Brave New Mobility World?

No energy transition without transport transition

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Abstract

An energy transition cannot happen without a simultaneous transport transition. Society is open to decarbonising transport in Europe. The technical requirements are clear: expansion of renewable energies and digitisation. In Europe’s biggest cities, younger generations are making pragmatic transport choices. There is a lack of political parameters. Strategies for a successful entry into post-fossil fuel mobility are ambitious limits on CO₂ emissions, large-scale transport and parking space management with exceptions for shared zero-emission vehicles, as well as experiments smart grid trials in living lab situations.
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<tbody>
<tr>
<td>BEV</td>
<td>Battery-electric vehicle</td>
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<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
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<td>DB</td>
<td>Deutsche Bahn</td>
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<td>FCV</td>
<td>Fuel-cell vehicle</td>
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<td>H₂</td>
<td>Committee of the Regions</td>
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<td>km</td>
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<td>kg</td>
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<td>kWh</td>
<td>Kilowatt per hour</td>
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<td>NPE</td>
<td>Nationale Plattform Elektromobilität</td>
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<td>PT</td>
<td>Public transport</td>
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<td>PV</td>
<td>Photovoltiac</td>
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<td>R&amp;D</td>
<td>Research and development</td>
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<td>V2G</td>
<td>Vehicle to grid</td>
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<td>TWh</td>
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Executive Summary

Problem and solution

Transport is a problem for the climate. The response of the EU Commission’s white paper is a “decarbonisation of transport,” meaning that passenger and freight transport should require no fossil fuels at all. The basic cultural attitudes required to exit the era of conventional internal combustion engines is widespread in many parts of Europe. Awareness of the finite nature of fossil fuels and of their environment- and climate-damaging effects is growing all around the world. Meanwhile, the steep rise of renewable electricity production is revealing obvious alternatives and makes a post-fossil fuel energy supply seem possible. In addition, digital technologies allow for networking and approaches in transport that were previously unthinkable or only possible with high transaction costs.

Technological trends and drivers of transport transition

In principle, all the elements needed for the transition beyond fossil fuels are available. Digitisation and the expansion of renewable energies offer unprecedented opportunities, but the collective mental maps are still the old ones. We must focus on the entire energy market and develop an overall transformation of the sector. Further expansion of variable energy production from wind and sun is also promoting transport electrification. Both the energy and the transport sectors can benefit from a more intelligent organisation of transport that helps to stabilize the network and smooth out stochastic residual loads.

Intermodal services and changing political parameters

The “transformation of transport” goes far beyond changing drive systems and fuel types. In practice, transport will become increasingly multimodal, with different modes of transport working together to form one useful service. The result is “smart networking” of transport and energy systems within decentralised networks that vary significantly between the city and the countryside. In the major cities and the capitals of Europe, the younger generations are leading a shift to an increasingly convergent intermodal style of mobility. In this new style, pragmatic choices for transport options dominate. In all of the variations, new actors like “prosumers” who both “produce” and consume energy and innovative service providers play a key role.

This “new post-fossil fuel world of transport” did not just fall out of the sky. Key strategies to achieve post-fossil fuel mobility are 1) ambitious limits on CO₂ emissions, 2) transport and parking space management, and 3) widespread real-world experimental trials. The potential of technology can only be reached by altering society’s legal parameters by creating new long-term business prospects.
1. Problem background and solution perspectives

The energy transition and climate protection can only be successful if accompanied by a transport transition. The challenges for the transport transition are clearly described in the European Commission white paper from 2011: By 2050 at the latest, greenhouse gas emissions in transport must be reduced by at least 60 percent as compared to 1990 levels. As early as 2020, transport-related CO2 emissions should be reduced by 20 percent as compared to 2008 (EU Commission 2011). For the future passenger transport market, achieving these reductions means networked and emission-free transport services within growing cities and also a network of long-distance transport via trains and buses. For the future freight transport market, this target means drastic efficiency advances achieved by shifting long-distance transport to rail and waterways. It also means assigning short-distance transport to logistics companies that use low-emission vehicles efficiently.

But the reality looks totally different than what it needs to be in order to achieve these targets: In addition to dependence on petrol, the congestion of transport infrastructures, and the devaluation of public urban space, emissions also pose major problems for transport. Greenhouse gas emissions have continued to rise despite major efficiency achievements in drivetrains over the last decades. The rebound effect, i.e. the phenomenon that improving energy efficiency may save less energy than expected due to a rebound of energy use, has offset any fuel savings in either passenger or freight transport.

The personal vehicle still has the lion’s share of the passenger market, as indicated by the modal split. In Germany and in most EU countries, motorised individual transport accounts for more than 80 percent person km travelled. The remaining 20 percent are divided among more environmentally sound means of transport such as buses, trains and bicycles. The private automobile has long been considered a marker of prosperity and the good life in many parts of the world. Meanwhile, however, an increasing number of people believe that too many vehicles are neither practical nor desirable in terms of environmental and climate-change policy. Merely changing drivetrain and fuel types will not reach the emissions targets. Services have to be created that will provide mobility without increasing the number of vehicles on the roads. Electric drive concepts are the key technology to do so. E-vehicles can operate in a climate-neutral way and, because their range is likely to remain limited, they also provide opportunities for networking with other transport modes.

This intermodal e-mobility is currently a future fantasy and has only been observed in a few pilot studies. Nonetheless, existing social and technological trends support its implementation and fruition. In some major cities, it has been possible for some years now to observe how modern mobility could work. “Urbanites” or the “metro mobile” population use all available means of transport and combine these modes based on pragmatic considerations. Possession of a transport mode is no longer the decisive factor; rather, it is much more important that modes be flexible and very easy to use. In various major European cities, including Berlin, Hamburg, Vienna, Zurich, London, Paris and Copenhagen, the “metro mobile” extend through all layers of society. The decisive condition for such multimodal transport practices is a selection of very high quality transport services, including public trains, buses, cars, and bicycles offered on as shared mobility services. Only in places where the use-quality is high can the “use-rather-than-own” model be a successful formula (cf. Rode et al. 2014). The attractiveness of the service depends not only on its availability but also on a user’s ability to use it directly and immediately. This requires uniform information design and
access mediums as well as appropriate disposition of modes of transport and payment systems. Connections between various urban and peri-urban agglomeration over longer distances must also be secured. This is an additional module for future integrated mobility. Initial empirical results from e-car-sharing pilot studies confirm the importance of the users’ connections (cf. Ruhort et al. 2014). The mass distribution of digital media, for example in the form of smartphones, enables comfortable use of information, access, and billing services. Existing legislation and regulations, however, are still designed to prioritize public transport services and licensed taxis. The virtually Europe-wide ban on the California-based service Uber illustrates this situation very clearly.

There is increasing support, however, for bringing various means of transport into one single service. Many urbanites already use several different modes and move in multimodal ways through the city. Digital networking may easily bring the different modes together, allowing for completely new efficiency benefits. The smartphone already acts as the master key for a well-developed network of buses and trains with direct access to long-distance transport modes. Portals and digital platforms, such as those already available for hotels, hostels and renting private apartments, will also be relevant to the world of transport. Platforms like Uber, Wundercar, or BlaBlaCar are thus just the beginning. The automotive group Daimler, for example, is offering its Moovel service for shared mobility and is thereby reinventing itself digitally.

The Deutsche Bahn is creating an info platform called Qixxit to offer digital booking and billing services. In the end, customers will be able to know all of the available options with full cost-transparency. They will check in for a travel service in the morning and check out at night (cf. Knie 2014). The choice of a transport mode at any given moment depends on availability, reason, personal preferences, and of course the price. Currently, however, transport modes and their corresponding business models are handled separately and organised in a public space that still privileges private vehicles. Even in cities, transport services have mostly been designed around the needs of the passenger car, although this trend is ebbing. This is because, inter alia, it has been convenient to own a private automobile even in the public spaces of cities. Public transport providers, have concentrated on their customers who do not own a private vehicle, whether that non-ownership is voluntary or involuntary, permanent or temporary. The notion of easily switching among services, which has made new mobile services so successful in recent years, remained foreign to the transport market for many years. The idea of making other transport services available to one’s own customers and accepting competitors’ customers as anonymous users was unfathomable.
2. **New Technological trends in the transport sector**

2.1 **New drive systems and fuels**

The CO\textsubscript{2} emissions of transport modes differ; the mix of modes chosen determines one’s personal carbon footprint. The average emissions values depend on the occupancy levels, as shown in the following overview based on realistic levels of occupancy for Germany.

![Figure 1: CO\textsubscript{2} emissions of different modes of transport in Germany](image)

Source: Canzler, Knie 2015: 19

This overview is incomplete, however. In the interest of climate protection, walking and bicycling should be encouraged. This is already the case for bicycling in any city dedicated to modern sustainable urban development. Whether in Copenhagen, Milan, Munich, London or New York, traffic planners in large metropolises all agree: bicycling should go through a new renaissance and become an important urban transport mode (again). In order to encourage this, cities are investing in bike paths, bike parking, and bike rental systems (cf. Gehl 2010).

Nonetheless, even the most bicycle-friendly city needs motorised public and also private transport. Technological innovations, such as electrification based on renewable energy sources and the substitution of fossil fuels with biogenic ones, are making it possible to push motorised transport toward zero emissions. There has long been research into technological alternatives, but the future of post-fossil fuel mobility is not merely a technological issue. Furthermore, it can be difficult to assess what is technologically possible; one-sided interpretations within highly specialised professional circles are often in favour of technological optimisations that may be theoretically possible and of innovations with hardly calculable potential. In the face of uncertainty, it is helpful to
gain an overview of what types of drive technologies and fuels are available and what perspectives are associated with them. Therefore, the following is a rough evaluation of conventional drive technologies, fuels from renewable sources, and the various kinds of e-mobility. This overview accounts for the CO₂ emissions from passenger cars.

![CO₂ emissions graph](image)

### 2.2 Conventional technologies

Many of the research and development expenses in the automotive industry are still set aside for optimising conventional drive technology. Such R&D focuses on the reduction of consumption and on minimising pollutant emissions, resulting in some trade-offs. However, improved fuels mostly address these trade-offs. The industry assumes it can achieve a CO₂ savings potential of 25 to 30 percent with internal combustion engines. Additionally, chassis construction is addressed again and again. Using lighter materials helps to reverse the tendency of vehicles to get heavier.

Since the automotive industry sees the internal combustion engine as the proven drive unit, its further development lies at the heart of all of their efforts to lower fuel consumption and emissions per kilometre (cf. Schade et al. 2012: 97 et seq.). This entails direct injection to variable valve timing and reducing both inner-motor mass and the friction alongside downsizing and turbocharging. Additionally, work is being done on temporary cylinder deactivation and improving start-stop systems. In recent years, R&D projects have achieved efficiency gains for petrol engines by implementing these technologies. The gains have even reduced the diesel engine’s consumption advantage. Hybrid versions are likely to result in further efficiency improvements (cf. JRC 2014).
However, the savings success achieved so far with the improved drive units and as a result of lightweight design are limited. These improvements are largely offset by widespread motor upgrades due to model improvement with heavier equipment for extra features and also a shift toward SUVs in the established markets. In addition, actual day-to-day consumption levels and consumption results from certified fuel consumption tests diverge, sometimes by a wide margin (cf. ICCT 2014).

Additional efficiency gains with the internal combustion engine technology can only be achieved with considerable effort. Although the technology has matured over more than one hundred years, it is inherently at a disadvantage to electric mobility in terms of overall efficiency. The internal combustion engine has an overall efficiency of only 19 percent while direct conversion of electrical energy takes advantage of 70 percent of its (potentially renewable) primary energy. Even fuel cells have an overall efficiency of 26 percent (cf. Canzler, Knie 2015: 21).

For a time, the automotive industry had high hopes for biogenic liquid fuels. So-called biofuels have an energy density approximating that of fossil petrol and diesel fuels. They can also be stored and used in existing refuelling facilities. For these reasons, biofuels seemed to be the way out of the fossil fuels impasse for many years. Through the mixing of fuels, the proportion of conventional fuels was supposed to successively decrease. But hopes have so far gone unfulfilled. The EU’s planning provisions call for the proportion of biofuels to be a maximum of 7 percent by 2020.

2.3 The challenge of public transport

Public transport (PT), and particularly the railways, represents the primary alternative to private individual transport under certain circumstances. PT is not only more space efficient, but depending on the level of occupancy, it may be significantly more energy efficient than the car. When used well, PT is far superior in the environmental balance for the current energy mix. In addition, the railway has a great deal to gain from switching to renewable sources for its power needs. This is the only way it can reduce specific CO2 emissions per kilometre travelled and meet climate policy expectations. In Switzerland and Austria, the share of renewables for railway power is almost at 100 percent. Even in Germany, the proportion increased throughout the entire rail transport system to over 40 percent by the end of 2014. By 2050 – according to the aims of the DB AG – all of the transport company’s transport rail lines in Germany shall be completely CO2 neutral.

Whether and to what extent PT can fulfil its transport and environmental benefits and encourage modal shifts also strongly depends on increased attractiveness and the “intermodal fit”. Given the importance of automobiles today, it is unlikely that people will again – as in the 1920s and 1930s – travel both locally and long-distance only with rail-based transport. Therefore, researchers and transit agencies are exploring service forms to develop modern rail transport into the backbone of an intermodal service offering. This can be done in various ways. In addition to increased infrastructure investment, taxes and levies can also reduce the burden of PT with taxes and levies. Most crucial, however, is the degree to which new transport services improve the potential efficiency of PT. These new services must drastically increase the market share and passenger volumes of PT. In addition to changing financial structures, a new competition for new business models is necessary to stimulate the innovative potential of the transport industry. Transport companies must also have further opportunities to open up, become more entrepreneurial, and operate independently on product development (Projektgruppe Mobilität 2004).
2.4 Digitisation

Digitisation in transport changes a great deal. Because users and devices are in constant communication, availability, prices, and access can be queried and compared from practically any location. Through the mass distribution of smartphones, large majority of the population has direct access to a gigantic vehicle fleet and can “personalise” it at any time. British transport researcher Glenn Lyons hits the mark when he speaks of “transport’s digital age transition” (Lyons 2015).

The car, as a technological device, is feeling the effects of digitisation. This is not only because the “connected car” is increasingly linked with other vehicles and infrastructure, but because its character is also changing. With the high distribution of smart phones and the growing array of transport bundlers, a vehicle’s attractiveness is increasingly disconnected from its physical properties and is instead defined by its availability in digital media. Ease of app use and which means of transport are present is decisive factors in the actual use.

The brands of these “devices” are becoming less important in view of the diversity of services and their ubiquitous access and use. In this constellation, public services could gain new appeal if their offers appear as attractive options in the digital realm. Vehicles must also continue to operate reliably – an app alone cannot take anyone from A to B. However, a vehicle’s mere availability no longer determines the success of its use. The vehicles’ presence in the users’ minds is crucial. In market terms, a “digital fog” is laid over the devices because the communication factor changes a “device manager” into a digital provider. Customer communication, and therefore customer loyalty, occur in the digitally networked world. Whoever obtains, keeps, and maintains the customer contact will determine the conditions for use over the medium and long term.

For the time being, this only applies to the metro mobile population. This market is likely to continue to grow and, hence, have a major impact on the value chain, which can already be seen in other industries. Department stores are being replaced by digital shipping platforms. The company Zalando went from being operated out of a garage to making more revenue than the Karstadt group. It is also no coincidence that the hardware group Nokia was purchased and quickly dismantled by the software producer Microsoft. The devices seem to really fall into the digital network and companies behind them are also threatened with disappearance. At least, the capital markets are convinced that digital platforms like Uber are more important than the device itself in both the short and the long run. Whoever relies on analogue, linear, and monomodal devices and distribution channels is at a disadvantage in the consumer goods industries during the age of the “digital kids”. The California giants of Facebook, Google and Twitter have successfully digitized social relations and have drawn the attention of billions of people worldwide who want to be involved.

The appearance of Uber shows how quickly seemingly stable orders of competition can be shaken up. One can create a digital community from practically anywhere in the world and downgrade traditional equipment providers to mere suppliers in a matter of seconds. This shakeup only requires a good idea that provides great customer benefit immediately and directly. These approaches are even supported by fair motives: What is negative about improving the use of transport capacities? If people have time and the desire for community and also have a car, why shouldn’t they become transporters? Legal restrictions, procedural and insurance restrictions, and rules that have developed
around the public transport sector to-date most likely cannot permanently hold back this “digital revolution”.

3. Renewable energy as a driver for the transport transition

Parallel to digitisation, renewable energies are expanding in Europe. American futurologist Jeremy Rifkin sees strong drivers for the emergence of a “zero marginal cost society” in these two parallel trends (Rifkin 2014). In view of declining renewable electricity production costs, we can expect rapid expansion of wind and photovoltaic systems in particular. Photovoltaics face obvious cost reductions at the same time as conventional energy technologies (especially coal-fired power generation and gas turbines) face higher production costs (cf. IEA 2014, Fraunhofer ISE 2015).

Most projections regarding the further expansion of renewables expect a significant increase in production capacity. Given this likely expansion of fluctuating wind and solar energy, the need for flexible options is growing immensely. In combination with various storage types, demand side management (DSM) is fundamentally suitable for feeding renewable energy into the power grid. It is also well suited for connecting conventional power plants (or combined heat and power [CHP]) to partially compensate for asynchronicities and to reduce the gap between supply and demand. At the same time, new options are emerging to use excess power and thus to attenuate the so-called negative residual load. The impact of stationary batteries and battery-powered electric vehicles on the attenuation of negative residual loads depends not only on their size, usable capacity, and network capability, but also if companies manage to establish viable business models.

In the current cost comparisons between the various flexibility options, construction of transmission networks usually appears to be the least expensive type. The two transport-relevant storage options of battery storage and power-to-gas are more expensive for load management, flexible use of biogas and CHP plants, and the use of electricity for the heating sector. Implementing these two types of storage options is expected to occur quite late – by the late 2020s (cf. DEFINE 2014). Meanwhile, however, batteries are showing drastic cost reductions. In particular, cost reduction is possible due to to large-scale production of batteries by Tesla and Panasonic starting in 2017; this production is expected to lead to battery costs below 200 euros per kilowatt. After 2030, battery costs are expected to drop by half to under 100 E/kWh (see fig. 3). This can result in lower vehicle prices and decreased costs for battery storage as a buffer for fluctuating renewable energies.
Local surpluses and occasional network congestion can mean that the question of whether to “switch off or save” must be answered much earlier and in more individual cases. Considering only national averages offers little help to individual regions with high renewable energy production and/or limited network access. In those areas, the pressure will rise to experiment with new flexible loads in cross-sector smart grid solutions (cf. Canzler, Knie 2013).

In addition, even small batteries at the distribution network level can compensate for short-term fluctuations. Electric cars attached to the network act as potential buffers when they are set to controlled charging mode. Quicker compensation is necessary at low voltage levels if several fluctuating feeders are connected. But how realistic is this idea of power stabilisation via e-vehicles in the “vehicle-to-grid” (V2G) concept? Time-delayed charging within a defined period has been tested successfully in e-mobility projects. In these tests, electricity feeders are given a useful amount of leeway; this occurs by setting the overnight charge so that the electric car’s battery is fully charged by 7:00 in the morning even though the vehicle is already connected to the electrical outlet by 21:00 the evening before. For ten hours the energy supply company can perform a controlled charge to stabilise its own network and avoid losing its oversupply of energy (due to the night time demand valley). Long-term tests of electric cars linked to PV systems, which gather a portion of their electricity needs directly from the solar modules, further show reduced operating costs and reduced network load at the midday peak. In the next step, the flexibility increases through bidirectional loading, which can even allow recovery from the battery when needed as well. To date, bidirectional charging has been available only for a few models.

Figure 3: Development of battery prices
Source: Canzler, Knie 2015: 30
It is still an open question whether and to what extent private users are willing to give up control of their vehicles beyond the overnight charge. For example, they may be able to extend the potential charge time in return for discounted electricity rates. A potential target group for controlled charging could be commuters, who would connect their vehicles to the network at the business car park in order to contribute to PV midday peak absorption. Further opportunities are open to professional fleet operators: both time-delayed buffering and above all bidirectional V2G are realistic prospects especially for fleets. This is true because fleets can ensure foresighted load management more easily and fulfil obligations to do so to a much greater degree than individual private users can. Fleet managers are already trained for optimal deployment of their available vehicles. Controlled charging of e-vehicles is simply an additional fleet parameter in their logistic core business.

Under the formulas for “power-to-heat” and “power-to-mobility”, electricity providers are already taking future business areas into consideration based on stronger sector coupling. Whether this can be achieved depends on economic and regulatory conditions and especially on the transaction costs of complex network stabilisation. In large numbers as part of fleets, e-vehicles can be integrated completely or partially into smart grids. These fleets will initially be primarily battery-electric and in the medium and long term will have a rising share of fuel-cell vehicles. Their role then shifts from storage components to integral parts of the complex load management system.

4. Economic conditions for the transformation of transport

How much additional power is required for more electric mobility? Let’s look at the example of Germany: For the target of 1 million electric vehicles by 2020, the national platform for electric mobility (Nationale Plattform Elektromobilität, or NPE) expects increased consumption of 0.6 percent (cf. NPE 2012). For an assumed 47 percent per year from renewables, that would mean an additional approximately 1.4 percent of electricity from renewable sources. With a hypothetical 10 million e-vehicles in 2030, the required electricity production from renewables would extrapolate to 20 TWh (cf. AEE 2014: 37). The possible effects of controlled charging for fleets or even further load management via V2G approaches have not been taken into account.

V2G models will only really become interesting with greater distribution of electric vehicles and especially with widespread implementation of power-to-gas facilities. In this scenario, battery-electric vehicles (BEVs) will no longer count merely toward consumption but instead will be loads that may be switched on and off. The vehicles would get a large part of the energy necessary for the driving via their contribution to smoothing out the residual load curve. A simplified example calculation would look like this: Assume 8 million BEVs and 2 million fuel-cell vehicles (FCVs) are on the road in 2030. They have 20 KW drives on average and about half of them are operated in professional vehicle fleets. That means 4 million BEVs are available to smart grids as potential network-friendly elements and 1 million FCVs can be supplied with green hydrogen. Both vehicle segments differ fundamentally in their functions as storage: BEVs are direct network components, while FCVs consume chemically-cached excess electricity. In this respect, they are complementary. Roughly estimated, we can assume the following:
Twenty-five percent of the 4 million BEVs are available to the network with at least 50 percent of their battery capacity (10 KW) on average. Their maximum buffer capacity is then 5 TWh. Thus load shifts within this maximum are possible, in principle.

One million FCVs with an average of 5 kilograms of hydrogen per refill, which allows for 500 kilometres of travel, yields 20,000 kilometres and a total volume of 200 million kilograms per year, which corresponds to 6.7 TWh of electricity. With 50 percent conversion loss, 13.4 TWh of surplus renewable electricity are necessary to fuel 1 million FCV with green hydrogen.

This rough calculation should be seen against the backdrop of the energy surpluses to be expected by 2030. According to estimates from the BET study on the whole an electricity surplus of 34.5 TWh is to be expected in Germany, which corresponds to 7.7 percent of renewable production (Krizikalla et al. 2013: 20). Therefore, renewable energy volumes are available for the altogether optimistic distribution of electro-mobility by 2030, even if a portion of the volumes will probably go toward heat pumps and other power-to-heat applications. The next issue to consider is that the negative residual load periods can be irregular. Furthermore the time periods in which they occur can be contiguous with surplus production for so long that the battery capacity is quickly exhausted. Future business models of networked mobility will have to cope with this stochastic residual curve of load and balance ratio of potential storage time and actual mobility applications.

Power-to-gas, which is still in its infancy, is another option to use surplus renewable electricity. In addition to biomethane, hydrogen is also a chemical storage option. Both biomethane and hydrogen can be fed into the existing gas network in substantial quantities. The electrolysis process for the production of hydrogen and renewable methane is sufficiently mature, but still too expensive because of a lack of economies of scale.

Hydrogen has been used mainly in stationary applications. An estimate of the future costs of producing hydrogen from excess energy has revealed that vehicles are the most viable option (Albrecht et al. 2013: 11). There have been many experiences made with e-vehicle prototypes that gain their energy from the chemical transformation of hydrogen into fuel over the years. Daimler AG has developed several generations of fuel-cell models based on their B-class vehicles. The first mass-production vehicle with fuel-cells, Toyota’s Mirai, is available since the end of 2015. Huyndai will also bring a fuel-cell model to the European market in the course of the year 2016.
Based on the empirical data from Daimler’s fuel-cell B-class and also from estimated future volumes of hydrogen available for sale in the various hydrogen scenarios, the hydrogen-based e-mobility potential by 2030 will be as follows:

| Average consumption of a Mercedes B-class FCV according to the New European Driving Cycle (NEDC) | 0.97 | kg H2/100 km | (= 32.3 kWh chem. energy at 700 bar) |
| Assumed drive performance | 15,000 | km/a |
| German Hy H2 production (August 2009) (scenario: climate protection) | 2020 | 2030 |
| | 3.3 TWh/a | 37.5 TWh/a |
| Amount of H2 available for the transport sector | 50% |
| Number of vehicles that can be powered on H2 | 343,646 | 3,866,018 |

Figure 4: Potential of hydrogen-based e-mobility by 2030  
Source: Canzler, Knie 2015: 34

One difficulty for the distribution of hydrogen and fuel-cell technologies in the transport sector is that these require their own refueling infrastructure. The storage and refueling of hydrogen is technically complex and expensive. Significant investments are necessary to solve the “chicken or the egg problem” in implementing these innovative technologies.

Neither increasing electrification of transport-based accumulators nor fuel cells’ growing market penetration means that biofuels are superfluous. In the longer term, they will be needed where electric drive technology is not enough. This is especially true for heavy transport by road or water, where hybrid drive systems with proportionally large combustion engines are expected in the next wave of innovation. For these, successively greater amounts of biogenic fuel will be required. In the future of air transport, biofuels may also see greater use.

According to current knowledge, it is assumed that the passenger car and the light-to-medium commercial vehicles segment will be electrified to a great extent by 2030. In both segments, the range of attractive vehicles on the market is growing. At the same time, costs are dropping, especially for the expensive storage units, thereby creating a secondary market. An increase in the use of electric vehicles is expected in urban transport as well. Delivery service vehicles typically have a daily range of 100 to 120 kilometres. In most cases, this is possible with a BEV without the need for a midday charge. Mass production in the heavy freight and bus segment is unlikely to be commercially and technically viable by 2030. Thus, there is actually no alternative to an additional
shift to rail transport. However, due to the “goods structure effect,” the quantities of goods are becoming “smaller, finer, [and] more diverse” and are thus less suitable for rail transport (Canzler, Knie 2011). For the post-fossil fuel future, therefore, it can be assumed that a proportion of freight transport and buses will have to reduce CO₂ emissions drastically with renewables. Various technological concepts are still only in the test phase. Projects with hydrogen buses and pilot studies on inductive charging for e-buses at stops have already been initiated. Even the idea of overhead cables to power freight vehicles on motorways is amongst the future options (Hacker et al. 2014: 39).

In aviation, bio jet fuel is currently the favourite as a substitute for fossil jet fuel. However, the worldwide production capacities of eligible bio jet fuel accounts for little more than a fraction of the jet fuel consumed annually. Therefore both road freight and air traffic, two important and growing trends in transport, are to remain largely out of the innovations picture in the foreseeable future. As a result, there will be far-reaching consequences. One such consequence is that the limited production of biogenic fuels must be reserved for these two applications. Bio-fuels are most likely the only post-fossil fuel option for the heavy freight and air transport of people and high-quality goods in the long run. Therefore, the pressure is rising to progress green electric mobility for individuals and shift biofuel consumption away from individual use to the transport sector.

5. Changing patterns of mobility and intermodal services

5.1 Shifts in value preferences

Although growth rates of the automobile market in Europe have remained stagnant for several years, the global success of the automobile has not slowed. There is a trend of “motorisation catch up” that is spreading through the BRIC countries – especially in China. These countries are closely copying trends and developments that have already occurred in the United States and Europe. One can assume that changes in behaviours in the United States or Europe, documented in various forms of applied intermodal practices, will in turn affect worldwide transport behaviours (Canzler, Knie 2011).

How are the attitudes and behavioural patterns in the early-motorised European countries changing? For some years now, these countries have been seeing a shift. This has been described with the term “peak car” and is paradoxically one of the consequences of the automobile’s success (Dennis, Urry 2009; Millard-Ball, Schipper 2011). The “more-of-the-same” phenomenon has led to saturation. The automobile is no longer a scarcity good; it is available virtually anywhere and at any time for almost everyone. Thus, a trend amongst young people has been evident for more than 10 years and suggests a slow “secularisation” of the automobile (see ifmo 2013). Individuals acquire driver’s licences much later in life, ever fewer people decide to buy or lease vehicles, and cars have lost their status symbol for many. On the other hand, significantly more people are using public transport, especially in the age group between 20 and 30. Finally, bicycle traffic has increased in many places as well. In Berlin, for example, the number of bicycles in the city centre has more than doubled in the last 10 years. In combination with these trends, car sharing has moved beyond a niche trend and become a visibly active transport practice. At the end of 2014, an estimated +1 million customers of different providers were registered in Germany (cf. BCS 2014).
5.2 The vision of the CO₂-free transport: Hub and spoke

A vision is emerging: All means of transport in cities are to be electric and operated on a completely renewable energy basis. Private availability is generally unnecessary. Mobility options are plentiful and shared forms of use are more attractive than owning cars. The number of taxis, self-driven rental vehicles, limousine services, and private car sharing or commercial providers has multiplied under these conditions. Since each means of transport has a digital signature, transport systems can be operated much more efficiently. In light traffic conditions, individual transport will have the priority, while high occupancy vehicles will be given right of way in congested traffic. All battery-electric vehicles are part of the storage landscape at all times. In this world without significant private vehicle ownership, long-distance rail services gain new meaning. Train stations may become intermodal hubs and enable comfortable travel on long-distance rail transport without having to look and pay for parking, check departure times, buy tickets. If all this could occur seamlessly, train travel would become comfortable. This is especially true when complementary infrastructures await in the other city at the end of the trip.

A traveller will simply disembark from the train, choose the best transport means for his next journey segment, get in, and drive off. “Broken up transport” with differing system landscapes and payment forms is unheard of within new digital portals. In the same way that one navigates the Internet via a browser, new services synthesize the various devices and equipment into one continuous journey.

In rural areas or in the peri-urban areas, such density of transport equipment is easily achieved. Changes in transport practice here will be propelled by other social phenomena, especially the desire for decentralized private networks. The main actor in these areas are civilians, who take charge of their entry into their own power generation and slip into the role of “prosumers.” In the prosumer role, the producer also is the consumer of the service (cf. Toffler 1980). If electric vehicles become part of the storage landscape in decentralised production communities a, other forms of vehicular management come into focus, especially that of storage on wheels. A vehicle could be thought of as part of a doubly intelligent fleet: On the one hand it is part of a decentralised network structure. On the other, it is integrated into a fleet programme, so as to be a spoke that connects to a hub.

This new world of transport in the countryside will be driven by the decentralized electricity production. A number of technologies and services are ripe for network stabilisation. New consumption and storage partnerships emerge via a link to other fields of consumption like transport. Battery-electric vehicles can be charged when excess wind or solar power is available. Bidirectional charging has still only been tried in small experiments but has enormous potential; in this charging system, e-vehicles function as mobile energy storage during peak loads and can transfer energy from the battery back into the grid when necessary. Large fleets of several hundred vehicles could ensure adequate quantities of electricity. Excess wind and solar power can be used for electrolysis to produce hydrogen and thus supply fuel-cell vehicles, whose numbers are also expected to grow significantly in the next few years. As a result, traffic can also contribute to solving the problem posed by the energy turnaround. All of the components are in place, but a gesamtkunstwerk in the form of a “smart power grid” does not yet exist (Canzler, Knie 2013).
The key is that the future is not primarily about making revenue from energy production but rather from energy services. A service landscape emerges of “energy suppliers” who ensure supply and sell access to end customers. For the energy customers, this means that he or she acquires availability rights and pays varying prices at different times for the usage rights. The trade of access to energy can then become an important new pillar of the electricity exchange, and new business models like “power insurance companies” would become possible.

Electricity trading will become primarily an insurance business in which supply rights are traded in the form of novel energy certificates. For the entire energy supply, private use and decentralised insular solutions will play an important role; however, they will probably only lead to self-sufficiency in exceptional cases. This is because even local smart grids will be dependent on parent grids, despite increasing numbers of prosumers, and they will also have to add their contributions to common load commitments. Generally, prosumers will be still linked to the power grid, even if only as a (rarely used) fallback option. This is a service for which consumers will nevertheless have to pay – not least because otherwise the solidarity network will continue to thin out. Fundamentally, these decentralised structures can only be conceived as complimentary components of the existing network hierarchy. The more these small-scale coverage areas can demonstrate their balancing and load relief effects, the more quickly decentralisation will be inserted into the current organisational/regulatory structure.

Future energy supply will be decentralised and complex system that is home to a variety of actors. The necessary storage must be able to compensate for short-term fluctuations in the production of energy, as well as for daytime and seasonal differences. The range of fluctuation is enormous. It ranges from the local second- and minute-long gaps in the low voltage range, caused (for example) by a cloud passing over several solar systems, to the sunlight and darkness of daytime/night time differences and the occasional bleak winter weeks, when cloudy weather neither lets sunlight through nor allows a breath of wind. Furthermore, heat demand is greatest in the cold and sunlight-poor months.

No storage technology is suitable for all requirements. The appeal of a decentralised power grid reveals itself with more wind and PV systems. These types of systems increase the efficiency of the overall system, allow new business models (sometimes through local demand side management), and offer on-site added value. Energy cost management for companies carried out by contracting energy suppliers will be another model for new services. However, in order for that to happen, the rivals for use rights and their different energy requirements have to be balanced and their opposing claims settled. This is especially true for vehicles. The fleet model is the operation model for e-vehicles as components of decentralised grids that makes the most sense. The first study results are in, and principle feasibility has been shown (cf. Scherf et al. 2013). The potential exists for drivable storage to be a central building block of such a system. The keystone is planning and controlling linkage to the grid based on short-, medium-, and long-term energy needs forecasting.

In urban and peri-urban areas, the intermodal services can fulfil most transport needs, but the car remains dominant in rural areas. However, even here, transport services can be powered by renewables. The majority of all commercial and private trips can already be undertaken with low emissions thanks to biogenic fuels. In the future, decentralized power generation will be also be a
driver for mobility in the countryside because prices for PV systems will likely continue to fall and need for storage capacity will increase.

Even in rural areas, battery-powered electric cars and electrically assisted bikes are sufficient for the majority of all trips. For longer trips, a concept that is already well known in aviation applies: “the hub-and-spoke concept”. In sparsely populated regions, a community will manage a decentralised car fleet which is available for booked and spontaneous trips with little administrative effort for any occasion. Gone are the days when households in the countryside need at least one vehicle for every adult. The spoke vehicles will also serve as feeders to the next hub, which itself provides a transition to buses and rail. The hubs are connected by speedy rail links to one another. The transition from car to train is easy here too, analogous to urban hubs: simply park, plug in the vehicle, and get on the train. Passenger cars and larger vehicles for car-pooling will be parked at the hubs. While parked, their battery capacities stand ready as energy system buffers. Technologies for scheduling and distributing of electric cars make it possible to integrate driving, storing, and bidirectional charging into a modern load management system.

5.3 Agents of transformation

The actors of the transport transition and energy turnaround need security for future planning. In addition to the investment from individuals and energy cooperatives, a range of new business perspectives have to be created for established companies as well. Several candidates could benefit from the new opportunities:

- **Automobile manufacturers**: If instead of only consuming energy, electric vehicles also become part of the storage landscape, new applications will be required. Manufacturers now also offer charging infrastructure for their vehicles and energy contracts with cooperating partners. With the purchase of a new battery-operated or plug-in hybrid vehicle, why not switch the entire housing complex or suburb over to renewables? Installing a power grid landscape is a complex technical affair, and thus new business fields could open up for automakers.

- **Railway companies**: Railway companies not only own their rail networks but are often energy suppliers as well. They operate storage facilities for rail vehicles and medium voltage networks to supply train stations. Any station could be retooled into a mini smart grid. Since the rail operators own huge tracts of unused land especially in rural areas, installing small wind farms and PV facilities around train stations could be the ideal beginning for the revival of small villages and towns. From a transport perspective, the idea of the station as a “multimodal arena” could become a reality. To use power generated by these stations, attractive participation formats must be developed by the companies who run the stations. Nationwide corporate structures offer favourable infrastructure prerequisites for developing rural or small-town participation. Thanks to a great deal of experience with electric traction in light and long-distance rail transport, further impetus for expansion of storage options is to be expected. Electric locomotives are already forms of kinetic energy storage. Currently, regenerative braking feeds considerable quantities of train power back into the grid. Railway infrastructure offers a number of ways to introduce more power storage beyond just electric road vehicles (Deutsche Bahn 2014). The station would then not only be the nucleus and “enabler” for civil society and small commercial activities, but it would also act as a provider.
of universal accessibility via CO₂-free forms of mobility. This vision would stem from use of 
the vehicle fleet not only by the local prosumers but also the guests and visitors from afar.

- **Civil society**: The energy turnaround has also shown the way for people who are able to 
produce power and heat themselves. This also applies to transport. Once, buying a car was a 
symbol of living the good life, but flexible services are what people pay attention to today. 
People offer their own trips as transport options or are asked for a lift. Sometimes people 
take the train, other times the bus, bike, or car pool. Organising the offers can be developed 
as services in decentralised units.

6. **New political framework conditions**

The basis of new business models for sustainable transport offers has already arrived. Pragmatic 
transport practices – especially amongst younger people – are increasingly on the rise, primarily in 
cities but also in the countryside. Quiet and clean technologies are available. Smartphones enjoy 
wide distribution, and these could be universal information and access tools for integrated transport 
services on digital platforms. The only thing lacking is the necessary set of framework conditions. The 
transport transition can only succeed if the political conditions change and new business models 
become possible. So far, the private car with its internal combustion engine has been the central 
frame of reference for EU legislation. This is true for both personal and commercial use.

The framework conditions decide whether the transport transition will succeed and whether the 
objectives of the European Commission’s white paper can be met. Without restrictions on private car 
traffic, the transition will not work and the objectives will not be met. However, new options must 
limit what people are used to and link to long-term goals. Ambitious limits thus open new 
possibilities. These will discourage internal combustion vehicles and instead privilege electric and 
fuel-cell vehicles. If high emission vehicles face high fees, vehicles with innovative drive types will be 
all the more worthwhile. Furthermore, ambitious limits open up opportunities for mobility providers 
whose rental fleets are low emission and CO₂ free. Another option is to limit the total amount of 
private cars in densely populated areas while offering leeway to car sharing services by excluding 
these vehicles from the rule. This is already a reality in overcrowded Chinese cities like Beijing and 
Shanghai. The offers of shared-mobility services would explode immediately.

6.1 **Electric mobility as a Trojan horse**

The success story of the automobile shows that the car became both the icon of modernity and the 
core element of the “dream of the good life”. A more powerful conclusion has been realised in the 
meantime, however: these vehicles will be available one way or another. In Europe, this feeling was 
strongly adopted with reference to the United States, where the car had practically become an 
everyday device since the 1920s (Flink 1984).

Thus for success, messages must have a chance of being appreciated by the majority of the 
population. These messages must announce that the changes will come one way or another and that 
the supporting measures have to take effect sooner or later. The messages would be accompanied 
by the hope of a higher insight, as was the case back when private motorcars were introduced and 
ultimately became ubiquitous despite the other dominant modes of transport at the time.
In this regard, electric mobility could develop equally potential prospects. In multiple stakeholder analyses, InnoZ and other research institutes found that electromobility is solidifying in the minds of customers, consultants, politicians, and even automobile manufacturers themselves. “Electromobility will come in the long run anyway” is the assessment garnered through many interviews (InnoZ 2014). It seems that, compared to all other alternative drive types and other renewable fuel sources, electric mobility claims the highest social consensus and the largest long-term persuasive power.

If one focuses on the success story of the private motor vehicle, then electric mobility is suitable as a guiding vision for positive associations with this necessary future option. While the United States was once the all-important reference, China can be used as a newer reference. The Middle Kingdom has followed a consistent course toward massive distribution of electric vehicles, and this serves to orient German automakers (MERICS 2014) because China will become the world’s largest vehicle market within the next five years (NPE 2014).

But the catalytic function of electric mobility does not stop there. Associating electric vehicles with mobility suggests societal insight that mobility means more than just cars and lorries. Mobility refers to a variety of transport means, some of which (including buses, trains, and bicycles) are also environmentally sound. Electric mobility is thus associated with the promise that electricity-powered transportation in all its forms will probably prevail in the long run. Thus, the concept alludes to a practice of multimodal transport choice in which ever more people use several transport means, not just their cars. Electric mobility is also a strong message for railways and public transport companies as a modernisation option. These enterprises have been around longer and have more experience with the technology than any automaker. “We have already been electric for more than 100 years!” declares the DB AG, quite rightly (DB 2014). Under the guiding principle of electric mobility, ecomobility proponents become energy proponents. They can address regulatory policy for their goals more effectively because, with this shift in mobility power sources, they believe that their goals can be achieved.

Electric mobility, as well as the higher insight associated with it, also connects the concepts of energy turnaround and transport transition, which to date have been entirely separate. In addition, it makes connections to the diversity of transport means. Through e-mobility projects, energy suppliers are suddenly forced to deal with the automotive industry and to develop joint projects. Individuals, developer initiatives, housing associations, and civil society actors bring together the previously separated sectors of the energy and transport markets. Together, they confront the issues of supply management under the direction of corporations via decentralised activities with completely new challenges (cf. Canzler, Knie 2013).

6.2 Strategic adjustment levers

In sum, electric mobility has great potential because it is strongly expected to have such. E-mobility faces – like a self-fulfilling prophecy – inevitable implementation. Three central levers can be derived from this chain of evidence. If they are communicated appropriately, these three strategic tools give the chance of leveraging wide social acceptance as grounds for an eventual implementation:

Firstly, there must be ambitious and transparent CO2 emission limits. The 2020 limits already adopted by the EU regarding CO2 emissions for new cars dictate that vehicles emit only 95 grams per
kilometre, which will be required for 100 percent of all newly registered passenger cars beginning 2021. This measure should be tightened quickly and consistently. The Environment Committee of the European Parliament calls for a target corridor of 68 to 78 grams/km by 2025, while the environmental groups call for 65 to 68 grams/km. We find both of these corridors to be insufficiently ambitious. Fifty grams per kilometre would be a reasonable limit and has been shown to be possible in current automaker prognoses. The target should be a limit of 50 grams/km that is sharply and bindingly reduced each year after 2025. Planning security is built into this model for car manufacturers and mobility providers as well as for the users. The instrument of limits placed on new automobiles has proven itself for the most part. Strict limits must be laid down for the long term, however, and must not be subject to change in the meantime.

In addition to the Europe-wide limitation targets for minimum levels, local or regional limits could go even further. Certain regions and communities should put forth their own limitation requirements for new cars that go beyond the minimum levels. Fulfilling these local levels could be incentivised through a certain community’s “seal of approval”. Imagine if prestigious metropolises like Paris or Helsinki, or regions like the area around Stuttgart, adopted very ambitious limits for new registrations by as soon as 2025. The result would be a further push toward electric mobility through the city’s forward-thinking brand leverage.

Second, there must be consistent management of public transport and parking. Another important lever is nationwide exploitation of public parking. So far these spaces have generally been available free of charge or for a rather symbolic price. Charging more can help overcome the decades of privileges given to private cars and to incentivise increased use of public transport. Regulatory authorities can exploit public parking along with obligatory parking certificates for new registrations and ownership transfer. This has been practiced in Tokyo and other metropolises for some time now and has proven effective. Shared e-vehicles should be excluded from these restrictions in public parking areas, as is currently the case in Stuttgart and other places. There are good chances that these will become enabling modes for networked and urban-friendly mobility, which in turn contributes to climate protection. Parking management is already long overdue and benefits from the higher insight offered by electric mobility with the exception of a few toll roads, street space, too, has been used free of charge by private traffic participants (as well as commercial transporters, excluding motorway usage). Building and maintaining roads is paid for via taxes, a flat rate for all transport participants. This situation not only directly contradicts the “polluter pays” principle of environmental economics, but it also invites overuse of public property. Hence, it is not surprising that transport and environmental discussions have long concluded that the costs for roadway use should be reimbursed directly by those who use the streets and motorways instead of by public budgets. Usage rates should correspond to use and should not be conceived as a flat rate for all. Instead, rates should be calculated as exactly as possible to account for kilometre distances, vehicle weight, occupancy levels, pollutants, and noise generation, etc. This is already technologically feasible with electronic systems. The only thing missing is the courage and political will to tackle this systemic change in the financing of transport infrastructures. We recommend starting the debate with the question of how to rapidly and comprehensively transition transport infrastructure financing from tax funding to a qualified usage-financed maintenance system. Such a system would make sense in terms of the joint energy turnaround and transport transition; shared vehicles running
on renewable energy sources (or e-car sharing systems) would be charged significantly less and could therefore be operated in an adequate manner.

Third, support for decentralised supply areas: The establishment of “smart grids in citizens’ hands” should begin as an experiment. Real-world trials should be initiated by a broad “coalition of the willing” under manageable conditions. The object of these self-organised living labs would be to test whether (storage) supply can be generated and operated so that enough energy is available for people’s desired lifestyles even when the wind dies down or during the darker months of the year. To increase the attractiveness of such initiatives, self-suppliers would not be charged. Instead, compulsory energy insurance i.e. an obligatory grid connection including tariffs relating to demand would guarantee participation in a smarter and market-compatible way. Solidarity would have to be at the heart of the matter for the society at large, which leads us to the basic socio-political issue. There are indeed open questions here: How much volatility will society accept? How much must it cope with in order to hold itself to the premises of sustainable development? Given the many uncertainties and possible unintended effects, it makes sense to initiate pilot studies under real conditions with a sufficiently complex constellation of actors, wherein clear guidelines are defined. The trials should take place in areas of a minimum size with a fixed degree of self-supply. These citizen-driven decentralized networks could very well develop into interesting business models with refined implementation and depth of service. The trials should employ a wide range of forms and configurations. With the right amount of complexity and innovation, these real-world labs have a good chance of incubating the transport transition and ultimately ushering in the energy turnaround. At the centre stands the prosumer, who produces and uses energy simultaneously. Decentralised networks require considerable management know-how and distributed intelligence. Storage and smart grids have to be designed with redundancies. This transformation opens a wealth of opportunities for innovative technologies and also requires new forms of governance and business models.

The transition to post-fossil fuel mobility can only be achieved through efficient networks created between the various stakeholders; these stakeholders include automotive and transport companies, energy providers, ICT providers, and society at large as users of the novel services. The necessary measures must be initiated at a very early stage, however. With the guiding principle of electromobility, these strategies have good prospects for societal acceptance. There is a strong belief in the inevitability of these technologies and thus there is greater readiness to accept the regulatory policies required. Under the concept of electromobility, the networking of transport systems and decentralisation of power generation forms can be incorporated into civil society just as the automakers once did with their technological programme. For a clearer discourse and action, we do not recommend simply creating a long list of individual measures to be taken, but identifying strategic levers that can be used toward target realisation. As with the historical implementation of mass motorcar transport, the fundamental condition for a “wonderful new transport world” of tomorrow is starting the discourse and defining the necessary measures within the appropriate discourse spaces.
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