One kWp for Each Electrical Vehicle

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ABSTRACT: At the end of this decade mass production of electrical vehicles (EVs) will begin in Japan, Europe and the US. The main driving force for the large-scale production of EVs is the prospect of lower emission rates of CO_2 , SO_x , NO_x and hydrocarbons (HC), which play an important role in the pollution by photochemical smog (O_3). CO_2 emission however, will probably remain unchanged in Germany by charging the EVs on the grid. Therefore the ecologically clean way is to use alternative energies to power EVs. The two-seater solar car TINO has a typical power consumption of 11 kWh / 100 km in real city traffic. Since January 1993 TINO is supplied by a stationary 500 Wp grid-connected solar filling station consisting of a-Si modules. With the energy provided by this small PV-station, TINO permits an average daily driving distance of 9km, a distance longer than that covered by 60% of the second car owners in Germany. German commuters travel an average distance of 25km daily, which leads to 5500 km per person per year or a power consumption of 825 kWh per EV per year (EV power consumption equal to 15 kWh / 100 km). A 1kWp sized PV-filling station meets this demand of electricity production in Germany. If for every EV one kWp PV-filling station were installed, forced either by legislative or by governmental promotion, the entire projected worldwide PV-shipment in the year 2000 would be needed to supply the power for about 200.000 EVs. The Zero Emission Vehicle Requirement which has passed the State of Congress in California forces the big car producers to sell 100.000 EVs in California at the turn of the century. In the future the external costs of the pollution of combustion engine powered cars will result in higher costs. The solar powered EV will lead to a cost advantage because the cost of PV electricity and the financing costs of the EV will drop with rising market penetration. Environmental reasons lead to the combination of EVs and alternative energy in order to establish an ecologically clean transportation system, and will find broad social consensus. Thus, EVs can play an important role in furthering the mass production of solar cells in the near future.

Keywords: Monitoring ; Small Grid-connected PV Systems; Internet Measurement

1. TRANSPORTATION DEMAND AND ENVIRONMENT

The amount of carbon released by burning fossile fuel has doubled worldwide in the last 30 years. Traffic contributes 20% to the global CO_2-emission. In the summer 80% of the ozone precursor substances (NO_x, HC and CO) originate from the emission of the car combustion engines [1]. Traffic noise and the emission of benzene present other health hazards linked with the present passenger cars.

Electrical vehicles avoid pollution during use and have thus become a powerful technical solution to overcome the above mentioned problems. Today´s EVs on the market have the capability to drive between 50 km and 100 km before recharging the lead acid or NiCd- batteries is required. The performance of these storage systems often seems to be the limiting factor why EVs are not in common use. Looking at the hard facts in Germany, 70% of the second car owners drive less than 10 km a day (see Fig. 1) [2]. German commuters travel an average distance of 25 km each working day. Small cities like Karlsruhe have lower daily driving distances than the average in Germany [3]. Seventy percent of all german private car owners drive less than 50 km daily, a distance which EVs on the market with today´s cheap lead acid batteries can reach. But most of the customers demand a driving distance larger than 200 km, a daily distance many times larger than their real requirements (see Fig. 1).

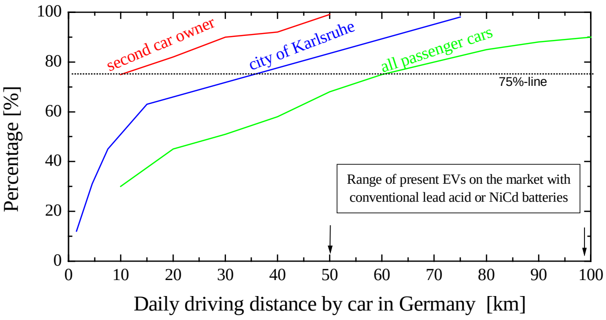

Figure 1: Average driving distance by car in Germany [2,3].

Closing down the inner-cities for non-zero emission vehicles will be an effective means to increase the number of EVs and improve substantiallly the quality of living in the cities. Most of the well known car manufacturers around the world are developing EVs. Companies like Peugeot, Mercedes, GM and Nissan are planning to put their EVs on the market within the next three years. At the end of 1993 in Germany 4000 EVs [4] and in Switzerland approximately 1500 EVs were in operation. The majority of these vehicles are produced by small companies in a small series production like the electric cabrio POP-E, built by the technical bureau for solar energy in Constance (see Fig. 2).

Figure 2: The electrical cabrio fun car POP-E (empty weight 800 kg, 12 kW asynchronous motor - Photo: Ingenierbüro für Solarenergie Konstanz).

For the above mentioned two countries, recent studies have shown that after the year 2000 a market share of about 5% EVs is realistic, equal to 200.000 electric cars in Germany alone [5]. The car manufacturer Peugeot also estimated the market in France at 200.000 electric passenger cars by the turn of the century.

Charging all these cars on the grid will transfer the pollution from the streets to the electric power plants. Besides, the amounts of SO_x, NO_x, HC, CO and benzene would be lowered dramatically by about a factor of four. In Germany the lowering will be about -75% of the NO_x emission and about -90% of the HC pollution based on the present emission of the average gasoline car [6]. The amount of emitted CO_2 during grid electricity production is dominated by the share of fossile fuel burning. In table 1 the emission of CO_2 per 100km caused by a grid-charged EV with a power consumption of 15 kWh / 100 km is shown for Germany, Bavaria, Austria and England. For comparison, the CO_2-pollution of a future combustion engine car with a low gasoline consumption of 3 litres per 100km is also given in table 1. There is no significant reduction of CO_2 if a 15 kWh / 100 km EV is charged on the german grid compared with this future gasoline car. The CO_2-emission is the main reason why EVs have to be powered by renewable energy. Otherwise, the marketing argument of an emission free transportation system with EVs will become an advertising trick.

Table 1: The average emission of CO_2 in the power plants by charging a low power consumption EV on the local grid.

Countries to charge the EVs on the grid (15 kWh / 100 km)	Emission of CO_2 [g / km]
England	117
Germany	89
Bavaria	35
Austria	32
Low gasoline consumption vehicle with 3 litres / 100km	92

2 EVs SUPPLIED BY SOLAR ENERGY

The 80 Wp solar cells integrated into the roof of the solar car TINO feed the car´s electrical system such as, lights, indicators, radio. The lead acid traction batteries are charged at a stationary photovoltaic filling station installed on the roof of the university building in Constance.

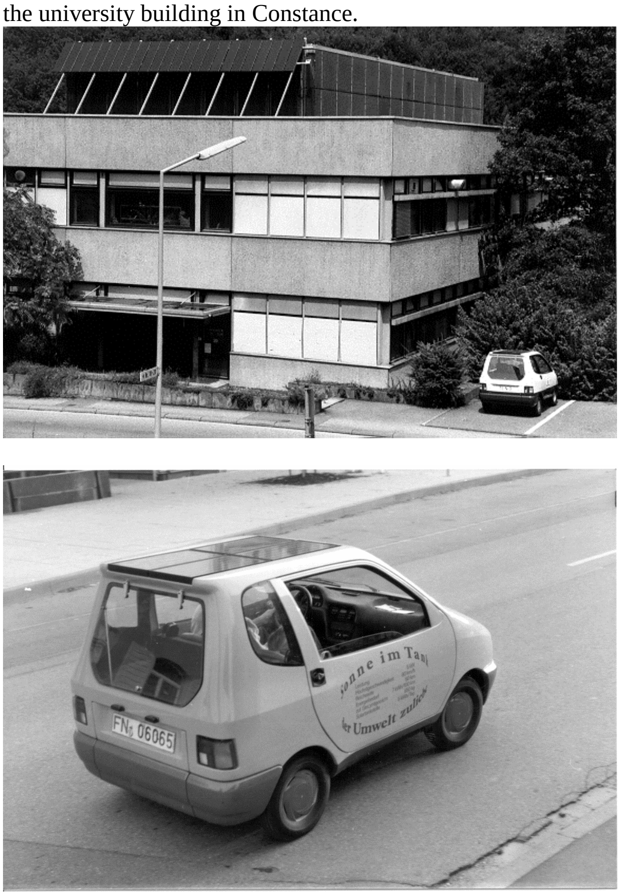

Figure 3: Solar filling station at the university building in Constance (500 Wp a-Si modules) and solar car TINO (80 Wp . roof integrated cryst. Si PV-modules)

In the year 1993 the 500 Wp PV-system (Siemens Solar, T20 a-Si moduls) transfered 300 kWh of solar electricity to the grid [7]. The amount of solar energy provided by this small PV-station permits TINO to reach an average daily distance of 9 km, a distance longer than that covered by 60% of the second-car owners in Germany (see Fig. 1).

TINO´s car body construction is mainly based on light weight glass fiber plastic, which yields a low empty weight of 650 kg (lead acid batteries included) and thus a low power consumption of 11 kWh / 100 km in city traffic.

Low overall energy consumption is not cost dominant if EVs are charged with cheap power from the grid. To supply EVs with PV-electricity, the power chain from charging to driving must be energy efficient in order to reduce PV-system costs. To become a high performance power train, each part motor, converter, battery-system and battery-charger, has to be highly efficient.

Fig. 4 illustrates the size of the required PV-filling station as a function of the average daily driving distance for different types of present EVs. The four-seater POP-E cabrio with an empty weight of 800kg, 12kW asynchronous motor and lead acid batteries requires 13 kWh to to 100km under typical city traffic conditions [12].

To drive a daily distance of 20 km in the city, 2.6 kWh have to be charged into the traction batteries of the POP-E each day. A typical roof integrated PV-system in Constance generates 930 kWh per installed kWp per year (crystalline or polycrystalline Si-moduls), a value about 10% higher than the average german PV-system output [8,9]. In Fig 4 it is assumed in a rough estimate that 1kWp produces 1000 kWh per year. Thus, a 1kWp PV system is able to meet the demand to travel 20km daily with the POP-E cabrio. The box-type Van Volta electric for example is operated by the municipal authorities in Constance to carry goods up to 500kg. The power consumption of 27 kWh / 100 km makes it necessary to size the PV-station up to 2kWp in order to match a daily range of 20km.

High temperature batteries like $Na/NiCl_2$ or Na/S can store 3 times more energy per kg battery weight (≈100 Wh / kg) than lead acid systems. High standing losses are the reason why for example the VW-Jetta electrics equipped with an Na/S battery, have a power consumption of 40 kWh / 100 km at a daily driving distance of 20 km [13]. By doubling the daily distance, the power consumption drops to 30 kWh / 100 km. Even when this electric Jetta stands still a 1kWp PV-station would be necessary to supply the battery heating system in order to maintain an inside temperature of 300°C. The thermal standing losses of the Na/S battery in the BMW E1 with 1.7 kWh per day is equal to the energy required by the POP-E cabrio to drive 15 km daily. These examples show that high temperature batteries require a PV-station exceeding 1kWp, and will find an efficient application if the average daily distance is greater than 50 km (5kWp PV-station required for 50km daily).

New concepts like ZnO-batteries (200 Wh/kg) are currently being tested by the German Bundespost and show a low self discharge rate of 2% capacity per week. If the exchanging of the electrode, which is necessary for charging the ZnO battery, is well organized within an appropriate infrastructure, EVs have the potential to replace 80% of the currently used combustion engines in the German Postal Service [11]. To reach overall emission-free transportation the electrode recycling plant should be powered by renewable energies like PV.

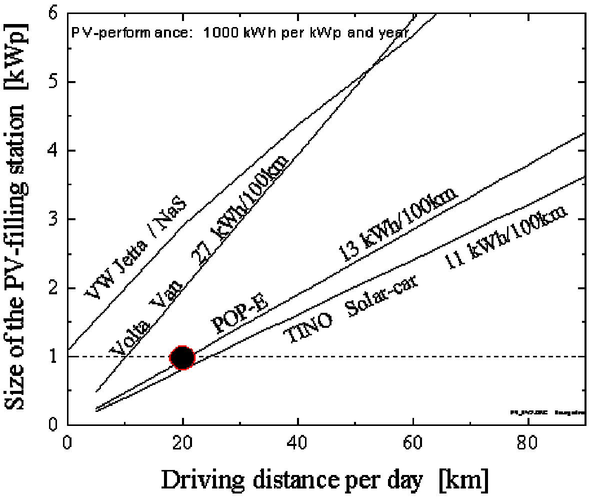

Figure 4: Size of solar filling station for different types of EVs.

3. COSTS

The environmental impacts of car pollution and the external costs of the present power generation are not considered in today´s energy prices. Supplying the POP-E with a stationary PV-filling station leads to electricity costs of 25 DM per 100km, based on the current cost of PV-electricity of 1.9 DM/ kWh. Today the average car in Germany runs 100 km per 10 liters gasoline, which results in fuel costs of 15 DM per 100km. Over the next years, as gasoline prices will, most likely rise, the operating costs of the solar electric car will pay off. Based on PV-electricity costs of 0.8 DM per kWh (3kWp, $CuInSe_2$ - roof mounted) [10] projected for the year 2000 and today´s gasoline costs, a rough estimate demonstrates a price advantage for the PV-powered EVs (15 kWh / 100 km) over the gasoline fueled car. This PV-cost degression will happen if the PV-market development trend is stable. With a present 17% annual growth rate of the PV-market, global PV-production will exceed 200 MWp by the year 2000, as shown in Fig. 5. If for every EV a one kWp PV-filling station is installed the projected worldwide PV-shipment at the turn of the century will be able to supply 200.000 thousand EVs. In California, the big car producers are forced by law to sell among their car fleet a certain percentage of EVs, starting in 1987. This Zero Emission Vehicle Requirement will bring 100.000 EVs onto Californian roads by the year 2000, as shown in Fig. 5. The MITI in Japan plans to produce twice as many EVs in Japan than is projected by the Californian law. An annual production rate of 50.000 electric cars will lower today´s higher prime costs of EVs to the same value as conventional small passenger cars. Thus, the EVs can find their way into mass production. If society wants to have the benefit of a pollution-free transportation system, the government has to enforce the combination of EVs and renewable energies. For example, the government should give financial support for purchase an EV only if the car is powered by alternative energy (PV-filling station).

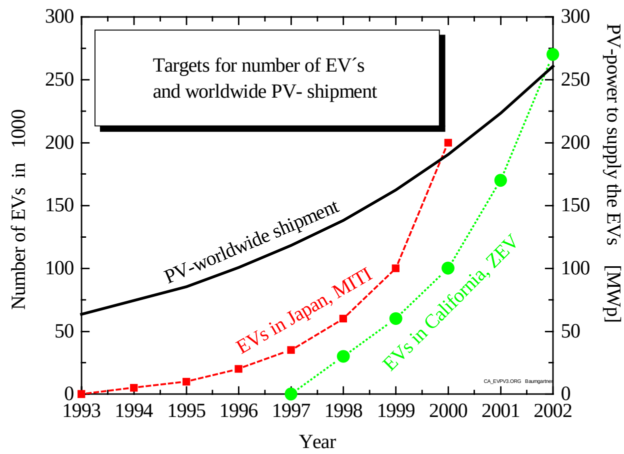

Figure 5: Proposed number of EVs in California and Japan. On the right axis the required PV-power to supply each EV by a 1kWp PV-filling station. Projected worldwide shipment of the PV-market with an annual growth rate of 17%. The projected EV-market by the year 2000 will be 200.000 electric cars for both France and Germany.

4. THE MUNICIPAL PV-FILLING STATION

In a promising demonstration project the city of Constance decided to build a 50 kWp PV-filling station able to supply different types of EVs in order to study the benefit of emission-free transport in the innercity. The PV-system will be installed in the roof of a new building where it functions as a PV-facade at the same time (see Fig. 6). Everyone can purchase a share of the PV-system in parts of 200Wp, with prices 30% lower than the average price for a conventional roof integrated system on a one-family house. The produced kWh PV-electricity is balanced by the Constance municipalities every year with the electricity consumption of the PV-share owner´s private household. Together with this initiative in the inner city of Constance electric parking lots will be installed. This methode of financing PV-systems on official buildings with the aid of local authorities seems to be an important step to increase the number of EVs as well as PV-production..

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Figure 6: Municipal 50 kWp PV-filling station to be built by the City of Constance.

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