As such certain confidence for this alignment can be assured.

5. Approaches for translation between models

5.1. Baseline assumptions

In order to deal with inconsistencies in baseline assumptions between the models, it was agreed that PTT-MAM market shares and stock shares, rather than absolute numbers, would be employed. This is not an unusual approach, and in fact reflects a limitation of System Dynamics modelling that is generally recognized by modellers using this technique – real insight is gained by studying changes between scenarios, not as a purely predictive tool.

5.2. Powertrains considered

It was relatively easy to make assumptions on how powertrains can match between the two models, although they do not have the same degree of differentiation for all powertrain/fuel combinations: The PTT-MAM currently includes a more encompassing set of combinations of powertrains and fuels, e.g., it includes pure Bioethanol and Biodiesel powertrain options and Diesel PHEV which are not explicitly represented in DIONE. Therefore, for the purposes of the present analysis, which focusses on electrified vehicles, pure biofuel options were assumed to be unavailable over the period of analysis within the PTT-MAM. In contrast, DIONE allows specifying mild hybrids, allocating FFV fuels and contains gasoline range-extended vehicles that are not considered in PTT-MAM. To overcome this, PTT-MAM single fuelled LPG and CNG vehicles can be assigned as 100% alternative fuel in DIONE, mild hybrid ICEV from DIONE can be included within conventional ICEV in PTT-MAM, and range extended EV from DIONE within PHEV for PTT-MAM.

5.3. Size segmentations

We performed a direct translation of sizes to align the two models, assuming that PTT-MAM market segment based vehicle categories are similar enough to DIONE segments based on engine displacement for our purposes. This entailed assigning PTT-MAM segments to the closest DIONE category, e.g., small gasoline ICE from MAM to the smallest category of conventional gasoline cars with an engine size of 0,8–1,4 l in DIONE. Validation based on recent data showed a good fit for the direct translation, where new registration segment shares deviated by +/- 3 percentage points at most. A verification of overall EU28 stock composition was not feasible, due to limited data availability. However, a comparison of the German stock composition in 2011 and 2012 according to Eurostat, which uses a segmentation based on engine power equivalent to DIONE segmentation, revealed a good fit for the direct translation in terms of overall deviations, as well as comparable maximum deviation ranges for the single segments. For electrified vehicle classes, just one size category exists in DIONE for HEV Diesel, PHEV Petrol, BEV and FCEV. All PTT-MAM vehicles with the respective powertrains were attributed to this single DIONE category. PTT-MAM HEV Petrol were assigned to the closest DIONE category, corresponding to the direct translation mechanism employed also for conventional PC.

6. Scenario definition and DIONE inputs

In this study we focus on comparing our baseline scenario to one particular optimistic “Technology Transition” (TT) scenario implemented in the PTT-MAM, which was first presented in previous work (Pasaoglu et al. under review). The main scenario assumptions are described in Table 1.

Table 1. Scenario description.

Scenario	Oil price and annual GDP growth	EV learning rate	EV purchase subsidies (% of cost difference between EV & ICEV)	Passenger Car CO_2 target (gCO_2/km)
Baseline	as in EC (2013)	10%	2011–13: 50%, 2014/15: 25%	2025: 70g, 2050: 41g
Technology Transition	50% higher	20%	2011–15: 75%, 2015–20: 50%, 2020–25: 25%	2025: 56g, 2050: 27g

The conventional and biofuel WtT energy and emission values are taken from JEC (2014). For electricity, we use the carbon intensity indicator for electricity and steam production from EC (2013), with a 10% add-on for transmission and distribution losses. This results in upstream carbon emissions of electricity declining from 101.1 gCO_2/MJ in 2010 to 23.9 gCO_2/MJ in 2050. For hydrogen, we depart from a 2010 WtT factor of 127.5 gCO_2/MJ, taken from (Pasaoglu et al. 2012), which decreases proportionally to the EC (2013) electricity carbon intensity, based on the conjecture that hydrogen from electrolysis can be decarbonized at an equal pace with electricity. We add 10% of losses for either electricity transport (in a decentralized structure) or hydrogen transport (in a centralized production structure), resulting in WtT carbon emissions for hydrogen which decrease from 140.25 gCO_2/MJ in 2010 to 33.2 gCO_2/MJ in 2050. Finally, we consider the mileage of BEV to be lower than the default value of 19,545 km p.a. for new vehicles. We assume a 14,990 km p.a. for a new EV (i.e., they now have the same activity pattern as gasoline hybrids and a similar one to medium-size gasoline vehicles), based on the assumption that in the PTT-MAM scenarios BEV are likely to be employed in cities and for daily commuting, but longer ranges are more likely to be covered by the equally available FCV. In DIONE, vehicle activity depends on vehicle age, which is implemented by multiplying vehicle-specific base mileage by an age factor <=1 which decreases over time. DIONE was then run to calculate fleet activity, energy consumption and emissions to compare them among scenarios as described in the following section.

7. Results

7.1. Fleet composition

In the PTT-MAM, new registration market shares of powertrains are driven by the user “willingness to consider” the powertrain in the first place (Struben and Sterman 2008) and then preferences towards the relative utilities (or attractiveness) that the powertrains offer them determine the relative market shares using a standard multi-nomial logit choice model. Evolving market conditions and powertrain characteristics influence the utilities, and government intervention can also lead to changing priorities. Manufacturers, given the need to avoid emission penalties, may incentivise users to purchase lower emission powertrains through pricing, but also through raising awareness by marketing. PTT-MAM stock growth is determined by vehicle sales and deregistrations (due to vehicle aging), where total sales are driven primarily through GDP growth and co-efficients calibrated from historical demand data.

Powertrain fleet composition in baseline and TT scenarios are presented in Figure 1. In the baseline scenario, from almost 100% in 2010, the non-hybridised ICE class declines to 50% of total stock by 2050, as the hybrid and electrified powertrains increase. Though some may believe this is a relatively optimistic outcome for a baseline, the user should recall that our baseline includes current proposed emission regulations and representative electro-mobility subsidies. Within this, diesel becomes the most popular fuel, accounting for over half of ICEV stock by 2050, and LPG and CNG both account for around 5% of the fleet from around 2040. HEV (as the only available alternative option in the early years) are the first alternative powertrain to replace ICEV and are followed by PHEV and BEV from around 2020. By 2050, these two electric powertrains together make up over a third of the fleet, and almost half of all new registrations (not shown). Lastly, FCV start to appear around 2030 with a small but growing market share. For PHEV powertrains, there appears to be no significant sales trend with relative shares in 2050 very similar to those seen in 2030, but fleet shares increase over time. This may be because the dominant factor affecting choice of PHEV in the first place is convenience and access to charging, reducing the impact of all other factors distinguishing between the sub-types. Likewise, FCV dominate the electro-mobility share by 2050, as once they become available and affordable, the technical attributes characterising the utility of powertrain are more appealing to users than the other options. In the TT scenario, ICEV fleet shares drop by an additional 10% points over the baseline by 2050, and sales share is down to 14%. From 2030, HEV sales are also lower than the baseline, and increasingly so, as PHEV, FCV and BEV have benefitted from additional subsidies increasing their attractiveness compared to baseline. All electric powertrains have higher fleet shares than baseline due to the optimistic conditions that were built into TT. BEV and PHEV stock shares in 2050 are both almost double the baseline scenario, and FCV is up by 27%. The more rapid increase in new registrations share increases visibility, familiarity to users and therefore willingness to consider. Alongside this, prices drop more quickly due to greater economies of scale and GDP growth, meaning these powertrains become affordable earlier than under baseline conditions.

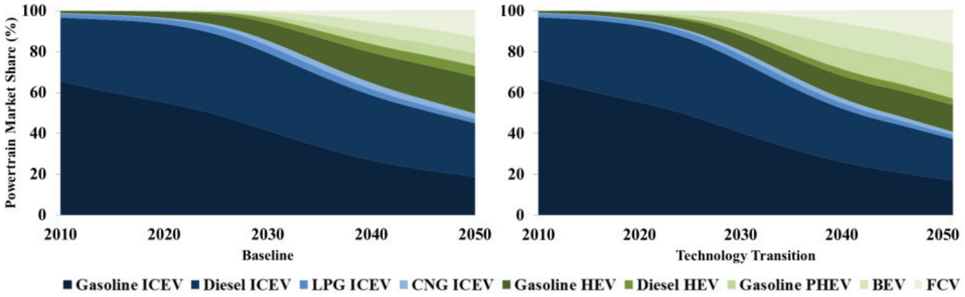

Fig. 1. Powertrain fleet composition transition under both scenarios.

7.2. Total stock size and activity development

Stock and Activity are presented in Table 2. Overall baseline stock exhibits continuous annual growth rates of 0.6% on average, which results in a 11% growth by 2030 and a 24% increase by 2050 compared to 2011. For the TT scenario implementation, stock growth is higher at 0.85% p.a., 13% by 2030 and 33% by 2050. The vehicle fleet activity is growing at a similar pace. Slight differences emerge because of the changing age and fleet distribution in the two scenarios.

Table 2. Baseline Passenger Car Stock and Activity Development.

Year	Scenario	Passenger Car Stock (in million cars)	PC Fleet Activity (in billion vkm)
2011	Baseline	244	3,247
	Technology Transition	244	3,247
2030	Baseline	270	3,587
	Technology Transition	275	3,543
2050	Baseline	303	4,305
	Technology Transition	325	4,512

7.3. Fleet energy consumption

Figure 2 shows the development of TtW energy consumption over time. It includes the baseline scenario (left figure) as well as results for the TT scenario (right figure), which are each given first in terms of ‘real world’ (RW) energy consumption, i.e., using the Copert methodology included in DIONE. For the different fuels, TtW trends are as follows:

- For conventional fuels, the decrease of gasoline consumption is especially pronounced and continues from 2011 to 2050, where gasoline consumption is just 43% (baseline) or 41% (TT) of 2011. For diesel, there is a sustained reduction as well, which is more pronounced in the TT scenario where 2050 diesel consumption is 51% of 2050 consumption, whereas it is 65% in the baseline scenario.

- Gas-based fuels as well as biofuels make up for relatively small fractions of overall energy consumption, as there are no dedicated biofuel vehicles in the presented scenarios, thus biofuels are used only as an admixture to conventional fuels. For LPG, there is a roughly 30% (baseline) or 40% (TT scenario) reduction from 2011 to 2050, but LPG consumption is volatile over time. CNG is very little consumed in 2011 and its consumption grows over time. Bioethanol and biodiesel consumption decrease over time.
- Due to the increasing share of electrified vehicles in the passenger car fleet, electricity consumption increases over time from zero in 2011 to a 6% share of overall energy consumption in the baseline and a 12% share in 2050 in the TT scenario. For hydrogen, 2050 shares are even higher, namely 13% of energy consumption in the baseline and 18% in the TT scenario.

As Figure 2 shows, compared to 2011, overall passenger car fleet energy consumption goes down for both scenarios until 2040, by 31% or 53 Mtoe for baseline and 33% or 58 Mtoe for TT. It then rises by 1 or 3% of 2011 consumption (by 1 or 5 Mtoe) towards 2050. In summary, the decrease can be attributed mainly to the described sustained savings in conventional fuels, fostered both through the assumed efficiency increase in conventional engines up to 2020 and through a replacement of conventional PCs by more energy efficient electric vehicles. As the overall vehicle fleet continues to grow, and as activity increases as described in the previous section, overall PC energy consumption starts rising again after 2035. This effect is stronger for the TT scenario, where passenger stock growth and overall activity is higher.

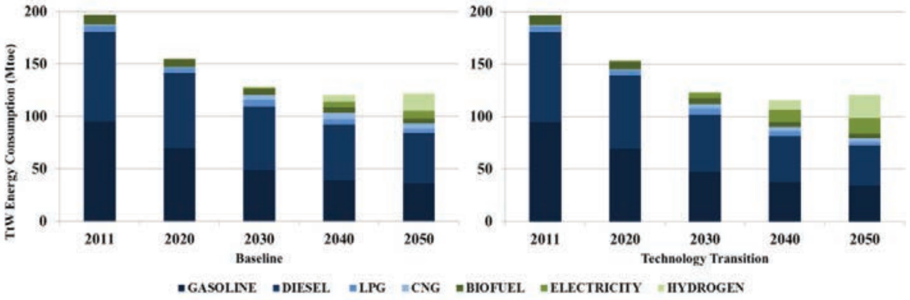

Fig. 2. Development of RW TtW car energy consumption by energy carrier for both scenarios.

7.4. CO_2 Emissions

7.4.1. Real world fleet CO_2 emissions

Corresponding to the presentation of energy consumption in the previous section, Figure 3 shows passenger car fleet emission development over time. Apart from TtW emissions (dark blue bars), the figure also includes upstream, i.e. WtT CO_2 emissions (light blue bars). The figure shows that TtW emissions constantly decline from 2011 throughout 2050. Baseline TtW CO_2 emissions go down from 528 $MtCO_2$ in 2011 to 295 $MtCO_2$ in 2050, i.e., to 56% of 2011 CO_2 emissions. For the TT scenario, TtW emissions shrink from 528 $MtCO_2$ in 2011 to 253 $MtCO_2$ in 2050, i.e. to roughly half (48%) of 2011 emissions. This is due to the reduced overall consumption in fossil fuels and biofuels because of efficiency gains and fleet shift towards electrified powertrains. The latter, however, also entails an increase in upstream WtT emissions over time. Initially, WtT emissions decrease, starting 91 $MtCO_2$ in 2011 for both scenarios, and arriving at 71 (baseline) and 75 (TT) $MtCO_2$ in 2030. By 2050, they then rise again to 81 $MtCO_2$ for the baseline scenario, and to 89 $MtCO_2$ for the TT scenario, i.e. overall, for 2011 to 2050, there is a 11% (baseline) or 2% (TT) decrease in WtT CO_2 emissions. This is caused by two trends, namely a reduction of fossil fuel consumption and related upstream emissions over time, and an increase in transport electricity and hydrogen consumption, which is linked to relatively high upstream CO_2 emissions.

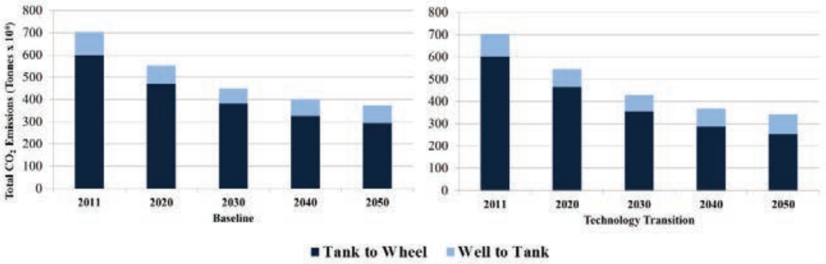

Fig. 3. Development of total fleet real world CO_2 emissions under both scenarios.

In sum, fleet WtW CO_2 emissions exhibit a constant decrease over time. As discussed earlier, efficiency increases and technology replacement reduce energy consumption, but fleet growth and activity increases partly counterbalance this trend. Due to the assumed decrease in CO_2-intensity of electricity and hydrogen, the resultant overall reduction is 243 (baseline) or 277 $MtCO_2$ (TT scenario) from 2011 to 2050, which corresponds to a relative emission reduction of 39 and 45% for the same period.

7.4.2. New Registration CO_2 Emissions

Currently, the main EU policy tool for addressing passenger car emissions is TtW CO_2 emission limits for new fleets. Such limits have been set to 130 gCO_2/km in 2015 and 95 gCO2/km in 2021, on a TtW, type approval (TA) basis. The details of a post-2020 regulation are currently under discussion. Figure 5 shows the development of new fleet average emissions. As can be seen from the TA TtW results (dark blue bars), in both scenarios the 2015 and 2021 targets are met or over-fulfilled. Especially the 2021 target is over-fulfilled by nearly 10 gCO_2/km within the TT scenario. As explained above, the TT scenario sets additional TtW TA targets of 56 gCO_2/km by 2025 and 27 gCO_2/km by 2050. When implementing the powertrain shares, as derived from PTT-MAM, in DIONE, the TtW TA targets are not met according to emission calculation in DIONE. Instead it results in TT scenario TtW TA new fleet emissions of 78 gCO_2/km in 2025 and 30 gCO_2/km in 2050. Also in the PTT-MAM, the targets are not fully met in the TT scenario. Apart from TA emission measurement discussed above, Figure 4 includes TtW new fleet emissions in real world (RW) mode (dark green bars), which are 9% to 11% higher for different years and scenarios. To account for the full impact of transport CO_2 emissions, however, also upstream CO_2 need to be considered. Figure 5 also shows WtT emissions on top of TtW results (light blue and light green parts of the bars), such that the complete bars show the resulting WtW emissions of annual new fleets for both scenarios and metrics. Among these, WtW RW emissions (olive plus light green bars) are the most complete representation of CO_2 emissions. In 2015, RW WtW emissions are roughly 30% higher than TA TtW emissions for both scenarios. In relative terms, the gap widens over time, resulting in nearly 60% higher WtW RW emissions in the baseline scenario and 85% higher WtW RW in the TT scenario in 2050 compared to TtW TA. Furthermore, Figure 4 shows the WtW CO_2 emissions of the total stock, which declines at a similar pace as the one for the new fleet.

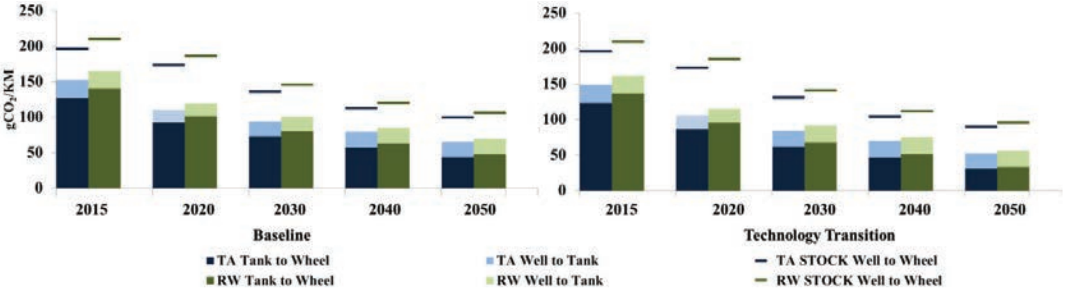

Fig. 4. New registrations' fleet average TtW and WtW CO_2 emissions (gCO_2/km), for real world and type approval under both scenarios. The line on top of the bars shows WtW emissions for the entire passenger car stock.

8. Discussion and conclusion

In this paper we have presented the results from soft-linking two complementary models to better understand the impact on EU energy and emissions from a likely progressive technology transition towards electro-mobility within the passenger car fleet. To do this we exploited the synergies of the two models and overcame weaknesses of using either in isolation. Despite the translation incompatibilities that would be expected in any similar task, we are confident that our adopted approach has produced initial results that provide some insight into the design of future EU policy for the decarbonisation of passenger cars.

An example of how the two models can benefit from each other is the projection of emissions. The PTT-MAM includes endogenously calculated improvements in vehicular emissions, determined by not only the user choice to purchase lower emission vehicles, but also the influence of emission penalties on manufacturer strategies, including R&D spend, marketing and pricing. However, it was designed for the study of market share technology transitions, not for a detailed representation of emissions. It is therefore limited by the quality of available input data, and required assumptions imposed when creating a simple but representative mode. DIONE, on the other hand was specifically developed to accurately capture the impact of incremental technology improvements on fleet emissions, but market shares are exogenous inputs. This is why the input of the PTT-MAM market shares into DIONE is a step forward in the study of the impact of technology transitions on emissions, as it combines the strengths of each model. We recognise that inconsistencies between the models do limit the conclusions that can be drawn. In future work, we hope that the output of DIONE may be used to re-calibrate PTT-MAM emissions for iterative improvements in the confidence of our findings.

The changes in fleet composition over the period 2011 to 2050 were determined in our first model, the PTT-MAM, and we identified that market and policy conditions favourable towards electro-mobility can double the share of electric vehicles (BEV, PHEV and FCV) in the fleet by 2050, compared to baseline conditions. Although this would appear to be promising, it would however still suggest that EU targets of the elimination of conventional vehicles from urban areas by 2050 (and more so the halving by 2030), may prove to be difficult as ICEV remain to be the single most dominant powertrain. However, it should be noted that our scenario did not consider separate urban policies on this occasion.

By using these results as an exogenous input into our second model, DIONE, which has a greater level of detail regarding energy and emissions, we have identified a realistic trend in reductions over the time period that can be used to inform potential progress towards current policy targets. In terms of energy, overall fleet consumption is steadily reduced over time in both scenarios, with TT being marginally more successful than baseline, but then actually increases towards 2050. This observation is due to the increasing efficiency of conventional ICEV coupled with the replacement by electric vehicles. The increase is due to overall stock and activity growth due to favourable market conditions. The above discussion has focused on the timeframe of 2011 to 2050. However, to compare the emission reductions achieved within the present scenarios to policy targets, different timeframes are needed, namely 2005 to 2030 with regard to the effort sharing decision (ESD) and 1990 to 2050 with respect to Transport White Paper targets. In terms of RW TtW emissions, the CO_2 reductions achieved over these timeframes are 25/32% (baseline/TT) for ESD and 33/47% for the White Paper. Thus, passenger cars would fulfil the ESD overall non-ETS sectors target of -30% from 2005 to 2030 under the TT scenario, but miss it by 5% under PTT-MAM baseline conditions. However, they don’t fulfil the White Paper transport sector target of -60% from 1990 to 2050, not even under the TT scenario, despite being 42% more successful than baseline. This shows that an ambitious electrification can help meeting current policy targets, but may not be enough to reach very ambitious targets for road transport decarbonisation. The optimistic assumptions of the TT scenario include a strong growth of GDP, which goes along with PC stock growth and activity increases. Further research into incentive structures and how electrified vehicle market introduction can come about with necessary emission reductions may be warranted.

Given the discussion above our main policy conclusion is that although ambitious policy may lead to great improvements in specific efficiency and emissions, second order effects could lead to increased passenger car activity, limiting the overall emission improvement achieved. Therefore, any policy portfolio requires not only technological policies (aimed at both users and manufacturers), but also would need to address wider mobility patterns in an integrated approach. In addition, such policies may need to be targeted towards specific user groups, such as urban drivers or business fleets. As we refine both the separate models and the soft-linking process, it would be interesting to design policies to this effect for comparison to the results presented here. The results from our research present a compelling argument for combining model-based simulations of policy scenarios and analysis of impacts as important tools in policy support. As such, not only does this paper provide interesting insights in policy aspects from scientific research, but also presents an innovative methodology of collaboration between not only academic disciplines (specifically economics and engineering) but also complementary modelling techniques. Such interdisciplinary approaches are important step-changes towards progressively holistic research designed to achieve more successful policy outcomes than traditional methods. As we move into times of growing uncertainty and complex problems, requiring understanding not only of the underlying scientific issues related to both technological innovation and environmental impacts in the road transport and energy sectors, but also of economic challenges, political constraints and societal concerns, will become increasingly relevant.

References

EC (2013). EU Energy, Transport and GHG Trends to 2050. Reference Scenario 2013., European Commission.

EEA (2014). Annual European Union Greenhouse Gas Inventory 1990–2012 and Inventory Report 2014: Submission to the UNFCCC Secretariat. Technical report No. 09/2014, European Environment Agency.

EMISIA. (2013). “TRACCS Project.” from http://traccs.emisia.com/.

EU (2011). White Paper 2011: Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system., European Commission.

EU (2014). “European Council Conclusions of Oct 23/24 2014.”

JEC (2014). Well to Wheels Report Version 4a, Joint Research Centre-EUCAR-CONCAWE collaboration.

Papadimitriou, G., Ntziachristos, L., Wüthrich, P., Notter, B., Keller, M., Fridell, E., Winnes, H., Styhre, L. and Sjödin, Å. (2013). Transport data collection supporting the quantitative analysis of measures relating to transport and climate change (TRACCS). E.D. CLIMA, Emisia, Infras, IVL.

Pasaoglu, G., Harrison, G., Jones, L., Hill, A., Beaudet A. and Thiel, C. (under review). “A system dynamics based market agent model simulating future powertrain technology transition: Scenarios in the EU light duty vehicle road transport sector.” Technological Forecasting & Social Change.

Pasaoglu, G., Honselaar, M. and Thiel, C. (2012). “Potential vehicle fleet CO_2 reductions and cost implications for various vehicle technology deployment scenarios in Europe.” Energy Policy 40(2012): 404–421.

Shepherd, S.P. (2014). “A review of system dynamics models applied in transportation.” Transportmetrica B: Transport Dynamics 2(2): 83–105.

Struben, J. and Sterman, J.D. (2008). “Transition challenges for alternative fuel vehicle and transportation systems.” Environment and Planning B: Planning & Design 35(6): 1070–1097.