Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 105 (2017) 2245 – 2252

Energy Procedia

The 8th International Conference on Applied Energy – ICAE2016

Electrification of commercial road transport – Attainable effects and impacts on national energy supply systems

Jochen Linssen*, Bastian Gillessen, Heidi Heinrichs, Wilfried Hennings

Forschungszentrum Juelich GmbH, Institute of Energy and Climate Research – Systems Analysis and Technology Evaluation

Abstract

The goal of the analysis is to quantify potential effects of electrifying the commercial transport and the impacts on a national energy system. This is done for the case of Germany, but can be adapted to other energy systems. Based on the historical trend of vehicle stocks and technologies a reference scenario is developed to the year 2030. Energy demand and supply, emissions and costs are calculated and evaluated with focus on the energy systems perspective.

The results point out that the impacts of an electrified commercial fleet on the German energy system are not significant. The primary energy consumption is only reduced very slightly by the assumed share of electric vehicles. However, the mix of final energy carriers in transportation is affected significantly. The use of mineral oil products is reduced by 8.4 % up to 2030 in comparison to a business as usual scenario. The additional electricity consumed by the electric vehicles requires no significant enlargement of the electricity generation capacity but a moderately increased utilization rate. The CO_2 emissions reduction by electric vehicles reaches around 6 million tons of CO_2 per year in 2030 for the German case study. The assumed electrified commercial fleet in urban areas contributes with approximately 3 million tons of CO_2 to this reduction. The emission saving depends on charging strategies as well as generation characteristics of wind and PV. Especially the policy goal of reducing final energy demand in the transport sector (-40 % to 2050 according to the German "Energiewende") turns out as an important driver for electric vehicle applications in road transportation.

Peer-review under responsibility of the scientific committee of the 8th International Conference on Applied Energy.

Keywords: Sustainable Transport, Electric Vehicle, Commercial Transport, Energy Scenario

1. Introduction

The electrification of vehicles for private transportation is worldwide strongly under discussion and close to market entry or at a starting point of penetration. The electrification of commercial fleets (passenger and goods) would allow a clear enlargement of electric mobility applications and the abatement of negative effects by transport. Reasons for the suitability of commercial transport for

* Corresponding author. Tel.: +49 2461-613581; fax: +49 2461-612540.

E-mail address: j.linssen@fz-juelich.de.

Peer-review under responsibility of the scientific committee of the 8th International Conference on Applied Energy.

doi:10.1016/j.egypro.2017.03.641

electrification are better scheduling of the distances and routes in comparison to private transport. With focus on urban transport the local reduction of noise and hazardous emissions is of special importance.

All around the world, demonstrations of electric vehicles in private and commercial use are undertaken, including technical, economic and social aspects of the use and integration in transportation systems (cf. [1], [2], [3]). Furthermore, electric vehicles as new electricity consumers, demand response and storage option including charging behavior and control strategies are subject of several studies worldwide (e.g. [4], [5], [6]). Nevertheless, the analysis of electric vehicles in commercial fleets for urban transportation and the impacts on the entire energy system, like power plant capacity, fuel savings and contribution to CO_2 reduction strategies, are not done in a sufficient manner. Because of this fact, this paper points out scenario results for a future electrification of a commercial fleet in urban areas using Germany as a case study.

2. Goal and approach

The goal of this analysis is to quantify potential effects of electrifying commercial transport and the impacts on a national energy system. This is done for the case of Germany but can be adapted to other energy systems as well. Based on the historical development of vehicle stocks and technologies, a reference scenario has been developed until the year 2030. A combination of technology, stock and cost modelling for commercial vehicles (passenger and goods) as well as the performed integration into the national energy system model IKARUS allows quantifying possible effects and impacts. Energy demand and supply, emissions and costs balances are calculated. The evaluation has a special focus on the effects and impacts of electrifying commercial road transport.

3. Commercial road transport – Status quo and trends

The phenomenon of commercial transportation especially in urban areas is currently not properly grasped in statistics. Because commercial transport is a combination of passenger and goods transport as well as combined transport, determining the status quo is only possible with a combination of different statistics and some assumptions about ownership and purpose of vehicles. Table 1 shows the share of the commercial transport according to the total mileage of all vehicles in German urban areas. For LDV and HDV commercial applications dominate by far. The mileage of urban PC (passenger car) transportation has a share of about 65 % of commercially induced trips. Commercial PC drivetrains are dominated about two-thirds and LDV (low duty vehicle)/ HDV (heavy duty vehicle) almost completely by Diesel engines. With this fact urban commercial transportation contributes, beside climate harmful emissions, significantly to hazardous particulate matter and nitrogen oxide emissions in cities.

Table 1. Shares of private and commercial transport according to total vehicle mileage for urban areas (source of data [7])

Share of total mileage [%]	PC	LDV < 3.5 tons gvw (gross vehicle weight)	HDV > 3.5 tons gvw (gross vehicle weight)	Other	Total
private transport	34.7	7.5	1.0	2.6	25.3
commercial transport	65.3	92.5	99.0	97.4	74.7

Important data sources for commercial transport are the German panel questionnaires for commercial vehicle owners [7] and for private owners [8]. The knowledge of owner constellation is necessary for developing vehicle stock scenarios based on historical data of the German vehicle register (cf. [9, 10]).

Together with regression of commercial and private vehicle life spans as well as sold new vehicles based on fitted logistic curves, a stock modelling has been performed for PC, LDV and HDV. Fig. 1 shows the development of new sold vehicles and of the vehicle stock for different drivetrains and vehicle classes in the reference scenario.

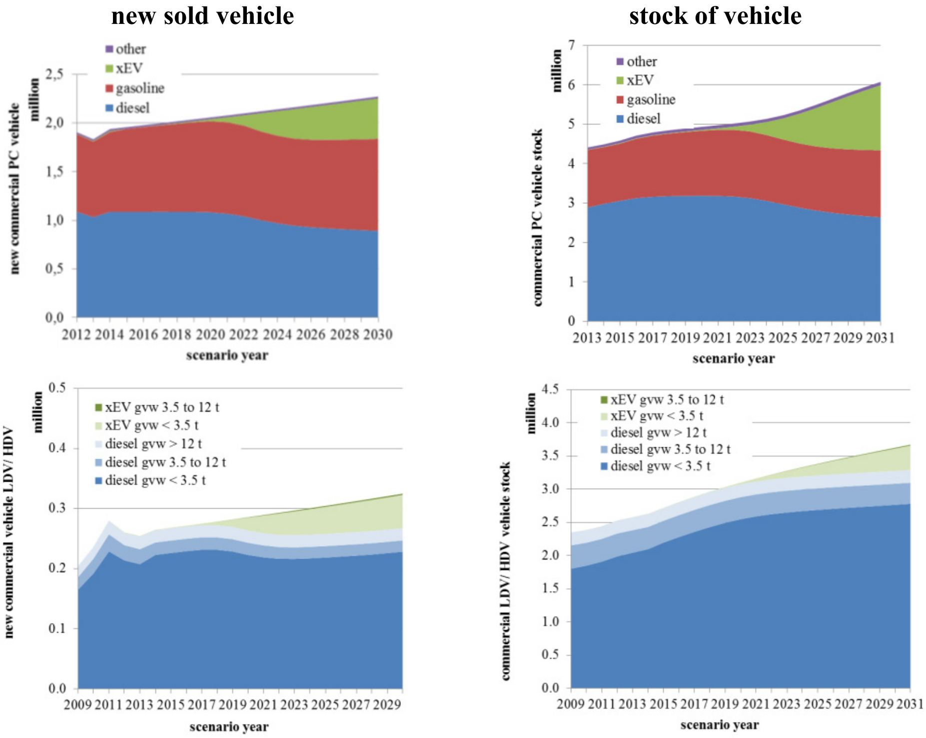

Fig. 1. Development of new sold vehicles and stock of vehicles for commercial application; (PC at the top and LDV/HDV at the bottom) reference scenario

The stock represents the total number of vehicles in operation to the reference date the first of January for each year. Therefore the stock is delayed by one year to the sold new vehicles. In the reference scenario xEV (all electric passenger cars and low/ heavy duty vehicles with grid charging option) reaches a stock share of 25 % for commercial PC respectively approx. 12 % for LDV/ HDV. The assumed share of privately used xEV is lower (10 % according to the entire PC stock), but compared to commercial xEV the absolute numbers are higher (4.1 million xEV).

LDV are well suited for drivetrain electrification and battery application because of moderate gvw (gross vehicle weight) as well as short and well known daily trips (cf. [7], [11]). The number of registered LDV is high in Germany and dominates the stock of goods transport vehicle. Both facts together are essential for reaching high market shares and for raising positive effects of commercial electric vehicles. As a result PC and LDV arise as promising vehicle categories for an electrification strategy of commercial transport. Together, they cover around 84% of all commercially owned vehicles in Germany [12].

As shown before, commercial transportation is responsible for an essential part of the total driven mileage in urban areas. For the future, it can be supposed that commercial transport demand will grow further in particular in urban areas. Reasons for the increase of the urban commercial transport are the promptness, the individualization and the flexibility of delivery, just-in-time transport, internationalization of the markets and the increase of electronic trade (cf. [13], [14]).

In a nutshell, electric mobility offers new opportunities, especially for urban road traffic. On the one hand, xEV can help to keep away local hazardous emissions from densely populated areas and hence to improve local air quality in urban areas. On the other hand, noise can be significantly reduced by xEV resulting in increased quality of life in cities. Quantifying the future contribution of xEV in commercial applications to national energy supply and CO_2 reduction strategies is focus of the scenario calculations presented in this paper and the applied modeling approach is described in the following chapter.

4. Energy system modelling

Economic and political strategies as well as the improvement of existing and the launch of new energy technologies compete in the energy system against the background of the political goals to reduce primary energy consumption as well as to protect the climate and environment. An integrated assessment according to technical, ecological and economic criteria is possible by applying a cross-linked energy systems model. Impacts on the generation, transport and distribution of electricity are expected as a consequence of an assumed market penetration of 6 million xEV in road transportation. Not only electricity demand will grow, but the daily demand profile will change, too. By shifting the final energy carriers portfolio from fossil transportation fuels to electricity, there will be effects in other sectors of the energy system. An isolated calculation of the electricity generation and the transport sector is not sufficient for the evaluation of cross-linked subsystems.

The energy systems model IKARUS considers the reduction of CO_2 emissions and the impacts on distribution and production structures. It maps the German energy system by cross-linked energy conversion and transport processes as well as final energy use within the demand sectors. Together with goals according to energy and environment policy, a cost-minimized primary energy and technology portfolio is identified. This portfolio allows the fulfillment of energy demand induced by services in the different sectors, for example transport of goods and passengers or industrial production.

The model follows a technology-based bottom-up approach. All technologies from primary energy exploitation over energy conversion to final end use are described by corresponding energy flows. For every five-year time period, a consistent dataset of all technologies is available. The dataset consists of capacities, efficiencies, costs, emissions and technical restrictions. It describes about 2,000 technologies, the demand for energy services and the import of primary energy source. A selection of already published studies supported by the energy system model IKARUS can be found in [15-18].

5. Results of Energy Scenarios

The reference scenario considers the current policy goals of the "Energiewende" and technical as well as economic assumptions of commercial xEV fleets. For technologies analyzed not in detail in this analysis, the technology dataset of the IKARUS model is used (cf. [15, 16]). A successful market launch and penetration of xEV in the private and commercial transport is assumed. The stock of electrified PC and LDV reaches 1 million vehicles in 2020 (share of total stock: 2.1 %) and 6 million (share of total stock: 12.1 %) in 2030. The charging power of the xEV fleet is modelled by an uncontrolled charging after the last trip of the day at private parking places and for commercial fleets after return to the company depot. The assumed charging strategy is a worst case scenario because controlled charging will decrease requirements of power generation and grid load by smoothing peaks over the day. Furthermore, additional emissions of the electricity generation for xEV can be decreased by controlled charging (cf. [5], [16]).

Two alternative scenarios are defined to calculate the difference in attainable effects. The first scenario "without xEV" quantifies the effects of other alternative fuels or drivetrains like CNG (compressed natural gas) with internal combustion engines or hydrogen in combination with FCEV (fuel cell electric vehicle). The second scenario "Business-as-Usual" (BAU) is used to represent the effects without any alternative fuel or drivetrain but conventional fossil fuels and internal combustion engines with trends for fuel consumption reduction. The objectives of the "Energiewende" not related to fuels and drivetrains are part of all three scenarios.

Fig. 2 shows the trend in final energy demand of the entire passenger and goods transport (including aviation, shipment, rail and road) for the reference scenario (on the left) and the scenario "without xEV" (on the right). For the reference scenario the consumption of fossil fuels (diesel, gasoline and kerosene) reaches 1,796 PJ in the year 2030. The share of the diesel fuels rises significantly to nearly 58 %. This is essentially connected to the strong increase of goods transport on roads. The assumed electrification and increase in vehicle efficiency cannot change this trend. The significant decrease in gasoline demand is induced by increased efficiency (reduction of new vehicle fleet consumption according to EU directive) and the assumed share of xEV (essentially substitute gasoline PC), mainly in private transport.

The electricity demand for transportation (including public urban rail transport as well as passenger and goods long-distance rail transport) increases from 2015 to 2030 by 105 % to approx. 31 TWh for the reference scenario. The share of xEV electricity demand in 2030 is 48 % of the total electricity demand of transportation (nearly 15 TWh). In spite of high increases, the share of electricity related to the entire energy demand in the transportation sector remains low with 5.4 % in 2030. The commercial transport with PC and LDV/ HDV has a share of approx. 36 % in the fuel demand in 2030. The share of urban commercial transport in the total fuel consumption is calculated to be over 18 % . For the assumed commercial xEV fleet (PC and LDV) 5.4 TWh electricity is needed. Thereof urban commercially used xEV have a consumption of 4.3 TWh in the year 2030. The reduction of fossil fuels in the reference scenario in comparison to the BAU scenario (essential substitute of diesel and gasoline vehicles) is approx. 2.2 million tons of gasoline and 0.9 million tons of diesel.

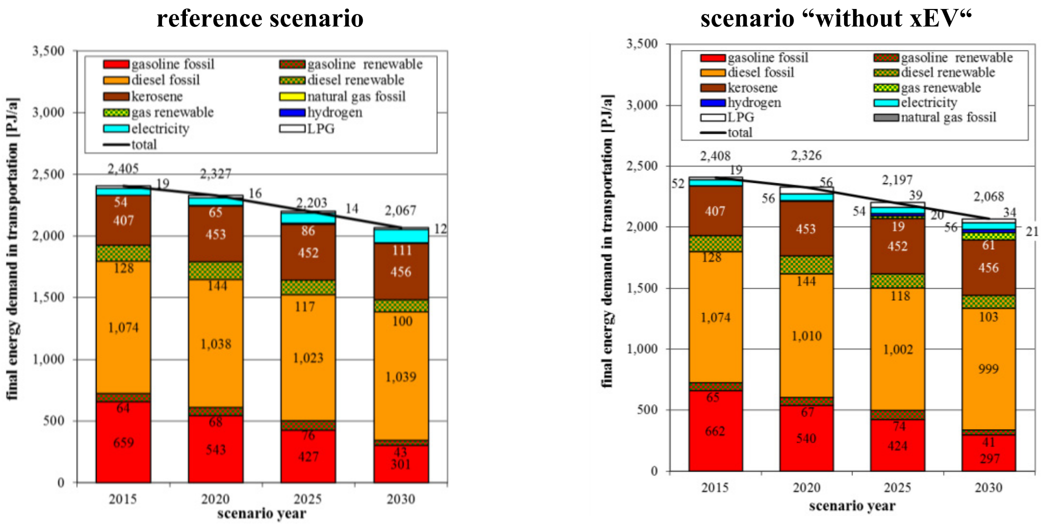

Fig. 2. Development of the final energy demand of passenger and goods transportation for Germany; left: reference scenario; right: scenario "without xEV"

In order to fulfil the goals for energy efficiency and CO_2 reduction in the transportation sector according to the German "Energiewende" in the scenario "w/o xEV", the model chooses the alternative fuels natural gas and hydrogen from renewable sources mainly for PC. Hence, the substitution of fossil fuels is in the same range than the reference scenario with xEV application.

The structure of electricity generation changes only slightly by the assumed xEV fleet. In the reference scenario a slight increase in electricity consumption takes place after 2025. The additional electricity demand by the xEV fleet is low (approx. 3% of the total net consumption of all sectors). The comparison with the scenario "without xEV" shows only a slight shift in the installed power plant capacities and electricity demand. The additional xEV electricity demand is generated by a slightly increased utilization mainly of natural gas power plants and by a 4 % higher installed capacity of wind generators.

Figure 3 shows the calculated trend of CO_2 emissions in the reference scenario. The German political goal of CO_2 reduction corresponds to interpolated 55 % until 2030 (in comparison to 1990). In the reference scenario the reduction is achieved essentially by the energy conversion sector. Power generation reduces CO_2 emissions by nearly 50 % and other energy conversion technologies e.g. refineries by 51 %. The CO_2 emissions of the transport sector decrease disproportionally low from 2015 to 2030 by only about 17 %. In spite of xEV and biofuels, transportation will already be the biggest emitter of CO_2 in the year 2020. The comparison to the "BAU" scenario reveals an emission reduction of xEV of just 6 million tons per year. The scenario "without xEV" (other alternative fuels and drivetrains renewable hydrogen and gas) comes to around 134 million tons per year and therefore to similar emissions for transportation. The share of the commercial road transport amounts to 43.8 % in the reference scenario in 2030 and the urban part to approx. 22 %. 3.2 million tons per year can be saved in commercial transport by the assumed xEV fleet (PC and LDV). The urban commercial xEV fleet saves thereof 2.9 million t of CO_2 per annum.

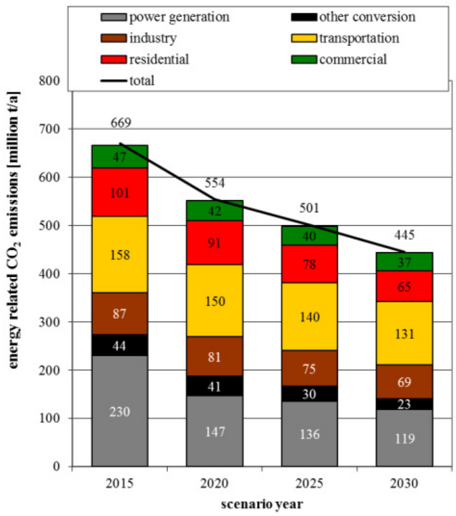

Fig. 3. Energy related CO_2 emissions in Germany, reference scenario

Under the assumptions of the reference scenario, the total system costs increase about 20.8 percentage points from 2010 to 2030. In the transportation sector, biofuels, efficiency improvements and xEV leads to an above-average cost increase of 25 percentage points. In comparison to the scenario "without xEV" (renewable hydrogen and gas), the reference scenario (xEV fleet in private and commercial transportation) shows lower system costs (about 1 %) in the year 2030.

6. Discussion of results

A comparison of the calculated fuel demand in the reference scenario to other German energy scenarios allows evaluating the results presented in this paper. For the final energy consumption of the entire transportation sector the study [19] calculates 2,219 PJ in their base case scenario. The general assumptions are close to the assumptions of the reference scenario presented here. The electricity demand for xEV is significantly lower (approx. 12 PJ), because the study assumes just 3 million xEV in 2030. In the scenario „current policy“ of the study [18] the authors calculate a value of 1,877 PJ for the fuel demand in 2030. The electricity demand for the entire transport is 77 PJ. Like in the other scenario study the stock of xEV is lower, too. The comparison to other recent and well cited scenario results shows the range of results which are essentially influenced by the assumptions of technology and their cost trends as well as assumed policy measures. Currently there is no detailed scenario study available for quantifying the effects and impacts of electrifying commercial transportation for Germany or other regions. This fact is mainly due to missing statistics of commercial transport and especially the focus to urban areas. The growth of urban transport and especially commercial fleets is one of the major problems of transportation and the negative impacts thereof will rise in future. The results of this analysis point out ways to overcome negative impacts on the environment, health and climate. Electrification is not the silver bullet to the problem, but can be one important step towards a sustainable transport.

7. Conclusions

The impacts of the assumed electrified commercial fleet on the energy system in Germany are not significant. The primary energy consumption is only reduced very slightly by the implementation of electric vehicles. The mix of final energy carriers in transportation is affected clearly and the use of mineral oil products is reduced by 8.4 % up to 2030. The additional electricity consumption of the electric vehicles requires no significant enlargement of the electricity generation, but a moderate increased utilization rate. The CO_2 emission reduction by electric vehicles is around 6 million tons of CO_2 per year in 2030 for the German case study. The assumed electrified commercial fleet in urban areas contributes with approximately 3 million tons of CO_2 to the reduction. The reduction depends on charging strategies and generation characteristics of wind and PV. Especially the policy goal of saving final energy in transportation (-40 % to 2050, German "Energiewende") turns out as an important driver for xEV application in road transport.

References

[1] Wikström M, Hansson L, Alvfors P. *Socio-technical experiences from electric vehicle utilization in commercial fleets*. Applied Energy. 2014;123:82-93.
[2] Van Duin JHR, Tavasszy LA, Quak HJ. *Towards E(lectric)-urban freight: First promising steps in the electric vehicle revolution*. European Transport - Trasporti Europei. 2013(54).
[3] GGEMO. *Die Schaufenster Elektromobilität stellen sich vor* Berlin Gemeinsame Geschäftsstele Elektromobilität der Bundesregierung; 2014. p. 11.
[4] Zhou B, Yao F, Littler T, Zhang H. *An electric vehicle dispatch module for demand-side energy participation*. Applied Energy. 2016;177:464-74.
[5] Hennings W, Mischinger S, Linßen J. *Utilization of excess wind power in electric vehicles*. Energy policy. 2013;62:139 - 44.
[6] Lund H, Kempton W. *Integration of renewable energy into the transport and electricity sectors through V2G*. Energy Policy. 2008;36(9):3578-87.
[7] Wermuth MJ. *Kraftfahrzeugverkehr in Deutschland 2010 (KID 2010) -Schlussbericht*. 2012.
[8] infas, Dlr. *Mobilität in Deutschland 2008. Ergebnisbericht*. Bonn und Berlin: infas Institut für angewandte Sozialwissenschaft GmbH und Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Verkehrsforschung; 2010.

[9] Kraftfahrtbundesamt. *FZ 13 - Bestand an Kraftfahrzeugen nach Umwelt-Merkmalen 1. Jnauar 2015*. 2016.
[10] Kraftfahrtbundesamt. *FZ 23 - Bestand an Kraftfahrzeugen und Kraftfahrzeuganhängern nach Haltern, Wirtschaftszweigen 1. Januar 2015*. 2016.
[11] Aichinger W. *Elektromobilität im städtischen Wirtschaftverkehr - Chancen und Handlungsspielräume in den Kommunen*. Bundesministerium für Verkehr und digitale Infrastruktur; 2014.
[12] Kraftfahrtbundesamt. *FZ 23 - Bestand an Kraftfahrzeugen und Kraftfahrzeuganhängern nach Haltern, Wirtschaftszweigen 1. Januar 2014*. 2014.
[13] Beckmann K. *Güter- und Wirtschaftsverkehr in Städten und Stadtregionen - Megatrends und Konsequenzen für handlungsstrategien und Handlungsansätze*. In: Urbanistik DIf, editor. Städtischer Wirtschaftsverkehr - International Conference 2012, Berlin: Wolf-Holger Arndt; 2013.
[14] Arndt W-H. *Entwicklung des städtischen Wirtschaftsverkehrs und Herausforderungen für die Stadtverkehrsplanung*. In: Urbanistik DIf, editor. Städtischer Wirtschaftsverkehr - Dokumentation der internationalen Konferenz 2012 in Berlin. Berlin: Wulf-Holger Arndt; 2013.
[15] Heinrichs H, Markewitz P. *A Coal Phase-out in Germany – Clean, Efficient and Affordable?* Energy procedia. 2015;75:2541 - 7.
[16] Linssen J, Bickert S, Hennings W, Schulz A, Marker S, Waldowski P, et al. *Netzintegration von Fahrzeugen mit elektrifizierten Antriebssystemen in bestehende und zukünftige Energieversorgungsstrukturen - Advances in Systems Analyses 1*. Jülich: Forschungszentrum Jülich GmbH; 2012.
[17] Martinsen D, Funk C, Linssen J. *Biomass for transportation fuels-A cost-effective option for the German energy supply?* Energy Policy. 2010;38(1):128-40.
[18] Matthes F, Busche J, Döring U, Emele L, Gores S, Harthan RO, et al. *Politikszenarien für den Klimaschutz VI* In: Umweltbundesamt, editor. Climate Change 04/2013. Berlin2013.
[19] Schlesinger M, Hofer P, Kemmler A, Kirchner A, Koziel S, Ley A, et al. *Entwicklung der Energiemärkte – Energiereferenzprognose* Bundesministerium für Wirtschaft und Technologie, Berlin 2014.

Biography

Mr. Linssen holds a diploma degree in automotive engineering of the RWTH Aachen University, Germany. His current position is senior scientist at the Institute of Energy and Climate Research - Systems Analysis and Technology Evaluation (STE) of the Forschungszentrum Juelich, Germany. Main field of research are new fuel strategies and corresponding infrastructures as well as energy storage options.