GUE/NGL
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European Parliamentary Group

The electric car and climate protection

Wish and reality

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For the DIE LINKE delegation to the European Parliament

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1. Imperatives of reducing greenhouse gas emissions

1.1 Climate change is for real

Natural disasters are almost everyday news items. Floods in the Philippines, Vietnam and Bangladesh, or protracted periods of drought in India and China – these are merely the most striking examples. The signs of climate change are visible in many parts of the globe. Science now recognises that these changes were wrought by man, our main contribution being the increase in greenhouse gas emissions. The latest models project that, compared with preindustrial levels, the global temperature will be up to four degrees higher by 2060, with as much as a 10-degree rise in the Arctic, if global greenhouse emissions continue to increase at the current rate.

The Fourth Assessment of Working Group II of the UN's Intergovernmental Panel on Climate Change (IPCC) contains important conclusions relating in particular to studies carried out since 1970. Observations from every continent and most of the world's oceans show that many ecosystems are being affected by regional climate change, particularly in the form of higher temperatures. It can be reliably assumed that changes in snow and ice cover and frozen ground (including permafrost) are having an impact on natural systems.

Examples include:

- the increase in the number and size of glacier lakes;
- greater soil instability in permafrost zones and more rockfalls in mountain areas;
- alterations to some arctic and antarctic ecosystems.

We now have a growing pool of data that reliably indicate the following alterations to hydrological systems in every part of the world:

- increased runoff and earlier-occurring maximum spring runoff in many glacier and snow-fed streams;
- warming of lakes and rivers in many regions, with an impact on thermic

structure and water quality.

A wider range of data covering more species shows that it is highly probable that recent warming has been having a massive impact on terrestrial biological systems. Changes have included:

- earlier signs of spring, such as leaf formation, arrival of migratory birds and egg-laying;

- the spread of plant and animal species towards the poles and higher altitudes in upland areas.

Satellite readings taken since the early 1980s reliably show that there is a tendency in many regions for spring vegetation to appear earlier and last longer, all under the influence of warming.

New data also suggest very strongly that the alterations observed in seawater and freshwater biosystems are linked to rising water temperatures and changes in ice cover, salinity, oxygen content and ocean currents. These phenomena include:

- range shifts and diversification of algae, plankton and fish stocks in polar latitudes;

- changes in the range of river fish, which are also migrating earlier.

Through the burning of fossil energy sources such as coal, crude oil and natural gas, atmospheric concentrations of carbon dioxide are increasing. However, other climate-impacting substances are also released by burning, including nitrous oxide, methane and soot, as well as hydrocarbons and nitrogen oxides, both of which are conducive to the formation of ozone. Then there are other emissions, such as nitrous oxide and methane from agriculture, which also play a key role in climate change.

The IPCC's most recent progress report (2007) states the scientific basis for climate change and includes an impact assessment of policies to reduce greenhouse emissions. There is a broad consensus among scientists that global warming must be limited to no more than 2 degrees Celsius above preindustrial levels. Otherwise, dramatic planetary changes far exceeding those recorded so far are to be expected.

The climate models calculate that this two-degree limit will require a cut in global greenhouse emissions of at least 50 % by 2050. This will mean restricting the annual emissions produced per person to no more than 2 tonnes in CO_2 equivalents. To put this into perspective, around 10 tonnes of greenhouse gases are currently produced per head in Germany, and over 20 tonnes per head in the USA. However, given that developing countries have every right to pursue further economic development, the developed world will have to make drastic emissions cuts.

In Germany this will mean a reduction of at least 80 % compared with 1990 – assuming, however, that cuts begin forthwith. The later efforts to reduce emissions start, the greater the reduction must be, as greenhouse gases, once released, remain in the atmosphere for a very long time. In this context it is possible to speak of a greenhouse gas "bank" – i.e. we cannot continue as before until 2045 and seek reductions only in the final five years.

1.2 The risks of insufficient cuts in greenhouse gas emissions

We still have too little understanding of how the climate reacts to higher atmospheric concentrations of greenhouse gases. We are as yet unable to second-guess the likelihood of sudden abrupt changes such as, for example, disruption to the Gulf Stream. Modelling still cannot predict changes due to non-linear processes. It is characteristic of such "tipping points" that they fit within the human timescale, arising both rapidly and, above all, irreversibly.

The United Nations Environment Programme (UNEP) recently sounded the alarm. It drew attention in the *Climate Change Science Compendium* 2009, in a chapter entitled "Earth’s Ice", to the dramatic, and accelerating, retreat of glaciers in mountain ranges such as the Alps and Himalaya, the rapid shrinking of Arctic ice, the instability of the ice shelf and the increasing melt rate of the Earth’s large ice sheets in Greenland, West Antarctica and East Antarctica. What is particularly disturbing is that this process is occurring significantly faster than the climate models forecast.

These dramatic changes are having far reaching consequences. In many parts of the world, glacier runoff forms the mainstay of water for domestic needs, agriculture, energy generation and river transport. The subsistence of more than one hundred million people is therefore under threat.

However, even in our regions the retreat of the Alpine glaciers is having a serious economic impact. Even if drastic greenhouse gas reduction programmes were launched as a matter of urgency, climate change can no longer be stopped. It can only be slowed, because the substances already released into the atmosphere will last such a long time. The CO_2 emitted to date will not entirely break down for more than 1 000 years. As well as reductions, therefore, there is a need for adjustment measures. In a new study, the World Bank estimates that adapting to climate change will cost the poorest nations from 75 to 100 billion USD each year between 2010 and 2050 if they are to be spared the worst consequences of global warming. This amount, which is roughly equivalent to current worldwide spending on development aid[1], will be necessary for measures to reduce climate change impacts such as heatwaves, drought, storms, floods and other extreme weather events.

1.3 Trends in energy demand and climate protection

Worldwide trends

The International Energy Agency (IEA) issues an annual "World Energy Outlook" report describing how energy demand in various sectors is expected to evolve over the next 20 years. Figure 1 shows that world energy demand is expected to keep growing strongly. In other words, the trend of recent years will continue to accelerate, leading in 2030 to 45 % more demand than at present.

[1] "The Economics of Adaptation to Climate Change (EACC)", 2009, http://beta.worldbank.org/climatechange/content/economics-adaptation-climate-change-study-homepage

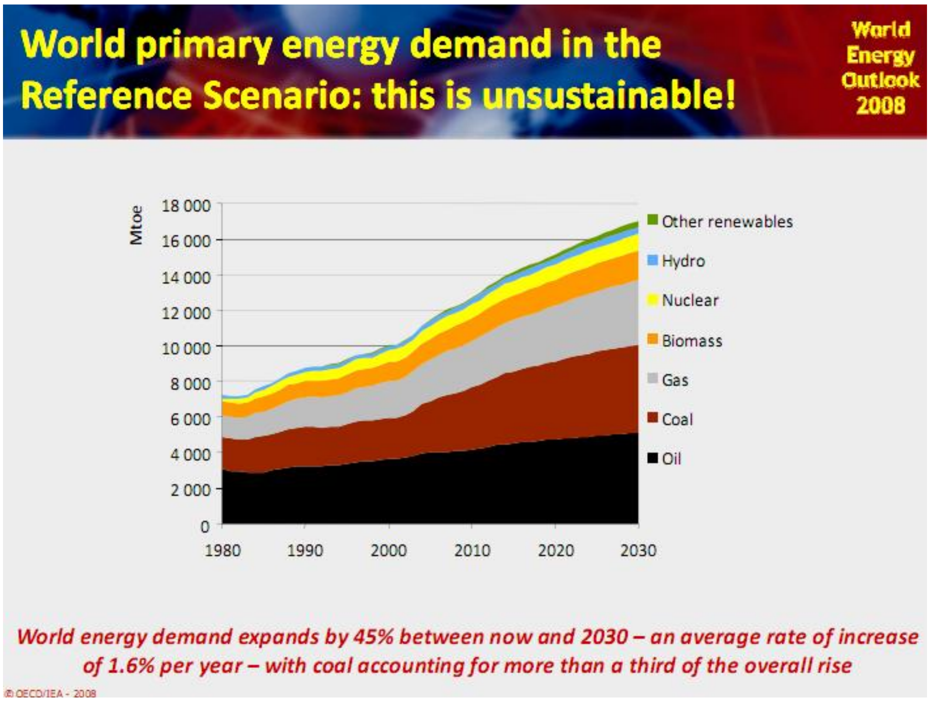

Figure 1: World primary energy demand (Reference Scenario)

The IEA report states that this scenario is unsustainable and conflicts with the imperatives of climate change. It will lead to a massive increase in CO_2 emissions rather than to the necessary reduction.

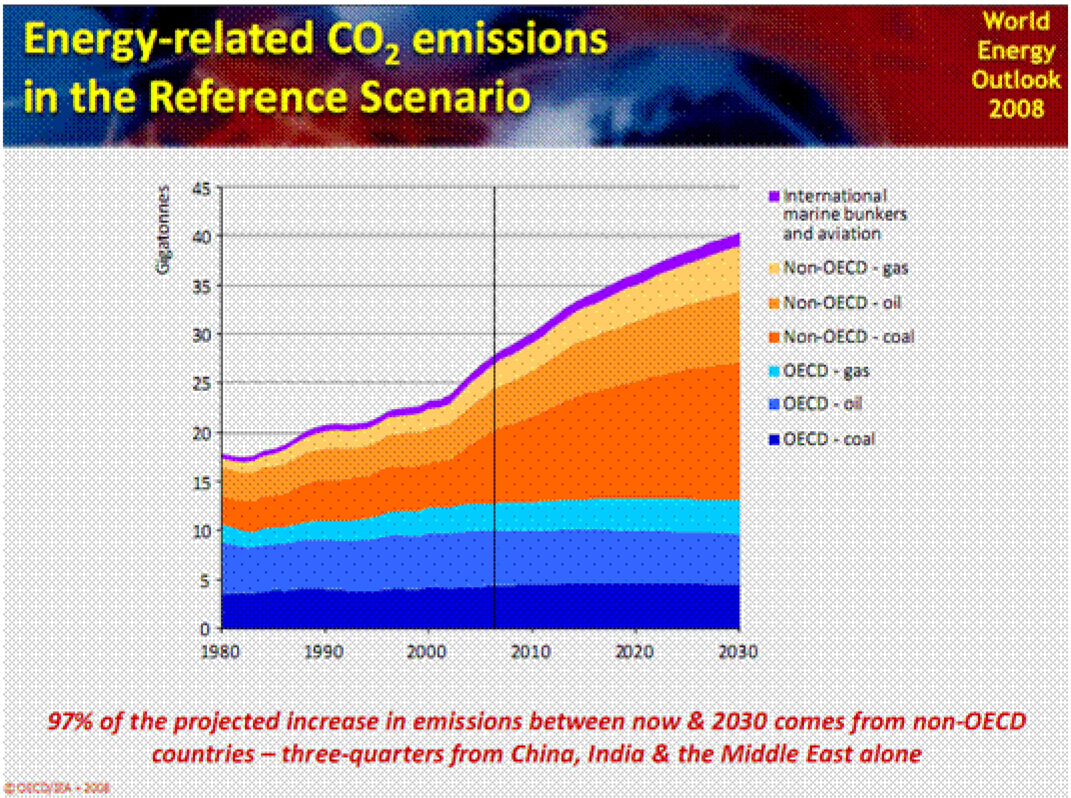

Figure 2: Energy-related CO_2 emissions in the Reference Scenario

Demand for crude oil will also continue to grow, driven above all by the worldwide expansion of automobile use. In absolute terms, the largest increase in oil demand is expected in China, the Middle East and India.

Conversely, western Europe and the USA can expect a fall in oil demand. However, this will be so insignificant that it can in no way offset increases in other regions.

Figure 3: Change in oil demand by region in the Reference Scenario, 2007-2030

Growth in demand will largely be due to increased traffic. The remaining sectors will have little impact.

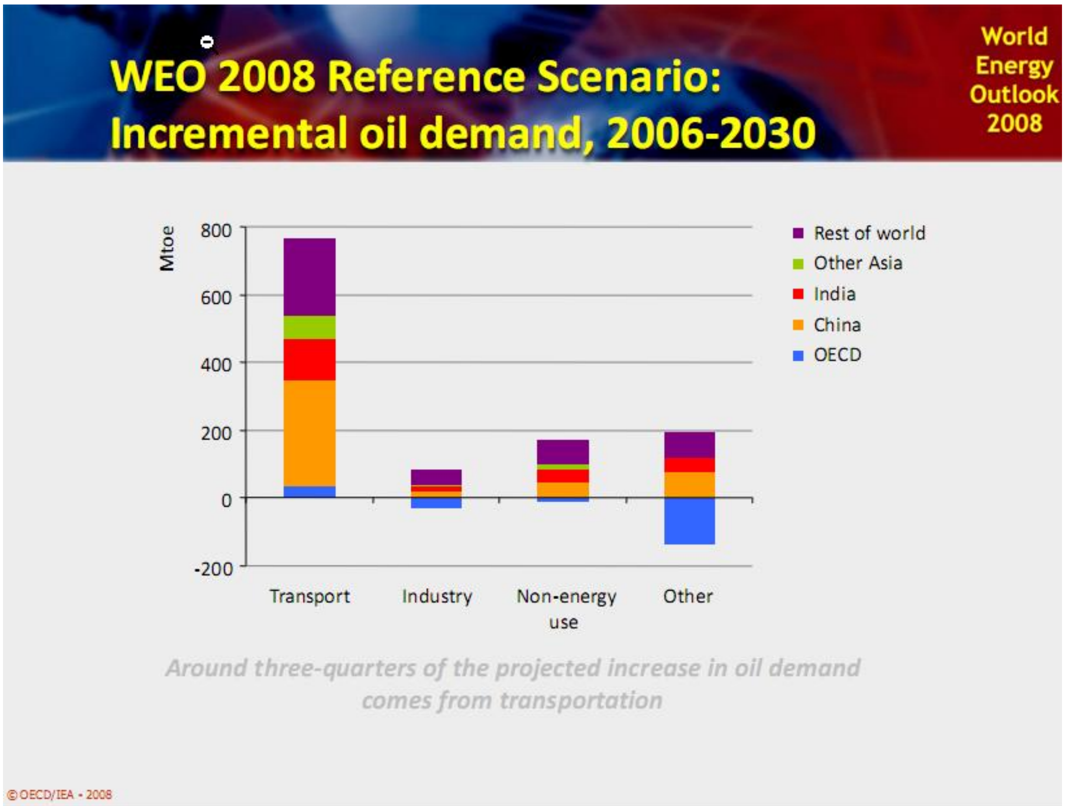

Figure 4: Incremental oil demand, 2006-2030

One question naturally arises: where will all this new oil come from? In many petroleum regions the oil supply has already peaked. While on occasion new deposits are still being found, their volume is negligible compared with the total current supply. New improved technologies allow existing deposits to be exploited more fully, but this will only postpone the problem for a few years.

Higher prices will make prospecting and supply in difficult geological strata increasingly profitable, and it is probable that further discoveries await, for example under the oceans. However, oil will become considerably more expensive, and the underlying problem – that resources are limited – is set to remain.

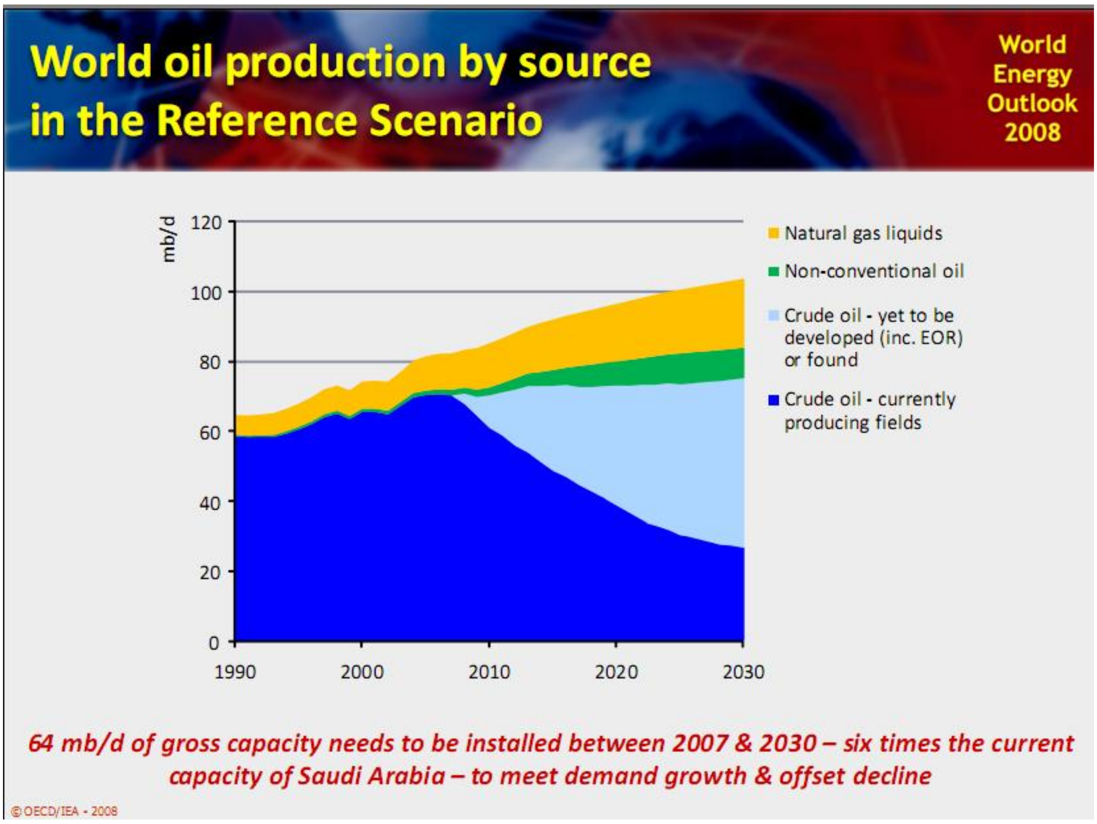

Figure 5: IEA forecast for future oil production (including liquid gas)

For a number of years now, "non-conventional" oil reserves – which include heavy oils and oil from tar sands and shale – have been showing greater commercial viability[2]. Synthetic fuels, produced using the Fischer-Tropsch process to convert natural gas into diesel or petrol, should form a significant part of future supply.

There are two fundamental problems with this "oil optimism":

1. New discoveries: these are usually estimates of anticipated volumes rather than measurements. There can be no certainty that the expected reserves will actually be discovered or exploitable.

2. Non-conventional oil reserves cannot be exploited without higher CO_2 emissions and other environmental burdens.

[2] In 2007 Canada redesignated its oilsands and shale as "oil reserves", whereupon, with 174 billion barrels in reserves, it climbed abruptly to second place on the IEA list of petroleum-producing countries (after Saudi Arabia). See IEA 2007, IEA 2008.

Regarding the second point, Canada's exploitation of its tar sands and shale using hot water and high pressure is causing considerable damage to the regional environment, and the poor energy balance is leading, compared with today's situation, to a marked increase in specific and absolute greenhouse emissions. Given that exploiting these reserves in full would increase Canada's climate footprint by 25 %, this is not about to happen.

Developments in Europe

In Europe the distribution of energy sources by demand and CO_2 emissions is similar. The European Environment Agency (EEA) gives oil a share of around 36 %. This is not expected to change substantially by 2030.

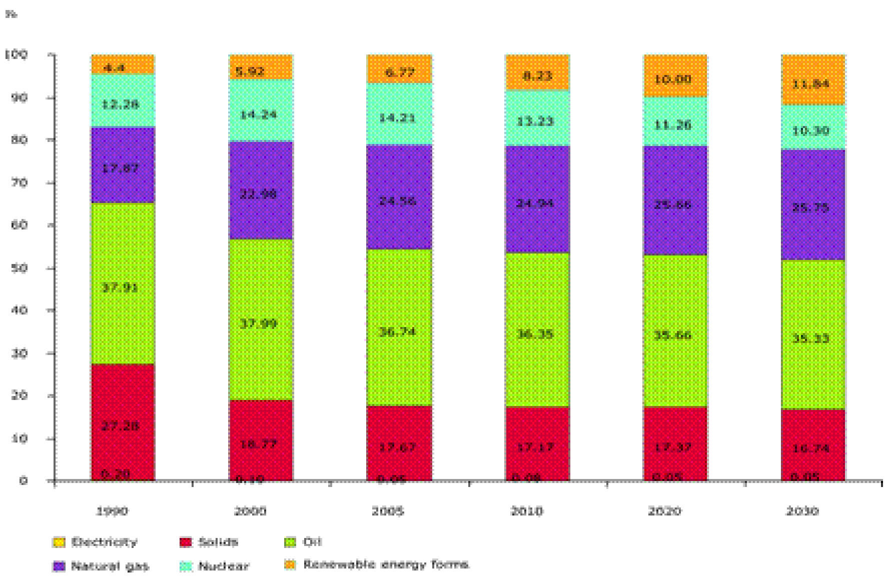

Figure 6: Structure of energy demand in the EU27, 1990-2005, and forecast for 2030 (EEA 2009)

The European transport sector has grown out of all proportion to other sectors.

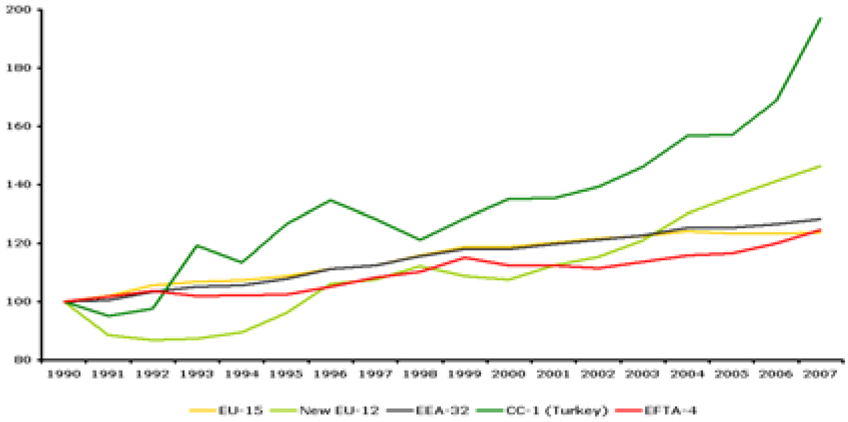

Figure 7: Total greenhouse gas emissions from transport in the EU (EEA 2009)

It is clear from the following graph (Figure 8) that the EU Member States have shown very varying rates of progress in the reduction of greenhouse emissions from traffic. Just four countries managed to reduce their traffic emissions between 1990 and 2006, and in three of those States the reduction can be attributed to the economic turbulence that resulted from the collapse of the Warsaw Pact. Only Germany can boast of a successful policy to reduce vehicle emissions, and here it should be noted that Germany has benefited from cross-border "petrol tourism" owing to the decline in fuel duty in certain neighbouring countries, since the calculation method in the Kyoto Protocol counts the volume of fuel purchased in a country rather than the volume actually used.

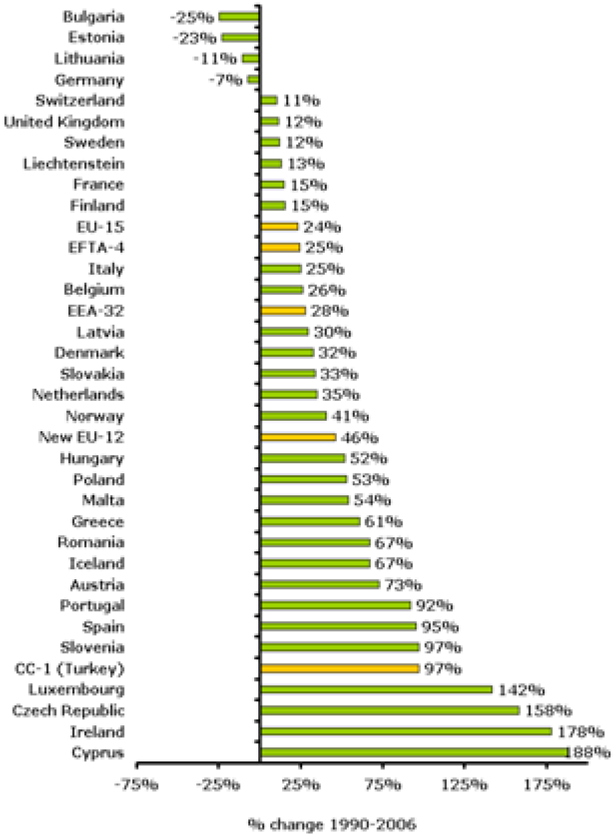

Figure 8: Trend in CO_2 emissions from traffic in the EU Member States, 1990-2006 (EEA 2009)

As Europe's population ages, it is anticipated that demand in central and southern regions will cease to grow. Alongside the change in mobility patterns as people grow older (no work-related travel), CO_2 ceilings will be crucial to achieving low-cost reductions. From 2015, the CO_2 emissions of passenger cars will be limited to 130 g/km, and the EU Directive provides for a further reduction to 95 g/km in 2020. Analogous ceilings are now being agreed for light commercial vehicles, and the Commission is planning to introduce ceilings for HGVs. However, other measures are also important, such as improvements to local public transport, better general conditions for non-motorised traffic and amendments to the taxation framework.

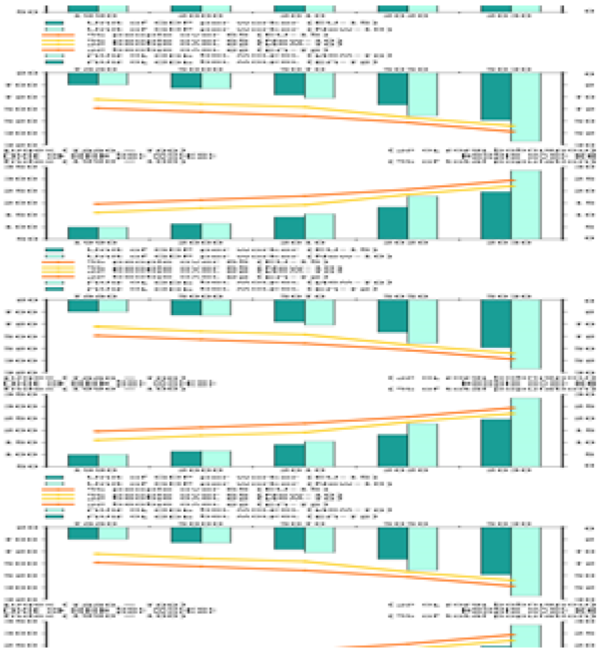

Figure 9: Share of people over 65 in total population and requirement for income generation per working person (European Environment Outlook, EEA 2005)

Taken together, however, these developments will still be far from sufficient to bring about the reductions made necessary by the climate crisis. As developed countries, the EU Member States, the USA and Japan have the obligation to make drastic cuts in their greenhouse emissions from transport, and to devise solutions that can also be borne by the developing world.

In the past, vehicle manufacturers emphasised alternative energy sources in order to avoid the need for fundamental changes to our transport system.

Following government-backed tests using methanol and ethanol in the 1980s and 1990s, and the first major trial of electric vehicles, interest then shifted to the use of biofuels and hydrogen in fuel cell vehicles. After it became clear that fuel cell technology will not be commercially available for a long time, and no solution was found to the problem of cheap hydrogen generation and storage, hope was placed in biofuels, despite Federal Environment Agency warnings as early as 1993 about the environmental impact.

When the debate about the impact of the wider use of biofuels reached the political arena and the general public in the context of rising food prices, interest in the electric car returned to the fore.

2. Technical aspects of the use of electric motors in road vehicles

2.1 Current paradigm: liquid fuel and internal combustion engine

It was around 100 years ago that the internal combustion engine conquered the market for motorised road vehicles. Although still well represented before 1910, the competition, in the form of electricity and steam, then disappeared from the roads within a few years.

The key to the success of the internal combustion engine using the Otto cycle – which at the time was exclusively petrol-driven – was that the fuel's power density made it possible to combine long-distance travel with high performance. Steam engines were structurally less compact and more complicated to start. Meanwhile, the weakness of electric motors lay not in the power train but in energy storage.

This difficulty persists today. Whereas a car driven by an internal combustion engine and carrying 50 litres of fuel weighing less than 50 kg (tank included) can travel further than 700 km, to travel just 100 km an electric car requires several hundred kilogrammes of batteries.

A practical example: a compact car travelling at a constant 100 km/h requires power of around 25 kW (35 hp)[3]. Modern diesel engines use roughly 250 g of fuel per kWh[4]; seven hours at 100 km/h, the equivalent of driving from Hamburg to München, will require 35-40 kg of diesel.

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[3] Given a modern vehicle weighing 1 000 kg and standard values for road and wind resistance.

[4] This value, which is true for a wide range of performance characteristics, allows, in this example, for efficiency losses due to the transmission. Diesel injection engines in passenger cars are capable of consumption values of at best 200 g/kWh, or 41 % efficiency.

While one kilogramme of diesel can generate power of 4 kWh, a modern Li-ion battery produces 200 Wh (0,2 kWh) per kg – an energy density that is 20 times lower[5]. It is immediately clear from these figures that a battery-electric car is unsuitable for the type of use that is standard for modern passenger cars.

It is often forgotten that the search is not only for an alternative drive train, but for a coherent overall concept of what a vehicle is and does. Internal combustion engines and electric motors require very different energy sources and storage arrangements, and importance also attaches to the intermediate links in the chain from primary energy source to the vehicle's useful energy. Electric cars have such different characteristics that making the switch will not fail to have an impact on routine driver behaviour.

2.2 Alternatives to petrol and diesel engines

In our summary of the climate crisis in chapter 1, we stated the need for a significant reduction in CO_2 emissions, including those from road traffic. Since around 1987, when climate change mitigation became a political objective in both Germany and Europe, a range of technological solutions to the problem have been proposed. Hopes were high, firstly in connection with the biofuel rapeseed methyl ester (RME) and then with natural gas, both of which were coupled with generous tax incentives.

From around 1995 widespread enthusiasm grew for the idea of hydrogen fuel cells. At the time, Daimler-Chrysler in particular was responsible for drawing government attention to this option. Mass-produced hydrogen vehicles were going to become available in 2005. For the experts these fuel cells have now become "fool cells", as the bold claims made for them have come to nothing. The costs and technical difficulties associated both with hydrogen power and with the supply of hydrogen as a fuel (methanol was cited as an alternative fuel cell energy source) were entirely underestimated – notwithstanding, once again, the Federal Environment Agency’s warnings about raising hopes too high.

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5 The value of 4 kWh/kg corresponds to the useful mechanical output of a diesel engine. In a battery-electric arrangement further deductions must be made (at least 15 % in total) for efficiency losses due to battery discharge and in the motor itself.

From 2002, for a few years, renewable fuels found favour as a solution to the environmental and supply problems. Biofuels were given very short shrift, however. Not only was there competition for land used for food-based agriculture, but it had also become clear that the demand from wealthy countries with a high rate of car ownership could only be met by importing vast quantities from the developing world. Given the destruction of the rain forests in poorer countries, there can be no question of using biofuels for sustainable climate protection – in fact the opposite is true.

Since 2005, both politicans (who are virtually unanimous) and the automotive industry (at confederation and PR level at any rate) have seen the future in battery-electric cars. The alliance of proponents of this future remains considerably broader than for previous ideas, and the electricity sector has lent its considerable industrial weight to the cause. Almost without hesitation, society has linked the idea of a battery-electric car "fuelled" from the power grid with the notion of "mobility", which has only positive associations, and distinguished it with the term "electromobility".

It is entrenched in public perception that "electromobility" has already existed for a very long time in trams and railways, not to mention that battery-electric vehicle technology is very old and draws on the conventional energy supply infrastructure. We shall now examine which technical characteristics and circumstances can be used to put the case for battery-electric passenger cars.

2.3 Key features of battery-electric power

Replacing a petrol or diesel power unit with an electric motor brings a raft of technical and environmental benefits.

Electric motors[6] can operate at a far wider range of loads and rotational speeds without the need for clutch or transmission systems.

- When power is not needed the motor simply stops, using no energy.
- The drive is then engaged gently and almost silently.

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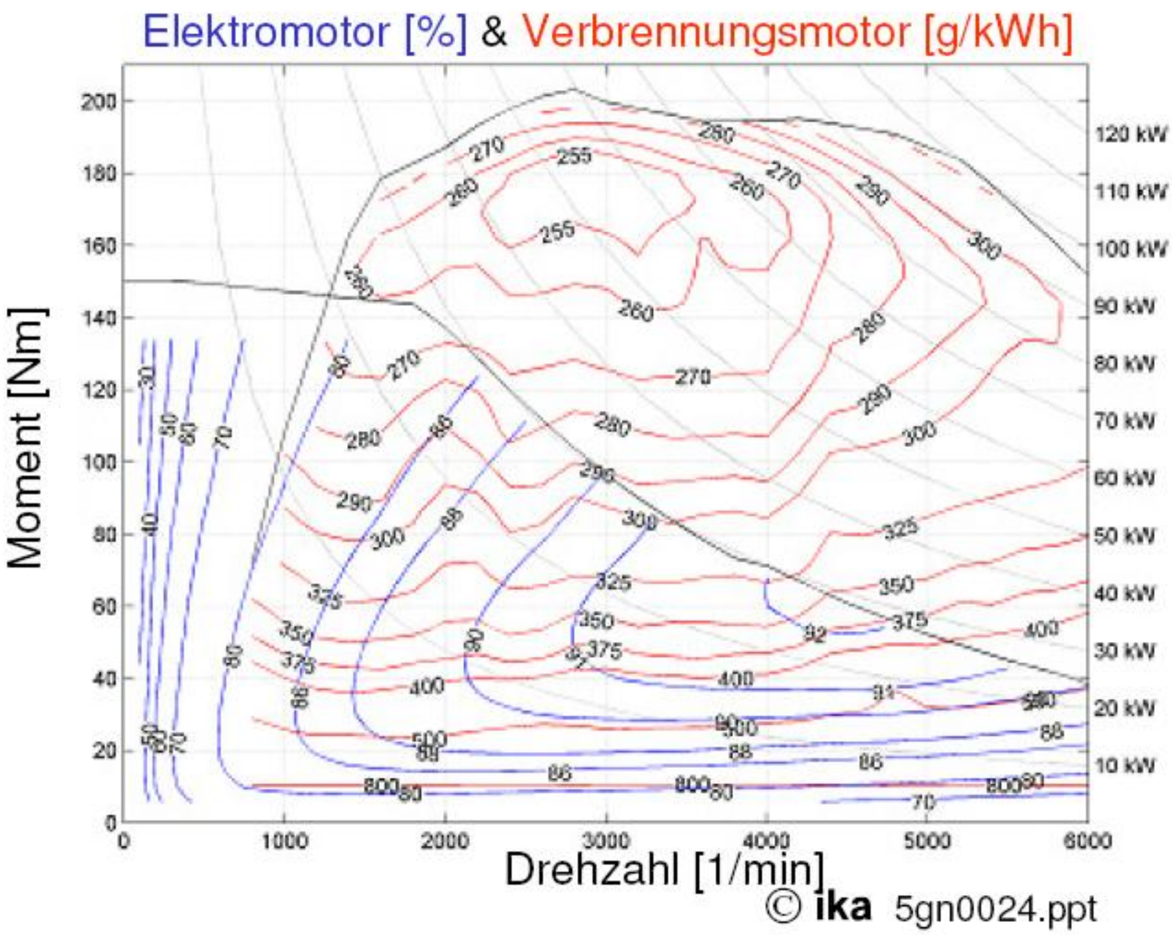
6 The various technological variants (synchronous/non-synchronous, etc.) are of no relevance to this discussion.

- There are no *direct* local emissions, as all pollution occurs at the power station.
- The conversion of electrical into mechanical energy is highly efficient at a wide range of rotational speeds and loads.



[Figure 10 captions: Electric motor (%) & internal combustion engine (g/kWh)

Torque (Nm) Rotational speed (1/min) **]**

Figure 10: Performance characteristics of internal combustion and electric power units (source: Wallentowitz, ika RMTH Aachen 2008)

Compared with internal combustion engines[7], therefore, electric motors have significant advantages. This is why the moving parts of stationary machinery – from factory drills to vacuum cleaners – are not petrol-driven. What is necessary – and for electric motors this is the crux of the matter, however trivial it may sound – is an electric power socket. For over 100 years, non-stationary machines (electric locomotives, trams and trolley buses) have made use of a collector running along bare cables.

Where power is not continuously available, electric motors rely on power storage units. These come in the form of one-way (non-rechargeable) batteries or accumulators (reuseable after charging)[8]. Electric cars and comparable machines (from laptops to cordless screwdrivers) are powered by accumulators, although these are always popularly referred to as batteries. There can be nobody who has not become aware, often at the most inconvenient moment, of the limits to the capacity even of modern "batteries", and therefore to the life and power uptake of electric motors.

The current developments in the field of power storage units – which, for simplicity's sake, are referred to here as batteries – are described in a later paragraph. At this juncture it is enough to state that the experts believe lithium-ion (Li-ion) technology (like nickel-metal hydride (NiMH) cells[9] before them) to be the most likely battery of choice for powering electric cars.

Irrespective of the battery type, the available energy source is not unaffected by the ambient temperature. In winter this leads to problems, especially as heating is now a standard "comfort" feature of passenger cars. Modern cars have a great many such electrically-driven elements, including power windows and windscreen heaters. In the case of internal combustion engines, which are fitted with powerful alternators, these

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7 Combustion engines exist in many forms. Petrol and diesel engines, the only types in cars and trucks, use a piston arrangement with an internal combustion cycle. Other designs include Wankel engines (using rotary rather than reciprocating pistons), gas turbines (continuous internal combustion) and Stirling engines (continuous external combustion). These other types have made no headway as vehicle power units.

8 See German industrial standards 509 and 510 and the corresponding DIN standards.

9 NiMH cells are available as both non-rechargeable and rechargeable batteries (accumulators).

elements' energy consumption is inconsequential[10]. In the absence of a conventional engine (non-hybrid electric vehicle), additional functions are highly optimised and may even be omitted so as not to compromise performance in terms of acceleration, speed and range.

The advantages of electric motors include regenerative braking and use of the power train as a generator to recycle current to the battery, where it is made available to the power unit and thus extends the energy supply. The degree to which braking energy can be recycled depends on a range of technical vehicle parameters and driving situations.

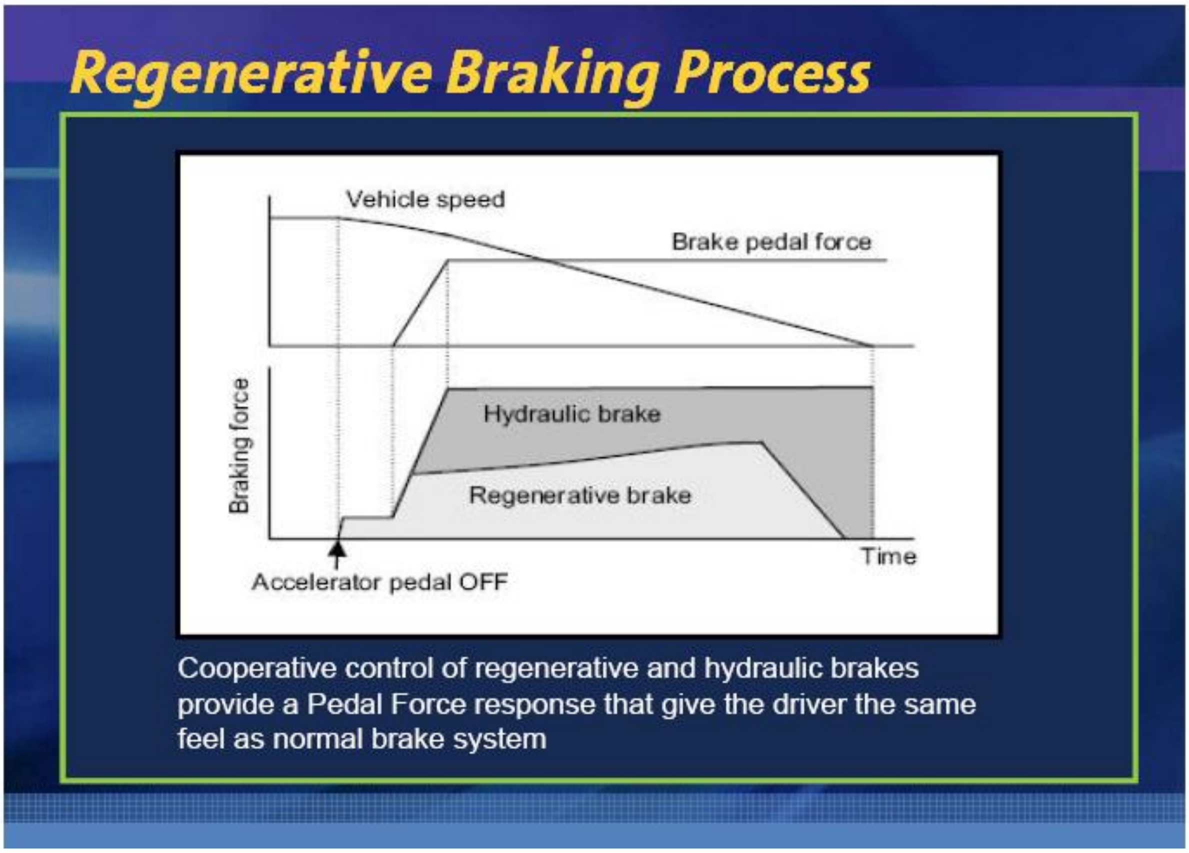


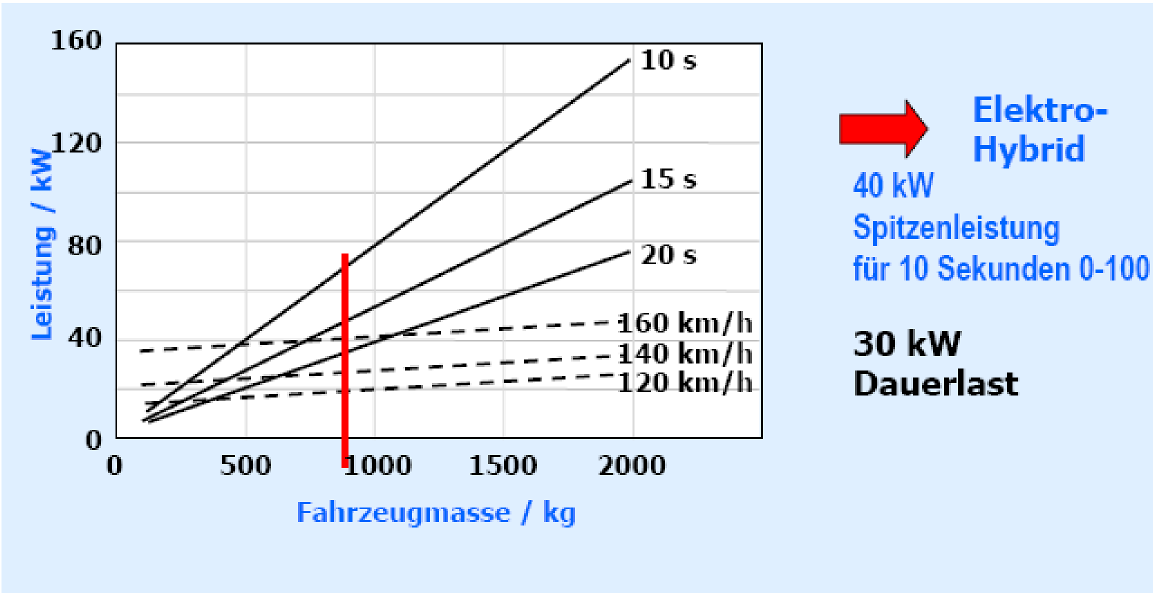
Figure 11: Partial recovery of braking energy (source: Walraven, GM 2008)

[10] "Comfort" features do however increase fuel consumption, although they are not switched on during statutory fuel consumption and emissions tests.

It is generally the case that the New European Driving Cycle (NEDC), which heavily weights urban and low-momentum driving – i.e. low acceleration and deceleration coefficients – is conducive to the recovery of braking energy, as less traditional braking power is "destroyed" in gentle braking than in heavy use of the brake pedal. The more braking power is taken up by the generator, the more, in theory, can be recycled to the battery. There are two obstacles to the total recovery of braking energy. Firstly, it will not be technically possible to convert the energy that is briefly given off by the decelerating weight of the vehicle at times of heavy braking into electricity and feed it into the battery, because this would cause unacceptably high peak loads. These braking peaks must then be converted by friction, as hitherto, into ambient heat. Secondly, the energy chain leading from the generator to the charger to the battery and back to the drive train is such that energy is lost at each stage of the process. It will be possible to assume that 50-60 % of regenerative braking energy is returned to the motor. In other words, 40-50 % will continue to be lost.

The engines of all modern road vehicles are overpowered for the NEDC. As can be seen from the following graph, a medium-sized vehicle is required briefly to perform at around 40 kW, and considerably less when driven at a steady speed.

Wieviel Leistung brauchen wir wann?



KKL, September 2008 / PD05

[Figure 12 captions: When is power needed, and how much?

Power (kW) **Vehicle weight (kg)**

Electric-hybrid 40 kW peak performance for 0-100 in 10 seconds

30 kW steady load]

Figure 12: Energy requirement of a car driven at a steady speed and when accelerating (source: Dietrich CCEM-PSI 2008)

In recent decades it has become normal for lower-medium-sized cars to deliver much higher performance and 0-100 km/h acceleration times of under 12 seconds. This and the fact that cars of this size (VW Golf) rarely weigh less than 1 200 kg necessitate around 90 kW in rated power. "Sportier" drivers not infrequently make full use of this capability on motorways.

Electric motors are capable of high output figures, and the nominal power may also be temporarily exceeded by a good margin. Rapid acceleration is therefore no problem for electric cars. The problem lies in the poor battery storage capacity.

Rough calculation shows that a medium-sized electric car would exhaust the energy in a 300-kg Li-ion battery within 15 minutes. If the brakes were applied sufficiently gently to allow the recovery of 50 % of all braking energy, the available range would increase to 25 minutes. Quite clearly, battery-electric cars are not suitable for fast driving at variable speeds.

2.4 General conditions for the use of electric cars

Every technology has optimum profiles of use, and every design has its strengths and weaknesses. Electric cars (to be more precise, cars powered exclusively by an electric motor using battery storage) cannot replace internal-combustion motor vehicles in all circumstances.

Owing to its limited battery capacity, the electric car[11] – a vehicle powered exclusively by electricity, with no internal-combustion unit for longer journeys – is not a suitable replacement for the conventional automobile. The battery-electric car will thus only be capable of a limited range of uses.

The electric car’s supporters are very well aware of this problem and have therefore argued that the great majority of all car journeys in any case cover only a few kilometres. Most trips – to work, to the shops or other private destinations – are so short that the energy stored in an electric-only vehicle would suffice. If this argument is followed through, the electric car becomes a supplementary vehicle, alongside a "real" car that is used for other journeys.

The question then arises as to whether, in the longer term, it will be possible for the electric car, as an overall concept, to display the same characteristics as a conventional car. Most important are the key fuel consumption parameters of vehicle weight, maximum speed, acceleration and engine power. A high maximum speed is less useful if electric cars are only used for short trips rather than longer journeys. And if electric cars continue mainly in urban use, comfort factors such as vehicle size will be less important.

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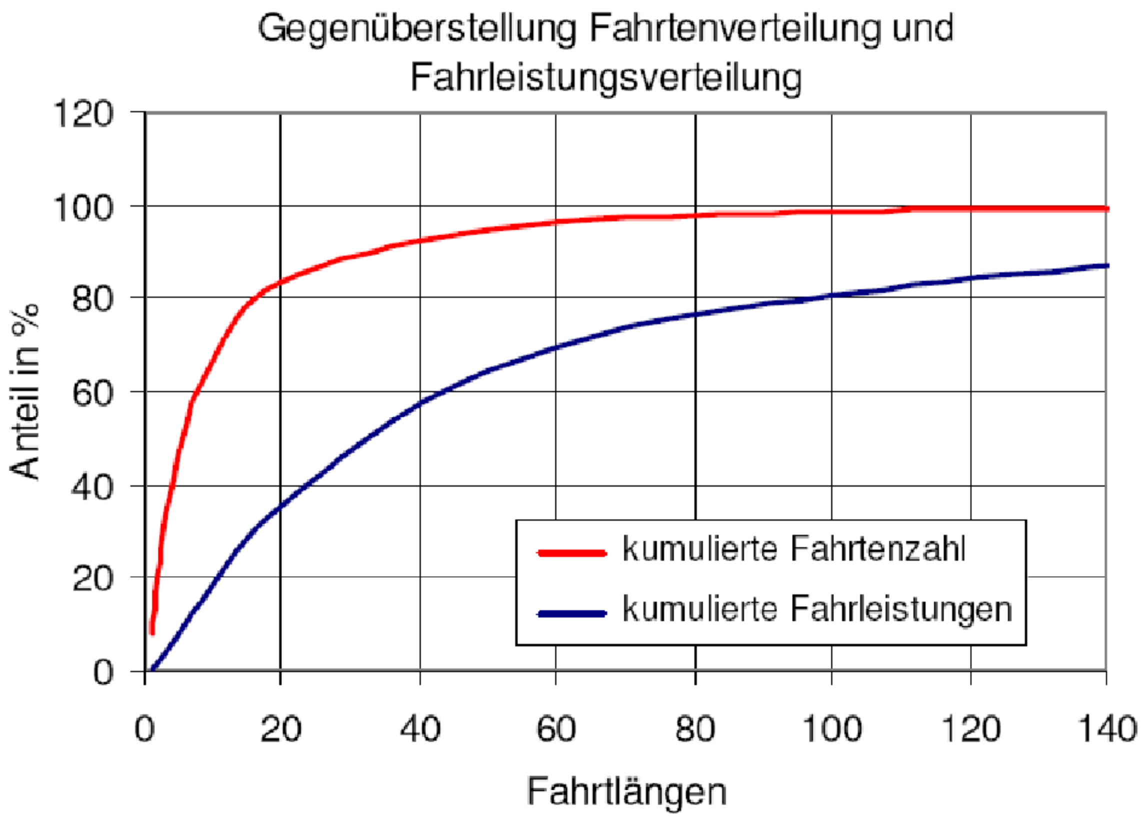
[11] Hybrid-drive vehicles, which have both a conventional and an electric motor and store energy in a fuel tank as well as a battery, can resolve the problem of range. However, dual technology also means (even) higher costs and greater weight.

From the dual perspective of market share and the environmental impact of support for the electric car, these considerations have serious implications. On the one hand, the limited market success of the Smart has shown that customers do not necessarily want a car tailored to their specific requirements, but one that they can also use for more infrequent outings. Even a single person, for whom a two-seater is perfectly appropriate for work and leisure needs, would clearly like to be capable of transporting passengers and undertaking longer journeys. Justifying the limited range of battery-electric cars by the fact that most journeys are very short would therefore not convince many buyers. Even if as few as five longer journeys requiring a conventionally-powered car are made each year, it is those five journeys that will influence the decision against the electric car.

When the Smart was first marketed, the eminently logical argument that most car trips are made alone or, at most, with one other person was significantly overplayed. Sales have never matched expectations, and production volumes are still not economically satisfactory even today. Generally speaking, the Smart remains a relatively expensive second or third car. Opel, for example, sells many more of its Corsa model because it is cheaper and allows mothers to ferry three children around. Although the average vehicle occupancy rate is around 1,3, for many people it makes sense to buy a car with four or five seats.

Despite the large number of shorter trips made – around 90 % of all journeys do not exceed 30 km and account for half of all kilometres driven (see Figure 13) – it may be sensible for individuals to invest in a car that is designed for greater distances.



[Figure 13 captions: Comparison of journeys made and distance travelled
Share (%)
Distance travelled (km)
cumulative journeys made
cumulative distance travelled **]**

Figure 13: Average daily journeys made and distance travelled in Austria (source: Leitinger, Vienna TU 2008)

From the environmental perspective, we need to examine what share of the total energy consumed by passenger cars could be redeemed if battery-electric cars were used for shorter trips, and indeed whether any significant CO_2 reductions could be achieved by using electric cars. In this context, two aspects require detailed analysis. Firstly, what distance travelled by conventionally-powered cars will instead be driven by battery-electric cars charged from the power grid? Secondly, what are the specific emissions of electricity generation and the corresponding losses down the energy chain to the drive unit?

So far, all estimates of the cost of the electric car, which essentially means the cost of the battery, lead to the conclusion that the market success of this motoring technology will depend on government intervention. The subsidies that are factored into some calculations of future travel costs by kilometer generally come in the form of an exemption from fuel duty. Both politically and economically, the level of fuel duty is always tied to road infrastructure costs (the environmental costs of motoring are still rarely taken into account).

It goes without saying that electric cars will not obviate the need to build and maintain roads. In the interests of sharing costs fairly, therefore, there can be no justification for not proportionately taxing the supply of energy from the grid by analogy with the fuel duty. One solution might be to impose a universal road toll on passenger cars.

Another aspect which is frequently overlooked is that of the competition between electric cars and local public transport, given that supporters of the electric car mainly envisage urban use.

3. Electric cars and climate protection

3.1 Situation today and in the short and medium term

Writers and speakers often assume without question that the introduction of electric cars will be beneficial for the environment, in particular as regards climate protection. It is true that electric motors emit no pollutants, unlike the internal combustion engine, and therefore e-cars are often referred to as zero-pollution vehicles.

However, it would be more honest to call them "displaced-pollution vehicles". Moreover, it is generally overlooked that concentrations of the classic pollutants – carbon monoxide, hydrocarbons and nitrogen oxides – are so low in modern Euro 4-compliant petrol vehicles as to be barely measurable. (Once Euro 6 comes into force, the local-pollution argument for electric cars will also cease to be valid in respect of diesel cars.)

The key statistic in climate protection is the aggregate of all emissions in the chain from production to use. This includes upstream emissions from energy- and technology-related activities. Talk of "zero vehicle emissions" in the context of an electric car only makes sense if all grid electricity is generated emissions-free.

The current share of electricity from renewable sources is still very low and ranges, according to one's viewpoint (e.g. net vs. gross electricity generation, inclusive or exclusive of electricity imports and exports), from roughly 15 % to 18 % (see also Table 1 below). Wind power and other non-fossil energy sources will almost certainly increase exponentially, but the current debate about "environmentally-friendly" electric cars and the planning of future incentive measures must take account of current circumstances and implementation times. If instead we buy into the illusion of zero emissions, this will adversely affect the climate balance and tie up resources that are required for more efficient options.

A rough calculation before we go into further detail[12].

As described above, an electric car of the same size and similar test performance as a conventional petrol or diesel vehicle (e.g. VW Golf) requires power of 20-25 kW to travel 100 km in one hour.

The German electricity grid currently emits around 600 g of CO_2 per kWh, which translates as 120-150 g/km. EU legislation stipulates that the average CO_2 emissions of newly-licensed cars (measured in the test cycle), must not exceed 130 g/km by 2015; given the many derogations the real figure will be closer to 140 g/km. In order to achieve this goal, many more economical small and compact cars will have to be sold for each high-emitting, heavy luxury-class car or SUV. Smaller models with CO_2 emissions of less than 120 or even 100 g/km are fortunately available on the market – in the very market sector being targeted for electric cars.

It is clear that, given the current energy mix, the introduction of electric cars will make no contribution to the reduction of greenhouse gases. (NB: this rough calculation omits emissions higher up the chain – including, for electric cars, losses in charging and self-discharge and, for conventional cars, the extraction, transport and

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12 For the sake of transparency, please note that all scenarios for the future of electricity generation are based on rough calculations.

processing of crude oil.)

It is often overlooked that, owing to their limited range and constraints on charging, electric vehicles are unsuitable for most people as a first car. Promoting electric vehicles will therefore amount to increasing the number of two-car and three-car households, leading to a range of undesirable environmental consequences:

- If the electric car fleet causes an increase in total vehicle numbers, an exhaustive technology and policy impact analysis will have to allow for the production process and factor in the life cycle of the additional vehicles. More greenhouse gases are expended in manufacturing electric cars and their batteries than in building conventional cars, and mathematically they are spread over far fewer kilometres per year. Overall this could lead to a negative impact on the climate, even if the share of electricity from renewable sources rises significantly.

- Many proponents of the electric car believe that local authorities should encourage sales by favouring inner-city access for electric cars and/or raising access charges for or otherwise discouraging conventional vehicles. A good example of this is the London congestion charge. The result, for the average suburban household, is that the large family car is freed up for, say, shopping trips. While the specific social consequences are unclear, there will be an impact (probably negative) on the climate.

Interim conclusion on climate protection:

The key point to retain is that only the use of electricity that is zero-emission at generation can improve the impact of the electric car. It would be environmentally and economically absurd to charge electric cars from renewable energy, thus limiting the availability of green power in other sectors where CO_2 emissions per generated kWh could be cut more effectively and at a lower overall cost.

There is very little possibility that the electric car will help to reduce the greenhouse emissions of road traffic. Why is the electric car nonetheless promoted so enthusiastically by the German government and automobile industry? An analysis of *the stakeholders' motives must focus on this question. First, however, we need to examine their views from the perspective of cost.*

3.2 Costs of the electric car and climate protection implications

The scenarios repeatedly cite figures suggesting that electric cars can be attractive economically as well as environmentally.

The basic data that are available today reveal such forecasts to be very unrealistic. At present, one kWh of battery capacity costs around 1 000 euro. Learning curves are constantly borrowed from other new technologies to predict ultra-low battery costs. A learning curve shows the fall in the cost of a technology over time owing to technological improvements and mass production (see for example Figure 14).

Battery costs include the cost not only of the battery cell but also of all associated elements, such as power electronics, heating and cooling. While there is still considerable scope for cost reductions in the area of power electronics, which are used to regulate an electric motor, the remaining components offer far less potential. The most optimistic forecasts suggest overall costs of 400 euro/kWh by 2020. To achieve this objective, the cost of a battery cell must fall to less than 250 euro/kWh.

Given that the life of a lithium battery depends on its charge cycle and discharge depth, batteries are currently discharged to only about 70 % of capacity, ensuring ten years of life. The greater the discharge, the shorter the battery's life. Researchers are currently striving for a 10-year life span with 50 % discharge – i.e. only half of inherent capacity can be exploited.

However, this will mean that, in order to travel 100 km, vehicles will have to be fitted with a 50 kWh battery delivering a useful capacity of 25 kWh. At 400 euro/kWh, therefore, the battery costs for a 100-km range will be 20 000 euro.

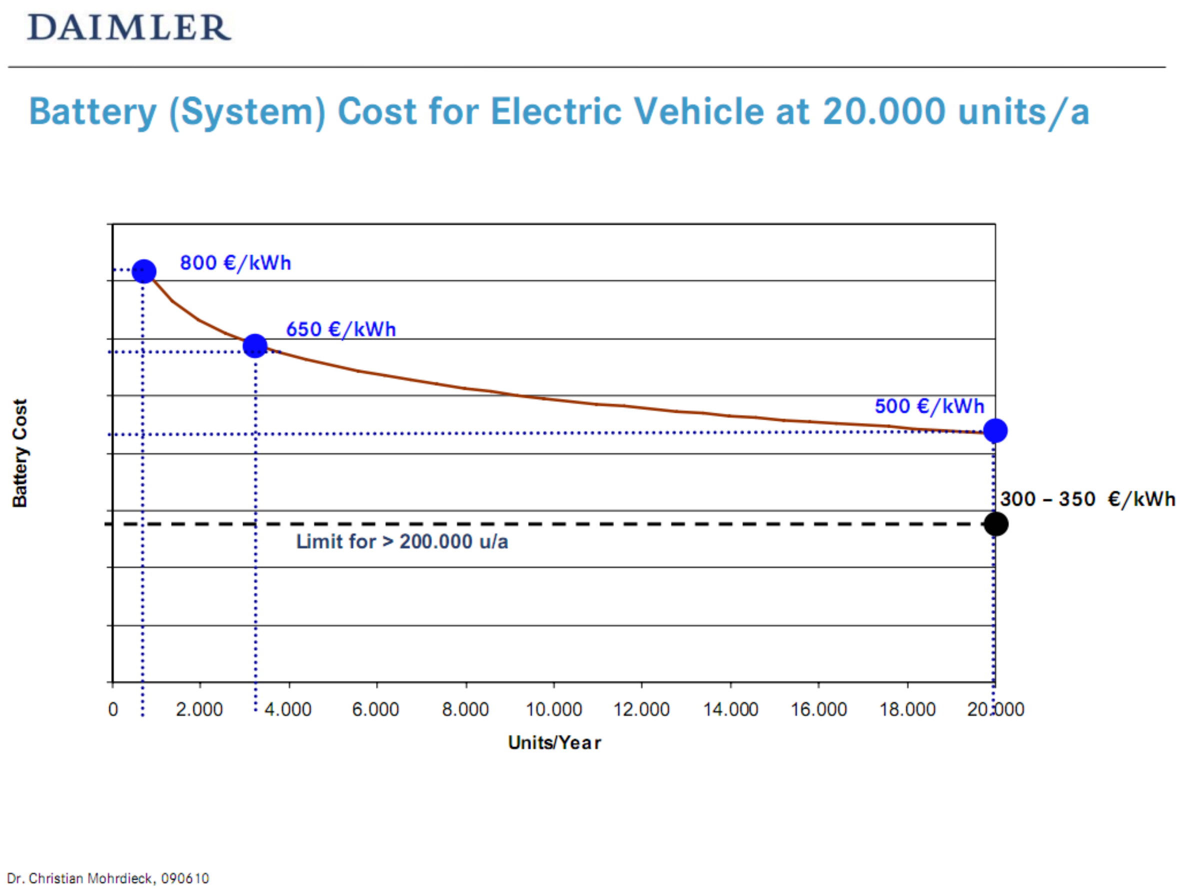


Figure 14: Projected learning curve for battery cost (source: Moordieck, Daimler AG)

How do these vehicle costs affect the political attitude towards "electromobility"? Shouldn't matters of cost simply be left to car manufacturers and, where appropriate, buyers?

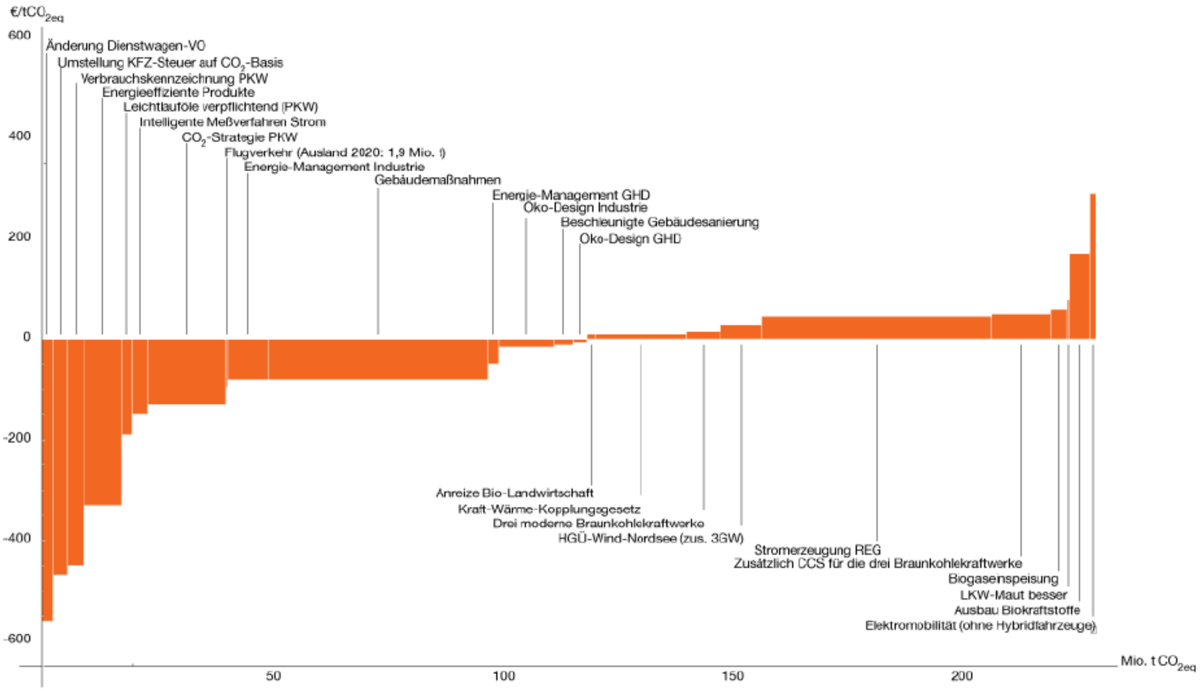
All parties to the electric-car debate are aware that there will be next to no buyers for electric cars, as the concept will be unmarketable. It is taken for granted that the State will employ public funds to build a market for the electric car, and that favourable tax arrangements will be made to offer users an economic advantage.

From the environmental-economic perspective, we need to consider whether this is an efficient use of resources. At issue are more than just purchase and fuel (energy) costs, as it is self-evident that no tax analogous to the duty on petrol or diesel will be levied – as if electric cars necessitated no spending on roads. Essentially, it is glossed over that the low energy cost per kilometre travelled is a result of government subsidies that will have to be lifted in the event that marketing is a success, with severe consequences for users' finances.

Where infrastructure costs are concerned, it is also either forgotten or covered up that huge investments will be borne by the public purse. Often it is wrongly assumed that the existing electricity network will be adequate. However, some 80 % of the population of large urban centres live in apartments and have no garage. Charging points will therefore be required, at an additional investment of 4 000 to 6 000 euro per vehicle.

Who will bear these costs? Should we assume that each on-street parking space will be equipped with a public charging point? In contrast to filling stations, where a car occupies a pump for no more than five minutes every two weeks or more, charging will be daily and will last hours. And even if the planners find technical solutions, electric cars are and will remain expensive, both for the individual and for society.

One question is therefore primordial: how much will it cost to save one tonne of CO_2 compared with the cost of reducing the emissions of conventional cars? A broad alliance of leading German research institutes has calculated the costs of a range of measures to reduce greenhouse emissions from motorised traffic. See Figure 15.



[Figure 15 captions:

euro / t CO_2 eq.

Amendments to company car legislation
Road tax aligned with CO_2 emissions
Emissions labelling of cars
Energy-efficient products
Compulsory use of fuel-efficient engine oils (cars)
Intelligent electricity metering
CO_2 strategy (cars)
Air traffic (international): 1,9m tonnes by 2020
Energy management (industry)
Buildings regulations
Energy management (trade and services)
Eco-design (industry)
Accelerated planning of buildings renovation
Eco-design (trade and services)
Organic farming incentives
Combined-heat-and-power legislation
Three modern lignite power stations
HVDC wind power in North Sea (3 GW)
Electricity generation from renewables
CCS measures for the three lignite power stations
Feeding-in of biogas
Improved HGV toll
Expansion of biofuels
Electromobility (except hybrid vehicles)

Million tonnes CO_2 eq. **]**

Figure 15: CO_2 reduction costs by measure (source: Jochem et al***, PIK 2008)***

Without examining these measures in detail, we can conclude that battery-electric vehicles are one of the most expensive routes to reducing CO_2.

4. Stakeholder motives

4.1 Political

There is enormous pressure for policy to be justified. The German authorities and the EU have made ambitious commitments to the reduction of greenhouse gases in Germany and the European Community. In the Kyoto Protocol the EU undertook to reduce emissions between 2008 and 2012 to 8 % below 1990 levels. In order to achieve this objective the Member States have signed up to national climate protection goals, with Germany agreeing to cut greenhouse emissions by 21 % (compared with 1990) during the same period. The rules relate to emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) (compared with 1990), as well as hydroflurocarbons (HFCs), perfluorocarbons (PFCs) und sulphur hexafluoride (SF_6).

During preparations for the UN Climate Conference in Copenhagen in December 2009, the EU Member States agreed to a 20 % cut in greenhouse emissions (compared with 1990) by 2020. Should other major nations commit themselves to significant targets, the EU is even envisaging a 30 % reduction. At its 2008 summit in Meseberg the German government targeted a reduction of 40 %. In the past, most sectors have achieved greenhouse gas reductions. However, in the EU the transport sector has substantially increased emissions. In Germany there has been a reduction, but this is far smaller than in other sectors.

Thus there have already been political steps to reduce greenhouse emissions from road traffic in the EU. Improvements to vehicles' operating efficiency are a major policy objective. In the case of heavy goods vehicles, the political view was that high fuel prices would exert sufficient pressure to bring about an improvement in consumption figures (and thus CO_2 emissions). Meanwhile, in 1995 the EU Council of Ministers – acting on a proposal by Angela Merkel, then the German Environment Minister – agreed on a ceiling of 120 g/km to be achieved no later than 2012 for the average CO_2 emissions of all passenger cars sold in the EU. The automobile industry successfully lobbied against this decision at all political levels, and in 1998 it persuaded the EU to accept a voluntary commitment by European manufacturers to reduce the average CO_2 figure for new models to 140 g/km in 2008. In return the EU agreed not to impose any statutory obligations. During the next decade the industry did little if anything to comply with this voluntary undertaking. Average CO_2 emissions fell very little, and in 2007 they still lay above 160 g/km. The figure for German cars sold in the domestic market was over 170 g/km.

As a result of this failure, EU Environment Commissioner Stavros Dimas proposed in December 1995 that the Commission impose a CO_2 ceiling of 120 g/km from 2012. Following long and difficult negotiations, in the course of which Chancellor Merkel vehemently opposed the setting of excessively onerous limits for larger cars in particular, a blanket introduction of the 120 g/km figure was postponed until 2015.

However, although it may appear politically attractive, this upper limit masks further dilutions. For example, 10 g/km are supposed to be achieved by the use of biofuels, fuel-efficient tyres and gear-change indicators. Given that biofuels are not marketed by the automobile industry and have a range of negative environmental effects, and that more efficient tyres are in any case being introduced in order to satisfy the CO_2 reduction requirement, the net result is to add 10 g/km to the original ceiling. It is still unclear how gear-change indicators can be included in the calculation, as the industry has not presented any clear-cut data on the reductions that they generate. A further 7 g/km should be factored in for so-called "eco-innovations", which raises the real ceiling to 137 g/km in 2015.

It is foreseeable that this moderate enforced reduction in CO_2 emissions will just about compensate for the rise in vehicle numbers. Given the forecast increase in HGV numbers, however, the growth in Europe’s CO_2 emissions from road traffic is set to continue.

Politicans are therefore clutching at any straw that might promise a reduction in greenhouse emissions from road traffic. Thus the EU Directive on limiting CO_2

emissions from passenger cars contains a clause providing for a CO_2 "super-credit" in the case of new environmental technologies.

These "super-credits" will apply as follows: in calculating the average for each manufacturer’s product range, cars with CO_2 emissions of less than 50 g/km will be counted as 3,5 cars in 2012 and 2013, 2,5 cars in 2014 and 1,5 cars in 2015. Manufacturers can quote zero emissions for electric cars, regardless of energy source. When used in electric cars, electricity from renewable sources counts 2,5 times towards the 10 % renewable-energy quota for the transport sector. When used by the railways, however, it is counted only once.

The problem with these credits is that the emissions of conventional vehicles will rise if sufficient numbers of electric vehicles are licensed. This will be aggravated by the fact that electric vehicles, with their limited range, will cover far fewer km per year than, for example, diesel-powered cars. The end result will be a still smaller overall reduction in CO_2.

4.2 Automobile industry

The development of new vehicle designs, such as the electric car, requires considerable financial and human resources. For this reason, it is at first surprising that the European automobile industry – and German manufacturers in particular – should have responded so positively to political expectations. For the next 15 or 20 years the electric car is universally expected to take only a minor share of car sales. The very ambitious forecasts of the government’s "National Electromobility Development Plan", which was published in August 2009, are for one million electric cars to be on Germany's roads in 2020. At present rather more than 41 million cars are registered in Germany. Consequently, even in 2020 conventional models will represent the German car industry’s core business.

Most cars sell not only for reasons of utility but also for the image that the buyer and his social group associate with the vehicle in question. Manufacturers therefore need to keep up with society's changing perceptions of image. As people become increasingly responsive to the issue of climate change, manufacturers have to offer the appropriate solutions. This does not guarantee sales of the corresponding vehicles, because car purchases also depend on a wide range of other factors, chief of which are price and utility. A recent German Automobile Club (ADAC) survey of its members' readiness to purchase electric cars showed a positive reaction of 90 %. However, almost 40 % of respondents would not spend more for an electric car than for a comparable conventional car. Only 10 % would be satisfied with a range of up to 100 km, while one person in five would require a range of 200 km and the largest share (31,6 %) would expect to travel 500 km without the imposition of charging.

What this means, however, is that the expectations of potential buyers cannot be harmonised with the technological and financial limitations that will for so long apply to electric vehicles.

Manufacturers can nonetheless influence the way they are perceived even if sales of innovative designs are low. The Toyota Prius is an admirable example of this. Although the CO_2 figures for VWs and Toyotas sold in Germany were virtually identical in 2007, Toyota has impressively managed to exploit the relatively low level of Prius sales to enhance its image. Models such as VW's BlueMotion range and BlueEFFICIENCY-badged Mercedes cars have the same aim.

It is therefore important for car manufacturers to be the first to achieve limited sales of electric cars. In so doing they will satisfy policy objectives without awakening public expectations that electric vehicles could soon replace conventional cars.

It is important for manufacturers to satisfy policy objectives because paying lip-service to a cleaner future could prevent the enforcement of more stringent CO_2 standards. It is equally important to stress innovation leadership and seek further tax breaks in connection with an emphasis on the automotive industry's significant export earnings. This is balanced, however, by the significant risk of giving customers false hope, which could translate into disappointing sales. Politicians might also use technological promises to set sales quotas, as in California, for example.

4.3 Electricity industry

Thanks to its stranglehold over the electricity networks since what was termed "liberalisation", the German electricity sector has earned even more in recent decades than in the days of its traditional monopoly. The market is ruled by four giants, and competition is practically non-existent. There is something amiss with political governance when the prices charged to private households can explode at the same rate as the Big Four's profits. The electricity market shows that profits can continue to increase at a constant rate of turnover.

German electricity generation is still heavily dependent on fossil energy sources entailing emissions of CO_2. Table 1 shows the latest trends. The share of wind energy in electricity generation has risen markedly, as has that of natural gas, but photovoltaics still account for a very small part of production.

Gross electricity generation by energy source in Germany

Energy source	**2006 bn kWh**	**2007* bn kWh**	**2008* bn kWh**
Lignite	151,1	155,1	150,0
Nuclear	167,4	140,5	148,8
Coal	137,9	142,0	128,5
Natural gas	73,4	75,9	83,0
Petroleum	10,5	9,7	10,5
Water	26,8	28,1	27,0
Wind	30,7	39,7	40,2
Other	39,1	46,4	51,1
Gross production	**636,8**	**637,6**	**639,1**
Imports	46,1	44,3	40,2
Exports	65,9	63,4	62,7

Net imports	-19,8	-19,1	-22,5
Energy consumption incl. grid losses	**617,0**	**618,4**	**616,6**

Table 1: Energy sources by share of electricity generation in Germany (source: Federal Office of Statistics, BDEW 2009)

The Renewable Energies Act allows the electricity sector not only to pass on the costs of renewable energy production to private households, but also to benefit from CO_2 certificates, which the State has effectively gifted free of charge. It is true that CO_2 emissions will actually cost something in future – that much the EU has been able to enforce.

Market saturation has made it necessary for the electricity sector to seek additional sources of income. For decades repeated efforts have been made – by RWE for example – to launch the battery-electric car, but without success because of the lack of a technological or economic basis. Generally speaking, electricity companies have never played more than a marginal role in the transport sector – apart from the fact that underground and commuter railways and trams run on electricity. Deutsche Bahn produces its own electricity via a separate grid.

In the past three or four years a greater degree of commitment has become noticeable in the form of the electric car, even though it is clear to all concerned that the market will remain negligible for a few years yet. The Environment and Energy Institute (IFEU) has calculated on behalf of the Environment Ministry that the government's target of one million electric vehicles by 2020 – see the detailed discussion below – would account for far less than 1 % of electricity production[13].

Image is also the main concern of electricity companies. For example, RWE has the advertising slogan "Experience the fuel of the future – RWE Autostrom". Although no economically relevant production will be possible in the foreseeable future, charging points are being built and roadshows proclaiming that RWE is the automotive fuel

[13] IFEU (2007): Electromobility, and working paper No 5 in the framework of the project "Energy balance – optimum system solutions for renewable energy and energy efficiency". Heidelberg.

provider of the future are criss-crossing the country. This is being done to distract attention from projects with a real economic interest – namely, the construction of new coal-burning power stations (both lignite and black coal) and extending the operating life of nuclear installations.

5. The environmental argument: electric cars and renewable electricity production

5.1 The main argument reprised: electric vehicles and zero emissions

In section 3.1 we gave a rough calculation demonstrating that, at current projections, electrically-powered cars will not bring any environmental benefit. Once account is taken of the high costs and side-effects, it will be impossible to overlook the disadvantages for climate protection.

However, environmentalists' visions for the electric car do not begin with coal-fired or nuclear energy, as the former produces excessive CO_2 emissions (as well as other pollutants) and current legislation provides for the latter to be cut back. Thoughts turn to a future in which electric cars will be powered by clean, renewable energy. When comparing CO_2 rates, then, there is a tendency to assume zero-emissions power for electric cars, in stark contrast to the CO_2 emissions of today's petrol and diesel-powered vehicles.

The question then arises, however, as to the availability of additional renewable electricity for this new use. E-cars will have to rely on "additional" energy because the German climate protection strategy already has other plans for renewable energy.

On the one hand, the high specific CO_2 emissions (i.e. per unit of energy produced) of lignite and then coal-fired power stations are set to be replaced by wind and solar energy. Another aspect of climate protection planning which is rarely addressed publicly is that, under the so-called "Meseberg programme" for the targeted 40 % reduction in greenhouse gases, there are plans to phase out night-storage heating, which is responsible for around 3 % of Germany's CO_2 emissions, by 2020. As far as electricity companies are concerned, the advantage of night-storage heating is that it exploits non-peak hours and can therefore be extremely profitable. In recent years, however, support for electric heating has justifiably declined, as overall it is highly energy-inefficient.

The use of electric cars could fill this future gap in sales. To that end, charging would ideally take place at night so as to match the pattern of consumption for night-storage heating, given that nighttime electricity is mainly what is known as "base-load" power generated by lignite, coal and nuclear power stations. "Base-load" greenhouse emissions are higher than those from the average German energy mix, which includes an increasing share of gas-fired power stations. The latter produce electricity that is lighter in CO_2 but relatively expensive. However, they have the advantage of being far faster to power up and down than coal-fired stations[14], and are therefore indispensable for daytime peaks. Base-load lignite and coal-fired stations would be perfectly suited to the charging of vehicle batteries. What price now the environmental impact of the electric car?

5.2 A straight comparison of electric power and petrol/diesel engines: energy consumption and greenhouse emissions

There follows an assessment of the climate impact of electric cars, in the form of a comparative analysis of the CO_2 emissions of electric and conventional internal-combustion vehicles. The comparison is based on versions of the Smart ForTwo, which exists both with a conventional drive and with an electric motor (so far used for road trials only). The load capacity and performance of both cars are broadly identical – save that the Smart electric drive has an inherently shorter range.

The manufacturer’s consumption figure for the Smart ForTwo electric drive is 12 kWh per 100 km (Daimler AG 2008). Given the average figure for Germany of 596 g of CO_2 per kWh of electricity[15], the Smart electric drive emits roughly 71,5 g of CO_2 per kilometer travelled.

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14 Nuclear power is only useful for base-load generation.

15 Average value for Germany, 2006. Source: Federal Environment Agency.

CO_2 – electric car using average energy mix

71,5 g CO_2 per km

The CO_2 emissions of the diesel version can be calculated as follows:

- Manufacturer's consumption figure: 3,3 l/100 km (Daimler AG 2009)
- Carbon content of diesel fuel: 86,3 %
- Density of diesel fuel: 830 kg/m³, or 830 g/l
- Specific ratio of CO_2 to carbon in the combustion process: 3,664

Thus, for the diesel version:

CO_2 – diesel

$$\frac{3{,}3l}{100\,km} * 86{,}3\% * 830\frac{g}{l} * 3{,}664 = \mathbf{86{,}6\ g/km}$$

At first sight, the electric Smart emits less CO_2 per km than the diesel version. However, we also need to consider whether the quoted average energy mix applies when charging the electric car. The ADAC has also given this matter some thought and has adjusted for electricity generated using coal only, with a further calculation for the petrol version of the Smart. The results are as follows:

Version	**Smart ForTwo electric drive E-Motor**	**Smart ForTwo electric drive E-Motor**	**Smart ForTwo coupé 1.0 mhd Otto**	**Smart ForTwo coupé 0.8 cdi Diesel**
Output	30 kW	30 kW	52 kW	33 kW
Energy source	Electric/German energy mix	Electric/black coal	Petrol	Diesel
CO_2 emissions	71 g/km	107 g/km	103 g/km	88 g/km

Table 2: Comparison for the Smart: electric, petrol and diesel versions

When charged with coal-fired electricity, the electric version performs least well in terms of climate protection. As well as the value for CO_2 emissions, consumption for the entire energy chain is of interest. The higher emissions figure of an electric car powered by coal-fired electricity is parallelled in its consumption of primary energy, as can be seen below.

The **diesel version of the Smart uses 3,3 l/100 km**, with a fuel density of 0,830 g/l and a calorific value of 45,9 MJ per kg of fuel.

Energy consumption in MJ/100 km:

$$= \frac{3,3l}{100\ km} * \ 0,830\frac{kg}{l} * 45,9\frac{MJ}{kg} = \mathbf{125,7}\,\frac{\boldsymbol{MJ}}{\mathbf{100}\boldsymbol{km}}$$

The primary energy consumption of the **electric version**, using coal-fired energy only, can be calculated as follows.

- Consumption: 12 kWh/100 km = 43,2 MJ/100 km
- Despite the extremely high efficiency of modern Li-ion batteries, it should be observed that charging and discharging cause losses of 20 % (Merten *et al* 2009, p. 6)
- Power distribution losses are assumed to be 5 %
- Average efficiency of German coal-fired power stations: 40 %

Energy consumption – electric:

$$= \frac{43,2\ MJ}{100\ km}/80\%\ /95\%/40\% = \mathbf{142,1}\,\frac{\boldsymbol{MJ}}{\mathbf{100}\boldsymbol{km}}$$

Although final-drive efficiency is far higher in an electric car than in a conventionally-powered vehicle[16], a full "well-to-wheel" comparison removes this advantage and even reveals electric power to be inferior. This is due above all to efficiency losses down the entire chain leading from generation, via distribution, to the conversion of electrical power into mechanical energy in the electric vehicle.

Mathematically speaking, electric vehicles attain energy equivalence above a power station efficiency threshold of around 45 %. Modern coal-fired stations are eminently capable of this value, and it is exceeded by gas-and-steam and CHP plants.

Whether electric vehicles offer any CO_2 advantage therefore depends heavily on the primary energy source and the efficiency of the power stations where the electricity is generated. The introduction of electric vehicles only makes sense from the angle of reducing total CO_2 emissions if the energy mix is heavily adjusted in favour of alternative sources. This was also the conclusion reached by the federal government in a decision taken at cabinet level on “electromobility”: "In order to achieve the government’s energy and climate targets the additional need for electrical energy in this sector will have to be met by means of power from renewable energy sources".

The word "additional" must therefore be understood as meaning that no renewable energy used for battery-electric vehicles will be withdrawn from use elsewhere. This has important ramifications for the economy as much as for the environment or the climate, since all studies so far have shown that renewable energy can save more CO_2 per unit cost in stationary applications than in motor vehicles (see above for the costs of the e-car).

The situation may be different in countries like Switzerland or Sweden, where renewables already account for a significant share of electricity generation. However, it should be remembered that Europe has an integrated power grid. So if Swiss

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16 For a number of reasons, electric/internal-combustion comparisons are not possible without making considerable assumptions. For example, no account is taken of the inferior performance and range of electric cars: a power unit-only comparison should assume lower output and smaller tanks for petrol and diesel engines. In electric cars, meanwhile, the power requirement of all comfort features, such as heating and AC, should be considered in isolation. Turning the heating on in winter would thus shorten the range by half (added to which battery capacity is reduced at low temperatures).

power is used in Switzerland for electric cars, less renewable energy will be available for export to other countries, such as Germany.

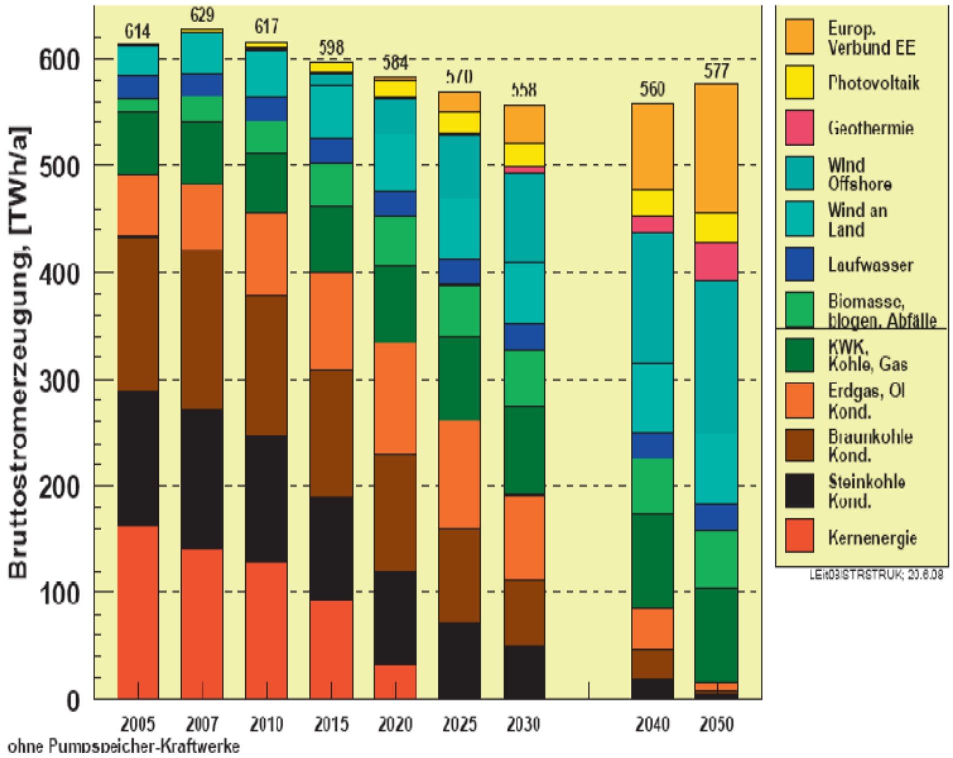
Given the globalisation of the automotive industry – development of the electric car is also promoted from the angle of future worldwide market guarantees – the aim will also be to export electric cars to countries such as Egypt, China and India, where, owing to the local dependence on coal for electricity generation, they will cause far higher CO_2 emissions per km than modern conventionally-powered vehicles.

5.3 The future of electricity generation

A major 2008 study on the future development of the strategy to extend renewable energies concluded that, if the federal government complies with the EU Regulations for the period to 2015, it will achieve its 2020 target of meeting at least 30 % of gross energy requirements from renewable sources (Nitsch 2008). The study even claims that renewables could furnish more than 80 % of energy by 2050 (cf. Figure 17).

The following remarks are predicated on the observations in the 2008 study, which was commissioned by the federal government and is frequently cited. It assumes a very steep increase in the use of renewables and stresses the – still valid – withdrawal from nuclear energy.

It should be emphasised that CO_2-intensive lignite and coal-burning power stations are expected to meet base-load needs until beyond 2040, and that no "surplus" renewable electricity will be available for new zero-emissions consumption, even offpeak, until after 2030. Environmentally, therefore, it would be absurd to reassign the electricity used for night-storage heating (quite rightly removed from the grid) to the transport sector.



[Figure 16 captions: **Gross electricity generation (TWh/year)**
Excludes pumped-storage power plants

European alliance for renewable energy
Photovoltaic
Geothermal
Wind offshore
Wind onshore
Hydro
Biomass, biogenerative waste
CHP, coal, gas
Conditioned natural gas, oil
Conditioned lignite
Conditioned coal
Nuclear]

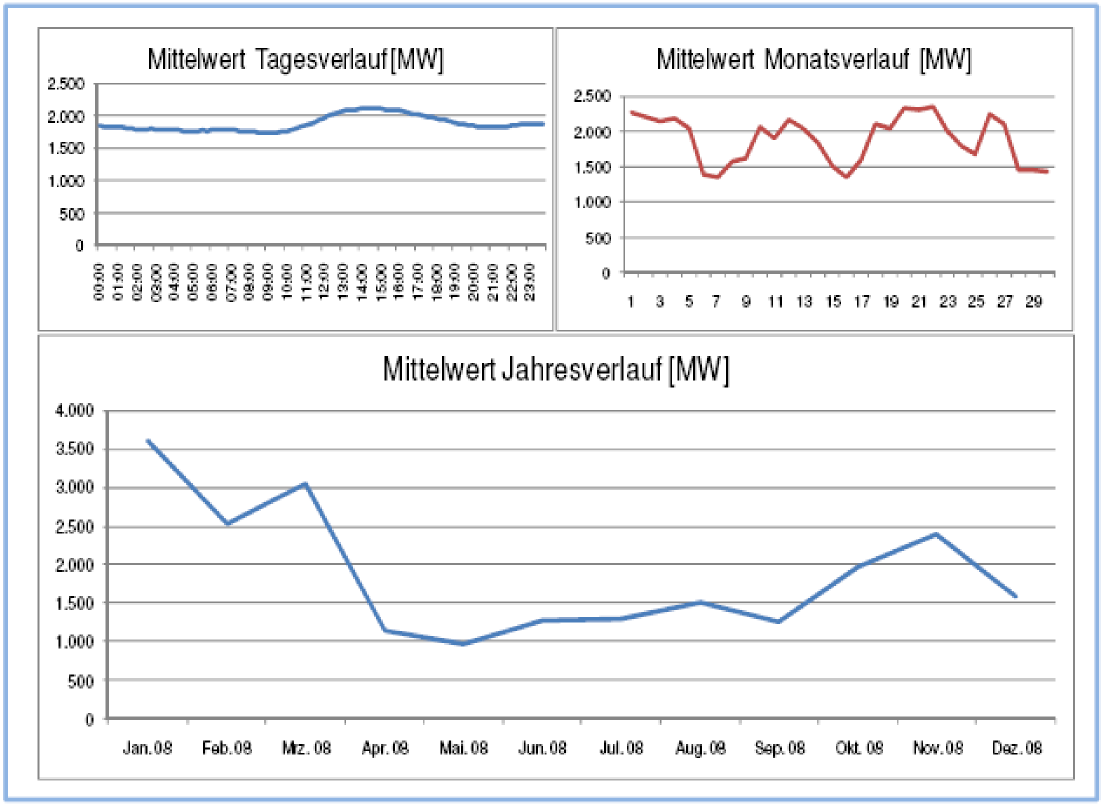
Figure 16: Structure of gross electricity generation in 2008 Lead Scenario (Nitsch** et al **2008)

5.4 The second environmental argument: electric cars as a buffer grid[17]

Many of the renewables that are being brought online for electricity generation, such as wind and solar energy, are subject to natural fluctuations that are largely meteorologically induced. It is becoming more difficult to regulate the electricity grid

[17] Main source: Pfister 2009. Fernuniversität Hagen.

so as to obtain a balance between power input and output, as, like the demand for electricity, so too the electricity supply increasingly defies direct control. As electricity from renewable sources becomes more widely available, there is a corresponding increase in the need for "reserve energy" – i.e. electrical energy that can be used, even temporarily, to compensate for imbalances in demand or (in the case of renewables) supply.



[Figure 17 captions: Hourly mean (MW) Daily mean (MW) Monthly mean (MW)
Jan 2008 Feb 2008 … ... Dec 2008 **]**

Figure 17: Input of electricity from wind power in the E.ON Netz control area, 2008. (Source: Pfister 2009, using data from E.ON Netz GmbH 2009)

Fluctuations in the generation of electricity from renewable sources are described below in relation to E.ON wind energy. As can be seen from Figure 17, which gives data for the electricity generated from wind power in the E.ON Netz control area in 2008, there are considerable fluctuations, especially from day to day and from one season to the next, in the production of electricity using wind energy. While power output varies with a certain regularity between the winter and summer months, over the course of a month fluctuations are more random and depend on the prevailing weather conditions.

When measured over the course of a day, however, the mean value for energy generation is relatively constant – as might be expected, given that wind speed does not generally vary much over a period of hours. The values in Figure 17 are for 2008 only. Although the basic pattern of daily and seasonal fluctuations remains the same, there are not inconsiderable variations in total energy output from one year to the next.

Much the same is true of the generation of electricity from solar power – using either solar thermal or photovoltaic technology. Here too the fluctuations are mainly seasonal or daily rather than by time of day, mainly because solar thermal plants can store heat energy in large thermal reservoirs for several hours, for example overnight or when the weather is unfavourable.

Although it is true that input variations from wind energy are less noticeable in the case of offshore farms, the load management problem is growing in urgency as fluctuating renewables take an increasing share of gross production. According to the 2008 "Lead Scenario" (Nitsch 2008), the share of fluctuating energy sources will surpass 60 % by 2050. Unless innovative load management systems become available, it will be impossible to retain control of such volumes, as today's peak-load power stations are either fossil-driven (e.g. gas turbines) or are nearing their expansion limits (e.g. pumped-storage power plants).

In this context, there are two technologies which are usually mentioned in connection with alternative power: the "hydrogen economy" and battery-electric mobility ("vehicle-to-grid"). The hydrogen economy will not be discussed here.

The current idea is to use the batteries in electric vehicles in order to cushion the grid fluctuations caused by wind and solar generation. A "vehicle-to-grid" connection would be established not only for charging but also, on a continuous basis (save of course when the vehicle was in use), so that the battery could serve as a temporary store for surplus electrical energy. Cars would be charged during off-peak demand and would discharge at peak times to send power back to the grid. Essentially, therefore, electrical energy would flow in both directions – from grid to battery and back again – as required by the vehicle and the grid. Charging points would be set up in homes, at the workplace and in public areas so that cars could be connected to the grid as frequently as possible. Charging and discharging would be controlled by the electricity provider using vehicle-mounted telematics devices.

The electrical energy stored in vehicle batteries would be used in particular to balance peak loads and level out grid fluctuations. Initially, "vehicle-to-grid" would "merely" provide a new load management option for public electricity networks – it would not lead *per se* to the more extensive use of renewables in electricity generation. In that respect, it would initially function as a new solution to an old, purely energy-specific problem. We have already shown that the main challenge of incorporating fluctuating energy sources into the public grid lies in their seasonal and daily variability. If guarantees are sought that an electric vehicle will really always be ready for use (rather than fully discharged when it is needed most), the energy stored in an electric car can only be used to offset temporary peak loads. The capacity to store charge for a matter of hours or, at most, a day will hardly contribute to the integration of fluctuating renewables.

6 Conclusion

Electric cars will make no noticeable contribution to climate protection for another 15 years. There is little sense in fleet trials of unsuitable vehicle designs. What is needed is a drastic improvement in the energy efficiency of conventional motor vehicles.

Nevertheless, it is appropriate to step up research into better and, above all, more cost-effective systems of storage. In the very long term, electricity from renewable sources could be so widely available that electric power becomes a sensible alternative to the internal combustion engine – on condition, however, that vehicle energy efficiency is drastically improved. Only then is there hope that, thanks to improved batteries, electric vehicles that are sufficiently attractive and cost-effective will be able to compete on the market.

Today's industrial and political interest in the electric car is damaging to the cause of climate protection, as it obstructs the really effective options for reducing the greenhouse emissions of road traffic:

- Rapidly lowering CO_2 emissions ceilings to, for example, 80 g/km by 2020;
- Improving public transport through the more effective use of public funds.

As regards the oft-repeated claim that electric power is more efficient, it must never be forgotten that electric and internal-combustion power units cannot be compared without making considerable assumptions. Most reports published range from the technically incompetent to the naïve[18]. The inferior performance and limited range of electric vehicles are constantly overlooked. Comparisons should also assume, for example, lower continuous power ratings and smaller tanks for petrol and diesel engines. It is also important to note that the few electric cars on the road today are hand-built and have hand-picked technical equipment. Mass-produced vehicles may look somewhat different. What is more, in electric cars the power requirement of all comfort features, such as heating and AC, should be considered in isolation. For example, turning the heating on in winter would significantly compromise range.

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18 On 2.11.2009, for example, the Süddeutsche Zeitung ran an enthusiastic article about a four-week regular-traffic test of the electric Mini, which returned a consumption figure of 250 kWh for 860 km. This corresponds to over 29 kWh/100 km, or (at the electricity grid's current CO_2 emissions rate of just over 600 g/kWh) 174 g/km. Compare that with a February 2009 press release: "The Federal Office of Motor Vehicles confirms BMW Group’s leadership in reducing fuel consumption, with a 2008 fleet average of 158 g/km."

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