Status Quo and Future Prospects of Sustainable Mobility

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1 Introduction

Climate change, CO[2] emissions, depletion of fossil fuels[1] and energy costs have been intensely discussed worldwide for many years. These topics can be called megatrends without having to exaggerate.

The transportation sector is one of the largest consumers of fossil fuels also making it one of the biggest producers of CO[2]. Therefore political and private stakeholders are becoming increasingly aware of the transportation sector. Generally it can be said, that the entire transportation system is a phase of transition.

This article provides a general picture of progress being made by different means of transport in making transport more sustainable and shows probably trends.[2]

2 Resource Consumption and Climate Impact of the Transportation Sector

Transportation and fossil fuels are up to today strongly linked together: More than 60% of the 84 million barrels of oil which are consumed daily are used to power LDVs, HGVs, airplanes, ships and other means of transport.[3] In the future a further increase in consumption of fossil fuels is predicted (see passenger transport volumes in 17 Western European countries in Table 1, excluding ships). On a global basis the increase of transportation services in fast growing markets of Asia have a considerable impact.

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1 The statistical lifetime (which assumes constant consumption and constant output) for crude oil is 41 years, for natural gas 61 years, cf. Dena (2010), p. 14.

2 Particular attention is drawn to the fact that status quo observations and forecasts are being made in the context of rapid change.

3 Cf. World Economic Forum (2011), p. 8.

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Table 1. Passenger transport volume in 17 Western European countries from 2008 to 2025. Source: Progtrans (2011).

Carrier	Total Traffic 2008 (in billion passenger kilometers)	Total Traffic 2025 (in billion passenger kilometers)	CAGR 2008 -2025	Percentage 2008	Percentage 2025
LDV	4,284	4,552	+ 0.4 %	74.1 %	71.1 %
Bus	442	492	+ 0.6 %	7.7 %	7.8 %
Long-distance rail traffic	376	466	+ 1.3 %	6.5 %	7.3 %
Short-distance rail traffic	68	87	+ 1.5 %	1.2 %	1.4 %
Airplane	604	751	+ 1.3 %	10.5 %	11.8 %
Total	5,774	6,348		100.0 %	100.0 %

It is established that for a “continue as before”-scenario the transportation sector will consume 40% more energy than today by 2030 (see Table 2). [4] The transportation sector would thereby be responsible for 97% of the worldwide increase in oil consumption.[5]

Table 2. Worldwide energy consumption of the transportation sector 2010 – 2030 in a “continue as before”-scenario. Source: World Economic Forum (2011), p. 61.

Carrier	Energy consumption (in Mtoe/year 2010)	Energy consumption (in Mtoe/year 2030)	CAGR 2010–2030
LDV	1,144	1,667	1.9 %
Truck	379	464	1.0 %
Bus	81	66	–1.0 %
Aviation	215	411	3.3 %
Marine	227	272	0.9 %
Rail	71	76	0.4 %
Other	69	125	3.0 %
Total	2,186	3,082	1.7 %

The wide consensus is that this development must be avoided due to several reasons: The earth’s oil reserves are limited, CO^2 emissions are causing the climate change, harmful substances and noise emissions are putting people’s health in danger, especially in metropolitan regions, and rising fuel costs, which result from rising crude oil prices[6], should be evaded due to economic reasons.

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4 Cf. World Economic Forum (2011), p. 11.

5 Cf. IEA (2009), p. 73.

6 Information on the increase of crude oil price see amongst others IEA (2009), p. 63ff.

The tourism sector is affected by these developments because change of location is the major fundament of tourism. Tourists are problem causers and victims alike: They are responsible for resource consumption and climate change, and travel is made more difficult for them when transportation becomes more expensive or rules are made adding restrictions.

Two means of travels are of utmost importance in the tourism industry: The passenger car is by far the most important vehicle for holiday trips. In Germany trips lasting longer than five days 48% of travelers use their own car. With 37% the airplane is the second most important method of transport.[7] The airplane has been publically criticized and labeled as a “climate killer”, because airplanes are responsible for an above average increase in energy consumption and exhaust emissions due to the above average growth of air traffic. Once more tourists are in general users of carriers in the destination, which they use for excursions and sightseeing.

If global warming is to be confined to 2° Celsius then an 85 % reduction of CO^2 emissions by 2050 against 2000 is necessary. The European legal framework under the act of the European Parliament EU regulation 443/2009 allows an EU fleet consumption of 95g/km[8]. Such ambitious goals are only attainable if the basic structure of the transportation sector changes. Efforts to help electric vehicles (EVs) make a market breakthrough are currently at the forefront.[9]

Electro mobility seems to be a renaissance of the mobility concept: Few are aware that at the beginning of the 20th century automobile pioneers experimented with electric motors as well as combustion engines. Gustave Trouvé presented a vehicle with electric drive in Paris five years before Carl Benz applied for a patent for his vehicle.[10] Around the turn of the 20th century many cars in Hamburg, Berlin and New York were powered by electricity. Electric drive was very popular then, because cars with combustion engines were loud, polluted the air and had to be started using a hand crank. Hybrid drive was also known over 100 years ago: Ferdinand Porsche presented a Lohner-Porsche with an e-motor and combustion engine at a world exhibition in Paris in 1900. Ultimately, internal combustion engines (ICE) won the race on account of the travelling radius they provide and the lower-cost fuel they use.[11]

The current challenge is to reshape the global transportation system in terms of sustainability. Sustainability is given when intact ecological, social and economic structure are handed down to subsequent generations.

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7 Cf. FUR (2011), p. 4.

8 Cf. EU (2009).

9 Cf. Malomy (2011). McKinsey calculates that 68-93% of all traffic must be powered by electricity so that the target of an increase in temperature of 2°C due to global warming can be met.

10 Cf. Mobility today (Mobilität heute) (2010), p. 5.

11 Cf. Greenpeace (2011), p. 24, 29.

3 Determining "Sustainable Mobility"

"Sustainable mobility" is not defined as a universally understandable term. The German government has a loose understanding of the term when it comes to classifying sustainable mobility into three segments:[12] Efficient and alternative drives or fuels, diversion of traffic and traffic avoidance.

The first segment – ensuring efficient and alternative drive systems or fuels – aims at cutting primary energy consumption and consequently also at reducing pollutant emissions. The following mobility concepts are generally described as "sustainable".

- Conventional mobility concepts with efficiency improvements: Efforts being made by all modes of transport (road, air, rail and waterborne transport) to reduce fuel costs were reason enough to make varied approaches to optimize drives, so that the same traffic performance can be achieved using less fuel. However such optimized conventional mobility concepts cannot really be regarded as sustainable, as consumption of fossil fuels is further required and exhaust emissions are still being produced – though be it in less amounts.
- Electromobility concepts: These are all concepts which involve the drive being at least partly powered through the help of electric motors. Electric Vehicles (EVs), road vehicles with an electric motor, are the epitome of sustainable mobility. Electric drive concepts are not suited to air traffic due to the unfavorable performance/weight ratio. They also play a minor role in waterborne transport, whereas in rail traffic they are a given. Currently most efforts are being especially made to help LDVs with electric motors to make a market breakthrough. Mention is given here to hydrogen as well as fuel cell drives.
- Mobility concepts with alternative fuels: Alternative fuels are those which are completely or partly produced by renewable resources. These can be algae, maize, sugar cane or other plants. Such "biofuels" possess the advantage, that contrary to fossil fuels they grow back and produce less or no exhaust emission.
- Solar mobility concepts: Drive concepts which use solar power generated by solar cells attached to the vehicle are still in the early development phase. Here the values for primary energy consumption and exhaust emissions are zero. Remarkable pioneer projects can be found in air traffic with Solar Impulse[13], in shipping traffic with Planet Solar[14] and in road traffic with Solartaxi[15].

[12] Cf. Becker (2010).

[13] Cf. www.solarimpulse.com.

[14] Cf. www.planetsolar.org.

[15] Cf. www.solartaxi.com.

Changing means of transport can be sustainable if the change involves more resource efficiency and causes less exhaust emissions. Politically intended for example is substituting parts of motorized private transport with short-distance public transport and the shift from air to rail traffic. Of course traffic avoidance is the most sustainable option. Here for example the substitution of business trips with video conferences is noteworthy.

4 Digression: Basics of Power Generation

The process of transport requires the input of energy.[16] Figure 1 shows the most important primary energy sources with their specific strengths and weaknesses.

Primary energy	Brief description	Strengths	Weaknesses
Crude oil	• Usage of heat energy through burning oil • Currently the most important energy source in the transportation sector	• Very high energy density • Very good deploy ability for means of transport • Optimal suitability for air traffic • Established crude oil distribution system	• Oil resources are coming to an end • Supply insecurities due to political uncertainties in oil producing countries • High pollutant emissions
Natural gas	• Usage of heat energy through gas combustion • Important energy source for generating electricity • So far little use in the transportation sector	• Natural gas reserves will outlast oil reserves • Switching quickly to and from gas power plants provides an ideal energy buffer • Compared to oil: Lower pollutant emissions • (Non-hydrocarbon methane)	• Natural gas reserves are coming to an end • High pollutant emissions (Hydrocarbons) • High infringement of the environment due to production and transport through pipelines
Coal (black coal and lignite)	• Usage of heat energy through burning coal • Important source of energy for generating electricity • No longer used in the transportation sector (earlier use by steam engines)	• Has probably the longest availability worldwide of all fossil fuels • Coal resources in countries which don't produce gas or oil (e.g. Germany)	• Extremely high pollutant emissions, especially lignite • High infringement of the environment, especially lignite production • Not suitable for any means of transport
Bituminous sands	• Currently of little importance as an energy resource	• Found in politically stable countries (e.g. Canada)	• Complicated mining and high production costs • High infringement of the environment • Low energy density
Nuclear power	• Power generation through nuclear fusion • Common source of energy for generating electricity • Not yet used in the transportation sector (exception: nuclear submarines)	• No toxic emissions • Low costs, if follow-up costs caused by nuclear accidents are not considered	• Limited uranium resources • High safety risks • Low level of acceptance in many countries • Not suitable for any means of transport

Fig. 1. Important primary sources of energy with their specific strengths and weaknesses

[16] The application of man power (e.g. cycling or walking tours) is neglected in the following. Changing location in this way is a marginal phenomenon in the tourism industry.

Primary energy	Brief description	Strengths	Weaknesses
Wind power	• Use of wind-produced kinetic energy which is generated by transformers • Common renewable energy source • Increasingly important for power generation	• Inexhaustible energy source • No pollutant emissions • Favourable cost structure in windy areas	• Necessity to expand the power supply system • High infringement of the environment • High costs for offshore wind parks • Inconsistent power production • Not suitable for any means of transport (exceptions: ships, gliders)
Solar energy	• Solar cells generate electric power • Relatively rare source of renewable energy • Increasingly important for power generation	• Inexhaustible energy source • No pollutant emissions • High potential of cost reduction in photovoltaic	• Necessity to expand the power supply system • Solar cells require a lot of space • High costs in regions with little sunlight • Inconsistent power generation in regions with little sunlight • Very limited use for any means of transport
Biomass	• Electricity generation through combustion of biomass (wood pellets, straw, grain, etc.) • Converting organic raw materials into oil • Still a relatively rare source of renewable energy • Increasingly important for power generation	• Renewable source of energy • Can be used to power modes of transport (in the case of bio fuels) • Bio fuels have similar qualities to fossil oils • Low toxic emission	• Release of greenhouse gases (which would be released anyway due to rotting) • Potential competition with food production • Water consumption • Deforestation
Geothermal energy	• Electricity generation through the Earth's heat	• Inexhaustible energy source • No pollutant emissions	• Not suitable for any means of transport
Hydropower	• Use of kinetic energy created by waterfalls (gravitational energy) generated by transformers • Currently of little importance • Increasingly important for power generation	• No pollutant emissions • Potentially low costs • Inexhaustible source of energy	• Very dependent on the natural environment • Infringement of the environment • Not suitable for any means of transport

Fig. 1 (continued)

In the first half of 2011 20.8% of kilowatt hours produced in Germany were generated by renewable energy.[17] In the course of this 7.5% was created by wind energy, 5.6% by biomass, 3.5% by solar energy, 3.3% by hydropower and 0.8% by others (electricity generated by waste-fuelled power station and other renewable energy sources).[18] The German government's aim is to increase the share of renewable energy up to 35% by 2020, to 50% by 2030 and to 80% by 2050.

On a global basis the consumption of primary energy will rise each year by 1.5% between 2007 and 2030 which corresponds to an increase of 40% during this

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[17] With regard to conventional sources of energy in 2010 22% came from nuclear power, 19% from black coal, 24% from lignite and 14% from natural gas.

[18] Cf. German Federal Association for Energy and Water Management (2011).

period. In global terms the renewable energy's share of electricity generation will increase from 18% in 2007 to 22% in 2030.[19]

5 Concepts of Sustainable Mobility

Concepts of sustainable mobility can be found with all modes of transport. In the following the modes of transport, road, air and water will be looked at in detail. The mode of transport "rail" will be excluded, as this has long been considered sustainable. Therefore, radical changes towards sustainability, as can be currently clearly observed for other modes of transport, are not found for the mode of transport "rail".

5.1 Road Traffic

Efforts to increase efficiency of conventional combustion engines, have characterized activities for decades in the automotive industry. Fuel consumption is one of the most important decision criteria when buying a car.

Even though in the last decades clear progress has been made in terms of increasing efficiency, significant amounts of potential still seem to exist: Once again in the summer of 2011 the largest European energy saving race took place on the Lausitzring in Brandenburg which is carried out by the Shell Group. In 2010 a French team from Nantes managed to cover a distance of 4,896 km using just one liter of fuel. This equates to a fuel consumption of 0.02 liters per 100 km. In the category "Roadworthy Vehicles" a vehicle from the Trier University of Applied Sciences managed to travel 233 km using just 1 kWh of electricity in 2011.[20] These experiments show what efficiency reserves still remain. The German automotive industry believes that increasing efficiency by 25% by the end of this decade is possible.[21]

There are numerous types of fuel available to power vehicles. Table 3 outlines the amount of greenhouse gas emissions of different fossil and **alternative fuels**.

Most newly registered cars in Germany still have conventional drives, see Table 4. It is astonishing that only 541 electric vehicles were registered.

The main concept of sustainable mobility, which currently dominates economic and political discussions, is to ensure that electric vehicles ("electromobility")

[19] Cf. IEA (2009), p. 73.

[20] Cf. Shell (2011).

[21] Cf. Wissmann (2011), p. 2.

Table 3. Greenhouse gas emissions of different fuels. Source: Dena (2010), p. 10.

Fossil Fuels		Biofuels		Electrical drives	
Fuel	Greenhouse gas emissions in g/km*	Fuel	Greenhouse gas emissions in g/km*	Fuel	Greenhouse gas emissions in g/km*
Petrol	164	Natural gas with 20 % Biomethane	100	Hydrogen (EU mix)	174
Diesel (with particle filter)	156	100 % Bio-methane (bi-fuel, dung)	5	Hydrogen (100 % wind power)	8
Liquefied petroleum gas (LPG)	141	Ethanol (com-position sugar beet, added waste material)	111	E-Mobility (EU power mix)	75
Compressed natural gas (EU natural gas mix)	124	Biodiesel (Composition: rape, added glycerin)	95	E-Mobilität (100 % power mix)	5

*Greenhouse gas emissions WTW in gCO^2eq/km. WTW: From the raw material's source (well) over the tank (tank) to the drive (wheel). gCO^2eq: CO^2 equivalent.

Table 4. Newly registered cars market share in terms of fuel type, Germany 2010

Type of fuel	Market share	Type of fuel	Market share
Petrol	57.30 %	Natural gas	0.170 %
Diesel	41.90 %	Electricity	0.019 %
Liquefied gas	0.28 %	Hybrid	0.370 %

Source: German Federal Department of Motor Vehicles, Flensburg, quoted in Gneuss (2011), p. 4.

make up a significant part of personal mobility. By way of example the German government has set a target of one million EVs to drive upon German roads by 2020.[22] The categories of vehicles reach from Pedelecs and Scooters over LDVs to busses for short-distance public transport, with an emphasis on LDVs.

Electric vehicles are said to have the advantage that they consume less primary energy (especially oil) and therefore cause lower exhaust emissions. Hereby the climate change problem is eased, health risk of people living in congested areas is

[22] The German government is nowhere near reaching this objective in the first quarter of 2011: Five hundred and eighty-two electric vehicles were registered which makes up just 0.08% of all registrations. Out of 42 million cars, which are on the road in Germany only 2,800 use an electric motor. See also the initiatives of the German Federal Association for E-Mobility (registered association) under www.bem-ev.de.

lowered and the dependence on oil is reduced. However if EVs are to actually produce less exhaust emissions and have a lower primary energy consumption, then power mainly coming from renewable energy sources must be used. If electricity would originate from old coal power stations, then "clean" vehicles would be running on "dirty" electricity. This is also a reason why car manufacturers are investing in green electricity projects.[23]

Electric vehicles are currently powered by several drive concepts which differ as follows:

- Hybrid electric vehicles (HEV): Without connection to mains with combustion engine plus electric motor.
- Plug-in hybrid electric vehicles (PHEV): With partial connection to mains and a combustion engine plus electric motor with batteries rechargeable using mains.
- Battery electric vehicles (BEV): Connection to mains necessary, with an electric motor, rechargeable batteries using mains and regenerative braking (recuperating breaking energy to recharge the battery).
- Fuel cell electric vehicles (FCEV): Without mains connection, chemical energy generation which powers the electric motor.[24]
- Range extender electric vehicles (REEV): After battery depletion a small combustion engine is used to increase cruising range.

Furthermore modifications of the concepts named above exist. The mobility concept of Better Place should get a mention here, where empty batteries can be swapped for full ones within ten minutes at service stations. Thereby problems related to battery charging time are reduced as well as insufficient cruise range of EVs. The company Better Place has entered into a cooperation with Renault-Nissan.[25]

Apart from the already mentioned positive attributes pure electric vehicles also demonstrate a number of negative features which hinder a quick market breakthrough:

- Range: To date most EVs available on the market have a low cruising range, on average about 100–150 km. Some vehicles have an even shorter cruise range. Cruise range such as the Tesla Roadster provides with 350 km is an extremely rare exception. Low and high temperatures, air conditioning and heating also reduce cruise range. Due to the short cruising range, EVs are barely suitable for overland travel like holiday trips. However cruising range seems to suffice for urban traffic or commuting because 80% of all car

[23] Cf. Handelsblatt, 29.08.2011.

[24] Cf. amongst others Becks (2010), p. 14.

[25] Cf.www.betterplace.com.

journeys are less than 70 km (in the case of Germany).[26] Car purchasers still feel that short cruising range is a major deficiency.

- Acquisition costs: Purchase costs of EVs are almost always over € 30,000, even for the smaller vehicles. The steep price primarily results from high costs of batteries (about € 10,000 – € 15,000), which are mostly lithium-ion batteries.[27] An EV doesn't pay off in the foreseeable future, despite having lower electricity consumption costs compared to petrol or diesel. The Mitsubishi i-MiEV for example has an average consumption of 16.6 kWh. This equates to electricity costs of about € 3.60 per 100 km for an electricity rate of 0.245 €/kWh.[28] Consequently numerous monetary and non-monetary government incentives are being discussed, with which car purchasers are to be encouraged to buy an EV. Car manufactures are also making an effort to release automotive purchasers from the burden of high battery acquisition costs by offering rental schemes for batteries.
- Availability of charging stations: Just like conventional vehicles which need filling stations, charging stations are essential for EVs. Domestic charging stations in one's own garage are especially suitable.[29] If EV drivers do not own a garage charging station nearby the home must be set up. Additionally charging stations can be set up in shopping centers, at the workplace or similar locations where people spend a lot of time. A low network density is a serious stumbling block for purchasing EVs.[30] Here a lot of investing needs to be done to achieve a satisfactory network density. A high network density seems to be a necessity for electro-mobility to break through the market. Incidentally charging stations must be equipped with payment facilities.
- Charging time: Charging time is largely dependent on the utilized voltage. Charging time can span from 30 minutes (for quick charging with high voltage) to about 6–8 hours when using domestic electricity which has 220V.[31] Charging technologies are being currently developed which enable

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[26] Cf. EON (not dated), p. 17. See also Lubbadeh/Niemann (2011), p. 26. Growth from Knowledge (GfK) even found out asking 6.200 people in an empirical study, that in Germany's case 76% of all car journeys are shorter than 20 km, cf. GfK (2011).

[27] Raw materials such as lithium and rare earths will in the future drive costs of battery production; cf. Lubbadeh/Niemann (2011), p. 27. China possesses a high concentration of these raw materials from which China profits in terms of international competition.

[28] Cf. Frankfurter Allgemeine Zeitung (FAZ) from 12.04.2011, p. T3.

[29] Ideally the roof of the garage is covered with solar panels which generate electricity for the EV.

[30] See amongst others Bulczak (2011), p. 6. McKinsey have a different opinion on the matter, which believe that a dense network of public charging stations is not needed, cf. McKinsey (2011).

[31] Cf. Lubbadeh/Niemann (2011), p. 28.

electric cars to recharge batteries for about 50 km within ten minutes using quick charging.[32] The Better Place concept is something special which allows empty batteries to be exchanged for full ones at service stations within ten minutes. Batteries are not acquired with the purchase of a car. They are only lent and solely the charging process has to be paid for.

- Type of energy generation: Compared with conventional (combustion) engines EVs aim to significantly reduce exhaust emissions. This only works if the electricity used comes from renewable energy sources. If electricity originates from conventional energy sources (such as coal power stations), then pollutant emissions may even surpass those caused by conventional combustion engines.[33] If electricity came from the German network in 2011, then CO^2 emission would be 71g/km compared to 103 g/km of conventional combustion engines.[34] Therefore it must be ensured that electricity used by EVs comes from renewable energy sources.
- Network expansion: For a large use of EVs the problem arises that electricity consumers have to charge their EVs in locations other than those where electricity is generated by renewable energy sources. For example energy is produced by wind power plants near the coast and actual electricity consumption occurs in Munich. It is necessary to expand existing overland power supply networks appropriately which also increases electricity costs and is often opposed to by the population.
- Safety: Although lithium-ion batteries are nowadays seen as safe, fears still exist from car drivers, that in the case of an accident serious personal injury occurs.
- Standardizing plugs, data protocols and payment systems: A standardization of plugs, data protocols and the payment system is a must should EVs manage a market breakthrough. Car drivers wouldn't accept if plugs or payment systems are not compatible at various charging stations. Looking at the tourism sector it must be taken into consideration that vehicles in holiday traffic normally cross borders. Therefore not only national but also international normative regulations must be established.

In September 2011 the EV offer on the German market was still quite lucid: Important EV models are the Mitsubishi i-MiEV, the identically constructed LDV Citroen C-Zero and Peugeot iOn (leasing only) or the Tesla Roadster. Almost all car manufactures worth naming are planning an EV market launch in the next few years: Volkswagen (VW Golf blue e-motion, VW e-Up), Audi (R8 e-tron), Daimler

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32 Cf. EON (not dated), p. 17.

33 Cf. the calculations in Lubbadeh/Niemann (2011), p. 29.

34 Cf. Mobilität heute (2010), p. 5, which quotes an ADAC (German Automobile Association) study.

(E-Cell, Smart ed[35]), BMW (Megacity Vehicle and i3 and i8), Opel (Ampera, same construction as the dem Chevrolet Volt), Ford (Focus Elektro), Fiat (500 ev), Renault (Fluence Z.E., Kangoo Z.E., Twizzy Z.E., Zoe Z.E.), Volvo (C30 BEV), Saab, Toyota (EV2)[36], Honda, Mazda, Nissan (Leaf), as well as the Chinese provider BYD E6.[37] Most EVs are small – medium sized LDVs. Exceptions are for example the sports car Audi e-tron or the Tesla Roadster. However the number of EVs currently produced is still very limited.[38]

There are many technical differences between EVs and conventional vehicles with combustion engines. The drive unit consists of an electric motor instead of a combustion engine and the transmission is left out, which must be replaced by extremely high-performance batteries.[39] Conventional filling stations are becoming redundant, instead charging stations are required. It should also be mentioned that due to their batteries, EVs can function as temporary mobile storage for electric energy which originates from a power mix with a growing share of renewable energy and therefore can provide a contribution towards solving volatility issues this type of energy has. Traditional providers such as engine manufacturers and mineral oil companies are losing importance whereas electronics and electricity companies as well as battery producers are gaining significance. Today the electro-technical share of value added per car is approx. 35%, for EVs this share increases to about 70%.[40] New materials are gaining importance. EVs must be significantly lighter than conventional vehicles.[41] As a result the entire value-adding chain in the automobile industry will be rearranged.[42] It is currently not foreseeable which companies out of which regions of the world will emerge as winners and which as losers due to this rearrangement. Fears still exist that automobile manufacturers will lose importance and that emerging countries like China (who are considered to be very ad-

[35] Daimler conducted a study with the chemical firm BASF where transparent solar cells on the roof of the Smart generate additional energy. The vehicle is also clearly lighter due to modern plastics being used.

[36] Toyota must be given the merit for introducing a series hybrid vehicle (Toyota Prius) into the world market early on. This results in Toyota having a pioneer income return.

[37] Cf. Neue Mobilität (2011), p. 24 and own analyses carried out by IAA 2011.

[38] In 2010 6,665 Leafs (Renault-Nissan), 3,917 i-MiEVs (Mitsubishi), 3,444 iOns und C-Zero (PSA), 2,881 QQ3s (Chery Auto), 1,984 Think Citys (Think), 1,878 Volts (GM), 1,844 Midsize Sedan Codas, 1,224 e6 (BYD), 800 Smarts ed (Daimler) and 769 Tesla Roadsters were produced, cf. PwC, quoted in: FAZ from 06.01.2011.

[39] A conventional combustion engine of a LDV has 1,400 parts installed in the powertrain where an electric motor only has 210.

[40] Cf. Schneider (2010).

[41] Metals used by modern automobile manufacturers are being increasingly substituted with plastics. A good example is the automobile manufacturer BMWs utilization of carbon. BMW secured its resource access by holding a share in SGL Carbon.

[42] Also cf. Arthur D. Little (2010).

vanced in terms of battery technology and production) will gain significance compared with traditional producing countries such as Germany.

A special role is given to **solar vehicles**. Here electricity is generated by solar cells attached to the vehicle to power electric motors. Pioneering work was carried out by people who demonstrate suitability for everyday use using prototypes. The Swiss Louis Palmer already managed to travel around the world in 2007 and 2008 with his self-constructed vehicle which had solar cells installed on a trailer.[43]

The introduction of electromobility means no less than a change of system for all parties involved.[44] The change of the model range of automobile manufacturers will lead to a fundamental transformation of the provider structure in the automobile industry. Figure 2 shows the "Eco-system of electromobility" including fields of activity and challenges.

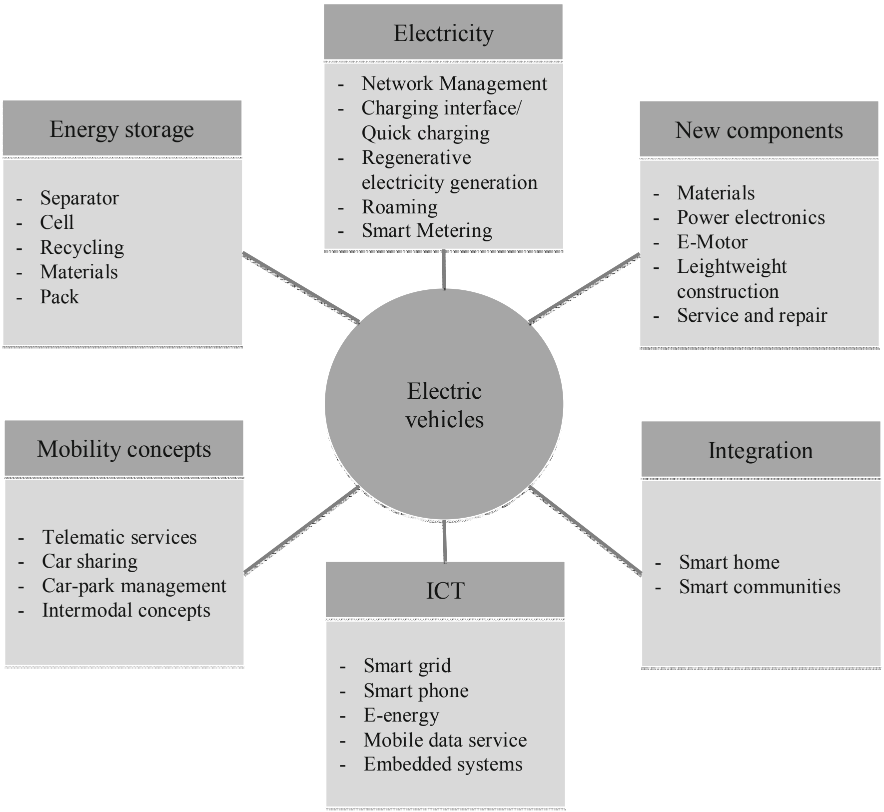

Fig. 2. Eco-system of electromobility

Source: IAA (2011).

43 See www.solartaxi.com.

44 Cf. Hornig/Kasserra (2011), p. 80.

Recently formed value-added partnerships prove changes in the industry structure:

- General Motors and the Korean electronics group LG are planning a joint development of electric vehicles.
- Volvo and Siemens are planning an extensive cooperation whereby Siemens produces electric motors for the Volvo C 30 Electric. As Volvo belongs to the Chinese automobile group Geely, Siemens could gain access to the huge Chinese market. [45]

Cooperations of German automobile manufacturers are not as extensive:

- Even though Volkswagen buys the batteries for the small passenger car VW Up from the electronics group Sanyo, the Japanese do not participate in the vehicle's development.
- Daimler cooperates with the chemical group Evonik for the production of batteries but reserves the construction of the Elektro-Smart for itself.
- Although BMW has its batteries for the city electric car i3 delivered by the German-Korean joint venture SB Limotive of Bosch and Samsung, it does everything else by itself.[46]

Rental car providers are expanding their fleet with electric vehicles. Avis announced the order of 500 Renault Fluence Z.E. and Kangoo Z.E., which are supposed to be bookable at the end of 2011. Sixt is planning to order just under 100 Stromos for business and local clients from the provider German E Cars. More and more often electric cars are being added to company car fleets.

As a market breakthrough is very unrealistic without government incentives, national governments in many countries have launched incentive measures.

The German government formed an initiative called NPE (nation platform electromobility), where different sectors of industry, on all political levels, science and research as well as consumer and environmental associations contribute. Concrete proposals how to reach the targets set by the national development plan electromobility are compiled in seven work groups. Ultimately the goal to establish Germany as the leading market for electromobility has to be reached and to put one million EVs on Germany's roads by 2020.[47] According to the notion of the NPE research funds amounting to € 4 billion will be required of which the government is to provide an as yet unknown amount. In its second final report the NPE presents a package of measures to compensate the cost gap and stimulate demand for electric vehicles:[48]

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45 China has for a long time made good experiences with electric scooters: in 2011 about 150 million electric scooters are driving in China's roads. With this in mind the sales volume of electric vehicles will increase quicker in China than in Europe.

46 Cf. FAZ from 27.08.2011.

47 Cf. The German government (2010).

48 Cf. NPE (2011), p. 7.

- EV preference for parking, permission to use bus lanes as well as supporting new, intelligent car sharing concepts.
- Compensation for disadvantages of private use of company cars with electric drive.
- Special amortization for commercial purchase of EVs.
- Loans at reduced interest rates from KfW (German government-owned development bank) for the private purchase of EVs.
- Granting yearly tax incentives, based on the storage capacity of an EV.

In May 2011 Germany increased the research support up to 2012 by € 1 billion. So far the following projects were supported: Electromobility in public space, electrochemistry research, information technology for electromobility, lithium-ion-batteries, system research for electromobility, energy research, traffic research, field experiments in LDV traffic, fleet experiments in trade traffic, battery test center.[49] So far € 200 million have been provided for "showcase projects". From September 2011 onwards consortiums consisting of automobile producers, electricity companies, short-distance public transport companies and communities from presumably eight different regions in Germany will apply.[50] Funds totaling € 200 million is supposed to be topped up to € 600 million through own means.

Previous regional government efforts to support electromobility have had different success. According to the Electric Vehicle Index EVI from McKinsey Germany is currently positioned midfield with a value of 30 along with Japan and China. USA and France are positioned at a value of a solid 40; Italy, South Korea, Great Britain and Spain are positioned at a value under 25.[51]

It can be established that Germany's support measures are minor when compared internationally. For example in other countries it is common that direct purchase incentives come in the form of subsidies when buying a car. "In many European countries, such as France, Great Britain, Spain and Portugal the purchase of an EV gets directly supported by an average premium payment amounting to € 5,000."[52] The Chinese offer substantial support measures. Up to 2020 funds amounting to € 11 billion will be provided to develop electromobility. Whether the development of electromobilty is successful remains to be seen. Distinct preferences of Chinese car purchasers towards conventional cars are sometimes reported.

According to an up-to-date study carried out by the GfK, 10% aged over 18 in Germany expressed their intention to buy an EV in the next few years. In the UK

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[49] Cf. FAZ from 16.08.2011.

[50] Cf. Wirtschaftswoche (2011), p. 52ff.

[51] EVI measures by how many percent electromobility reaches a country, which is predicted by experts for 2020, cf. Wirtschaftswoche (2011), p. 54.

[52] Bachmann/Mayer (2011), p. 90, also see Gneuss (2011), p. 4.

it was 8.7%, in Netherlands 29%. Fifty-six percent of people asked in Germany are also prepared to pay a higher price, whereby the maximum surcharge may only amount to € 2,000. Most of the people questioned will know that surcharges will be higher which leads to the purchase price being an important stumbling block. Yet the greatest obstacle for buying an EV is the extremely limited cruising range of the vehicle. A cruising range less than 150 km is only satisfactory for 6.6 % of German, 26.2 % of British and 13.4 % of Dutch people. A third important obstacle for purchasing an EV is the limited availability of charging stations.[53]

Mobility providers such as Deutsche Bahn, Lufthansa, car rental services such as Sixt etc. have an important role to play when it comes to expanding electromobility: They can provide EVs in destinations and thereby introduce wealthy clients and opinion leaders to EVs.[54]

Car sharing refers to mobility concepts, where several people share an undetermined LDV and do without the possession of a LDV. The LDVs are property of a company which provides members in a certain city with the use of LDVs. To be able to use LDVs users pay a fee that is mostly based on duration of use and kilometers driven. At present there are a number of car sharing providers in Germany and other countries.[55]

Car sharing concepts have several positive effects on the environment:[56] On the one hand the amount of cars produced and used will decrease due to many people sharing a car and on the other hand car sharing providers often employ EVs which drive on certified green electricity. For example the cooperation between Cambio and Greenpeace-Energy in Hamburg offers EVs, namely the Mitsubishi i-MiEV. Car2Go which involves the automobile manufacturer Daimler exists in Vancouver, Austin-Texas, Hamburg and Ulm. Car2Go, for example, also offers Elektro-Smarts in the municipal area of Ulm. The city Ulm is setting up a charging infrastructure consisting of 24 charging stations. This business model is currently running through practical trials where technical details and consumer behavior are tested. The Car2Go business model could set an example for other classical car rental providers in busy city destinations such as London, Paris, Rome or Berlin. Registered (regular) customers of a car rental provider could use the environmental friendly vehicle fleet in the urban area of a city destination without having to check-in first.

Concepts which include modal shifts in transport to more resource efficient means of transport, such as bus and rail, count as very sustainable. Especially busses demonstrate a very low consumption of primary energy and low production

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53 Cf. GfK (2011), p. 90 see also Future Foundation (2010).

54 Cf. also Arthur D. Little (2010).

55 For example see www.book-n-drive.de, www.car2go.com, www.stadtmobil.de or www.flinkster.de.

56 However sometimes it is criticized that car sharing can lead to people using short-distance public transport less, as cars can be used at any time for little money without having to own a car.

of pollutant emissions. A unique form of modal shifting is performed by companies with a business model that allows people to express their transportation needs on internet platforms. Should enough requests come together for certain routes then busses are rented to cover these[57]. These business models could further spread due to the extensive presence of modern information technology and high internet usage.

5.2 Air

The air traffic's share of greenhouse gas emissions caused by people is a good 2%. This share would increase due to the expected annual growth of world air traffic of 4–5% so long as the air traffic industry doesn't introduce any suitable countermeasures. The industry committed itself to ensure a neutral CO^2 growth of air traffic starting 2020 and from 2050 onwards greenhouse gas emissions are to be halved compared to 2005.

Sustainable mobility measures in air traffic are primarily directed at increasing **fuel efficiency**. Air traffic too shows a direct correlation between fuel consumption and CO^2 emissions: Saving 1 kg of kerosene leads to a reduction of CO^2 emissions by 3.16 kg. Airlines have massive interest anyhow in reducing kerosene consumption, as fuel costs make up 30% of operating costs of IATA airlines in 2011. Fuel costs of all IATA airlines totaled to about US $ 176 billion.[58] Substantial progress has been made in the past decades in terms of fuel efficiency. Nowadays new aircrafts consume about 70% less fuel than over 40 years ago. The last ten years alone increased fuel efficiency by 20%. Modern aircraft consume about 3.5 liters per 100 passenger kilometers, the A380 and die B787 about 3.0 liters per 100 passenger kilometers. The aim is to further increase fuel efficiency by 25% by 2020.[59]

Along with aircraft and engine manufacturers, airlines are also making efforts in the operations department. Route optimizations are targeted here (e.g. non-stop flights) to reduce fuel consumption by varying cruse speeds and optimizing aircraft load.[60] The airport segment is making efforts to optimize ground traffic flow and starting/landing processes. In addition the air traffic management sector is supposed to reduce jet fuel consumption and CO^2 emissions through route navigation optimization and avoidance of holding patterns.[61]

A very promising approach to reduce CO^2 emissions is to use alternative fuels. A 3% admixture of alternative fuels reduces CO^2 emissions by 2% – this currently equates to an annual reduction of ten million tons of CO^2. Alternative fuels consist of regenerative, biological raw materials such as algae, babassu palm oil, camelina, halophytes, jatropha and switchgrass (so called "biofuels").

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[57] For example see internet bus platforms such as www.deinbus.de.

[58] Cf. IATA (2011): Assumption: US $ 110 per barrel crude oil.

[59] Cf. IATA (2011).

[60] Also cf. the environmental strategy 2020 of the Deutsche Lufthansa AG, under: www.lufthansa.com.

[61] See European Commission (2011). Also see Sterzenbach/Conrady/Fichert (2009), p. 69ff.

The air traffic sector demands the following from biofuels:

- Biofuels must be able to be mixed with conventional kerosene made from fossil fuels and must be able to use the same supply infrastructure.
- They must demonstrate the same technical specifications as conventional fuels. Therefore biofuels must sustain low temperatures of – 40° or – 47° Celsius (corresponds to Jet A – and Jet A-1-Fuel) and turbine heat as well as have a high energy density (Jet A-Fuel has an energy density of 42.8 MJ/kg).
- Biofuel isn't allowed to be in competition with the food chain, to cause fresh water competition, is neither allowed to promote deforestation of pasture lands or put the biodiversity in danger.[62]

IATA believes that an admixture of 6% biofuel is achievable by 2020. This would mean a 4% reduction of CO^2 emissions. In its environmental strategy 2020 Lufthansa aims to add up to 10% regenerative fuels by 2020.

So far a number of experiments using biofuel have been carried out: In 2008 Airbus flew with an A380 with a GTL engine using the Fischer Tropsch-method, on 12.10.2009 Qatar Airways flew using a 50% GTL admixture in all four engines of an A340-600.[63] United flew with a A319 using 40% GTL. Between 2008 and 2011 a total of seven airlines flew using biofuels: Virgin Atlantic, Air New Zealand, Continental, JAL, KLM, TAM and Interjet. Overall the results are very promising: No airplane or engine adjustments had to be made, the addition to conventional fuel jet was unproblematic and fuel efficiency didn't drop. Since 15.07.2011 Lufthansa uses a 50% biofuel admixture in one of the A321s engines for the Hamburg-Frankfurt flight route to examine long-term biofuel effects. The initiative "Aviation Initiative for Renewable Energy in Germany" (AIREG) was founded in Germany to encourage the use of regenerative energy sources in air traffic over Germany.[64]

In Europe, air traffic is to be included in the Emission Trading Scheme (ETS) in 2012. ETS plans that every airline which takes off and/or lands in Europe has to purchase emission certificates. This would achieve internalization of external effects: Those responsible for pollution would take the blame for the effects caused. It can be expected that the ETS would incent the use of fuel-saving airplanes. However it is also to be expected that unfair competition in global air traffic would arise as for example airlines from the Gulf States would be less or even not burdened at all by the ETS. This is where European airlines begin to criticize the ETS.

For the next decade **electromobility concepts** in air traffic are still not technically feasible. The main problem is the power to weight ratio which reaches its

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62 Cf. IATA (2011).

63 GTL-fuel produces lower pollutant emissions than conventional jet fuel.

64 Cf. www.aireg.de.

physical limits. Conventional fuels such as kerosene have an energy density which batteries don't even come close to. Nowadays 30 kg of the best batteries are needed to store the same amount of energy as in one kilogram kerosene. [65] Crude oil counts as an excellent energy source in air traffic. Within the air traffic industry there is a saying: "The last drop of crude oil will be used by airplanes".

A far more observed pioneer project, which however is irrelevant for air traffic in the foreseeable future, is the **Solar Impulse** project of the flight pioneers Bertrand Piccard and André Borschberg. The Solar Impulse project aims to travel around the world using a solar airplane. The solar airplane currently used has four propeller motors which are powered only by electricity. The electricity is generated by solar cells installed onto the wings and stored in batteries for night flights. On 08.07.2010 the solar plane managed to fly 26 hours straight from the Swiss airport Payerne. Solar energy stored during the daytime flight was used at night.[66]

Airports are making a special effort to reduce burdens for people and the environment to improve the acceptance of air traffic from surrounding regions. Airport measures are primarily directed at reducing noise exposure, CO^2 emissions and use of space.[67]

Intermodal traffic concepts are suitable to reduce environmental pollution. The AIRail concept of Deutsche Lufthansa AG lightens the arrival by using railway connections to Frankfurt from Cologne and Stuttgart which leads to a modal shift to (environmental friendlier) rail traffic. Passengers can already check-in at Cologne or Stuttgart main station, i.e. they receive their boarding card and seating details whilst also being able to check-in luggage.

5.3 Water

It is little known that global shipping is responsible for approx. the same amount of pollutant emissions as global air traffic. In passenger traffic the cruise segment enjoys special attention, as this segment has for many years been developing faster than any other tourism segment worldwide. This is why environmental impacts caused by cruises have become more noticed. Air pollution (ship CO^2 emissions), water pollution, noise exposure, ship vibrations along with infringement on the environment by building ports and piers have become the subjects of discussion.

The branch seems to have understood the problem and is trying to contain harmful environmental impacts.[68] Success is actively communicated in Sustainability Reports. For example take a look at the in Figure 3 presented extract from the RCCL 2009 Sustainability Report:

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[65] Borschberg (2011).

[66] See www.solarimpulse.com.

[67] Cf. Beisel (2011).

[68] Cf. detailed: ECC (not dated), p. 44ff.

- Fuel consumption down 3.7% – almost double the 2% target reduction
- Total waste brought ashore down from 1.5lb per available passenger capacity day in 2008 to 1.4lb
- Hazardous waste reduced by 25%
- Chemwatch database and Green Rating System launched on all ships
- Advanced Wastewater Purification systems – beyond compliance standards – installed fleetwide at cost of more than US$150 million
- Ocean Fund awarded US$484,000 to 14 marine conservation and environmental organizations.

Fig. 3. RCCL sustainability report extract

Source: ECC (not dated), p. 53

With regard to ship drives and engine fuel consumption it should be mentioned that for many years **solar drives**, which are completely free of emission, are used in niche markets. This occurs especially on European waters in densely populated areas, on lakes or rivers, where powerful drives and speed don't play a major role. Instead, the focus here is on aspects such as water pollution and noise control as well as zero emissions.

The following are noteworthy examples: Since September 2009 the solar ferry Helio travels on the Lake Constance[69], since 2000 the Spree Shuttle drives on waters in the Berlin city zone.[70] In 2000 the "Alster Sonne" commenced service in Hamburg.[71] The solar catamaran "MobiCat", with a capacity for 150 passengers plies the lakes of Jura in Switzerland since 2001.[72] A solar ship drives on the Neckar River since 2004 with transportation capacity for 250 people.[73] The first crossing of the Atlantic with a solar ship, the "Sun21", followed in 2007. The Sun21 and its crew were honored with the Guinness World Record Award for the fasted crossing of the Atlantic using a solar ship.[74] Since 2007 the research and laboratory ship "Solgenie" of the Constance University drives on the Lake Constance using a hybrid drive which generates power by using fuel cells (along with solar cells).[75] Since 2009 the first solar-powered passenger ship, the Solar-aquabus "Solon C 60", on the waters of Germany's capital Berlin.[76] Since 2010 the

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69 See http://www.ecolup.info/docs/standard.asp?id=6350&domid=629&sp=D&m1=926&m2=590&m3=6347&m4=6350.

70 See http://www.spree-shuttle.de/.

71 See http://www.photon.de/news/news_technik_00-07_alstersonne.htm.

72 See http://www.bielersee.ch/de/schiffsmiete/flotte/ems-mobicat.283.html.

73 See http://www.hdsolarschiff.com/de/.

74 See http://www.transatlantic21.org/de/.

75 See http://www.htwg-konstanz.de/21-06-07-Bootstaufe-Solgeni.1584.0.html.

76 See http://www.schiffskontor.de/cms/solon-solarschiff-berlin.html.

first stages of a round-the-world trip are being covered using the Solarwave.[77]Nowadays solar water taxis and luxury solar yachts are being built.[78]

A lot of attention was also being paid to the round-the-world trip using MS TÛRANOR PlanetSolar. The construction of the world's largest solar boat MS TÛRANOR PlanetSolar is an event with huge symbolic power for the progress of solar navigation. With its approx. 500 m² solar panels the MS TÛRANOR PlanetSolar can also navigate up to three days without direct sunlight. The boat is supposed to symbolically carry the message of the possibilities of using renewable energy "around the world". The long-term use capability is to be tested during a round-the-world trip. The trip around the world was 80% complete in August 2011.[79]

Efforts also exist to achieve sustainability mobility in ocean freight traffic. The design study Orcelle incorporates the use of fuel cells, solar, wind and wave power to drive a car carrier.[80]

6 Sustainable Mobility in Tourism Destinations

Touristic destinations rely on capable traffic systems and an intact environment. Especially fast growing metropolises are already suffering under traffic problems and burdens of air and noise pollution today. EVs are ideal means of transport for heavily encumbered metropolises, as EVs don't produce any emissions and hardly any noise. If the majority of vehicles in the city were powered by electricity then districts near main roads would significantly gain in habitation quality and asthma, cardiovascular and cancer illnesses would become scarcer. Especially in fast growing mega-metropolises in Asia and Africa mistakes made by American and European cities could be avoided by making timely adjustments.[81]

Sustainable mobility approaches can already be found in several regions. In the Alpine region (Germany, Austria, Switzerland, Italy, France, Slovenia) 13 pilot projects closely linked to tourism are being carried out. Here EVs or biofuel powered means of transport are being tested in short-distance public passenger transport, solar boats are being used on alpine lakes and e-bikes and EVs are being rented.[82]

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77 See http://www.solarwave.at/autark-um-die-welt.html.

78 See http://www.solarwaterworld.de/produkte/passenger/solar-uno-wassertaxi.html und http://www.solarwaterworld.de/produkte/yacht/suncat-46.html.

79 See http://www.turanor.eu/ and http://www.planetsolar.org/de/home.html.

80 „The E/S Orcelle represents our vision for zero-emission car carrying. The idea combines fuel cells, wind, solar and wave power to propel the vessel, that will need no oil or ballast water. A car-carrier like this will never be built in its entirety but we hope to see some of the elements in future generation of vessels.", in: http://www.2wglobal.com/www/environment/orcelleGreenFlagship/index.jsp.

81 Cf. Lubbadeh/Niemann (2011), p. 26.

82 See www.co2neutralp.eu.

The project Alpmobil is worth mentioning, where tourists in the Swiss region of St. Gotthard can rent EVs from the brands Think and Twingo in different locations. Charging stations and parking spaces are provided free of charge.[83]

In Asia the project endemic to the Philippines for the use of "EJeepneys" (electrical drive minibuses for the transport of tourists and locals) is exemplary.[84] A test phase has been started in Singapore with Mitsubishi i-MiEV and e-Smarts. By 2012 63 charging stations will have been set up in the city zone.[85] Singapore is ideal as a region for EVs because the majority of trips made are under 40 km/day and 90% of vehicles are parked at home, at offices or shopping centers approx. 22 hours per day. "One advantage that we have is that we are a small compact urbanized environment, which makes it in a way, convenient. Your travelling distances are not too long. It's not difficult for you to set up charging stations around the island."[86] In USA, California seems to be developing into early adopter market of electromobility. San Francisco is making noticeable efforts to reduce CO^2 emissions in the city and has once again underlined its plans to grant fee charging of batteries at all city charging stations by 2013.[87]

7 Conclusion and Outlook

No topic is being as intensely discussed as electromobility in the transport sector. This seems to be ideal solution for sustainable mobility for government policy makers and providers in the transportation sector.

An electromobility traffic system is barely comparable to nowadays traffic systems. On the way to extensive electromobility a complete upheaval of the traffic system is unavoidable.

The traffic system changes are in many ways a "chicken-and-egg situation". For example on the one hand clients will barely be inclined to purchase EVs if a suitable charging infrastructure has not been extensively established. Yet on the other hand these can hardly be set up in an economically viable way should demand go missing.

An electromobility market breakthrough is only to be expected if framework conditions are put in place by political policy makers. These have to be decisive, consistent and coordinated internationally. A special responsibility is given to the automobile purchaser: Environmental protection can no longer be demanded to be

83 See www.alpmobil.de.

84 See www.ejeepney.org.

85 See www.channelnewsasia.com.

86 Chee Hong Tat (2011).

87 See http://www.smartplanet.com/blog/transportation/san-francisco-will-charge-your-electric-car-for-free-until-2013/380 and http://www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2011/05/09/BAJM1JE0CJ.DTL.

free of charge, additionally cherished habits must be thought over and changed if necessary. Even if favorable framework conditions exist it can hardly be expected that a transformation of the traffic system will take place short-term as it involves a process which will take decades.[88]

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[88] Also cf. Heymann (2009).

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List of Abbreviations

CAGR	Compound annual growth rate
Dena	Deutsche Energie-Agentur GmbH
ECC	European Cruise Council
FUR	Forschungsgemeinschaft Urlaub und Reisen e.V.
IAA	Internationale Automobil Show
IEA	International Energy Agency
LDV	Light duty vehicles
Mtoe	Million tons of oil equivalent
RCCL	Royal Caribbean Cruise Lines
VDA	Association of the Automotive Industry (Germany)
WEF	World Economic Forum