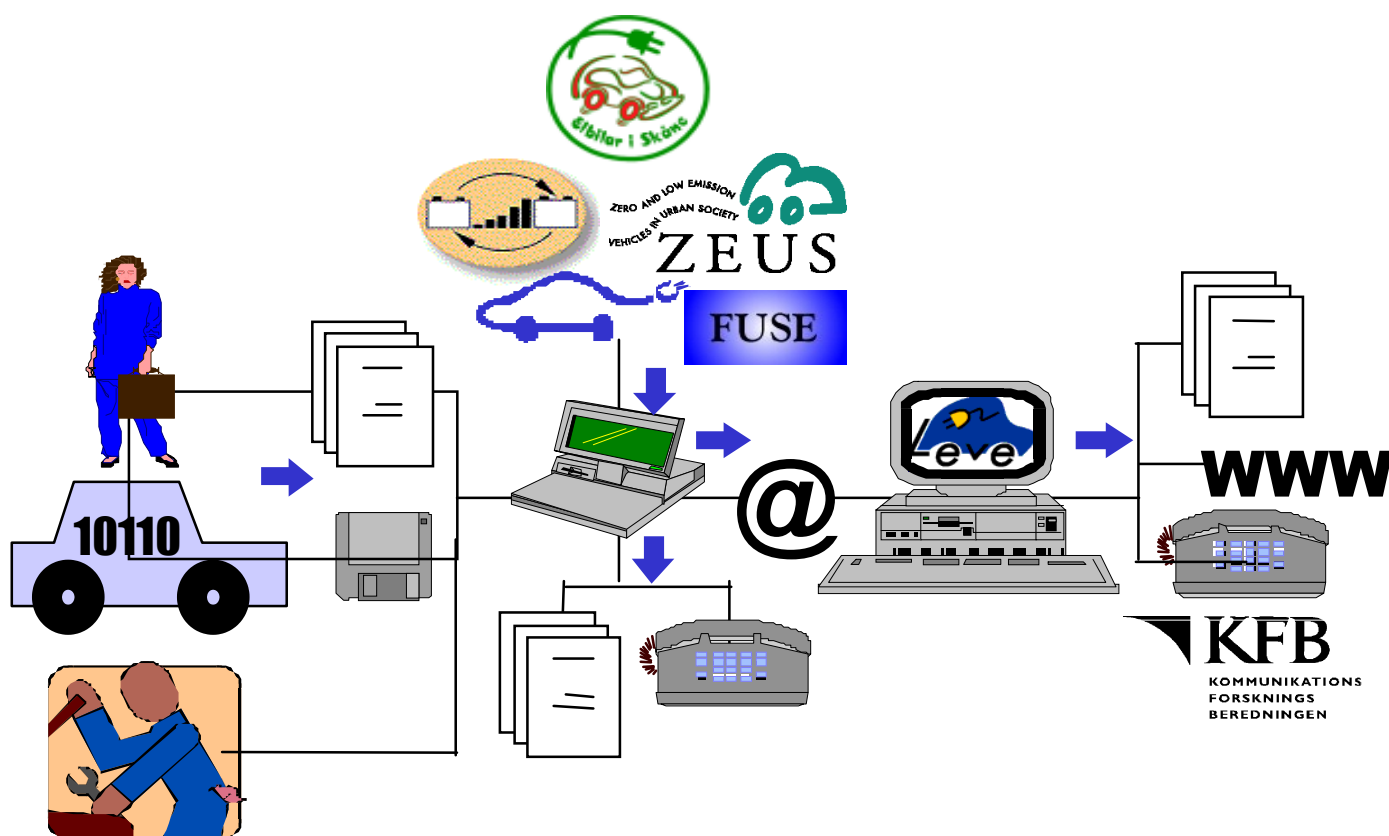A Database on

Electric Vehicle Use in Sweden

Final Report

Niklas Fridstrand
Lund Institute of Technology
Sweden

ABSTRACT and REFERAT:
See the following pages

A Database on

Electric Vehicle Use
in Sweden

Final Report

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Sweden

ABSTRACT (Aims, Methods, Results)

The Department of Industrial Electrical Engineering and Automation (IEA) at the Lund Institute of Technology (LTH), has taken responsibility for developing and maintaining a database on electric and hybrid road vehicles in Sweden. The Swedish Transport and Communications Research Board, (KFB) initiated the development of this database. Information is collected from three major cities in Sweden: Malmö, Gothenburg and Stockholm, as well as smaller cities such as Skellefteå and Härnösand in northern Sweden.

This final report summarises the experience gained during the development and maintenance of the database from February 1996 to December 1999. Our aim was to construct a well-functioning database for the evaluation of electric and hybrid road vehicles in Sweden.

The database contains detailed information on several years' use of electric vehicles (EVs) in Sweden (for example, 220 million driving records). Two data acquisition systems were used,one less and one more complex with respect to the number of quantities logged. Unfortunately, data collection was not complete, due to malfunctioning of the more complex system, and due to human factors for the less complex system.

Conclusions:
- For the 30 Renault Clio Electrique in the EV-related fault and problem survey, the number of problems&faults per year has decreased during 1998 compared with 1997. A large amount of the faults of the Renault Clio Electrique cars in the first year were due to insulation problems. Measures to improve the electric insulation mainly involved cleaning the traction battery and mounting a guard to protect the battery from splashing from beneath the car. This explains why this fault category decreased between the two years.

- The only EV-related faults for the 9 Peugeot 106 Electrique concerned the traction batteries. The system components in Peugeot 106 Electrique appears to be more developed than those on in the Renault Clio Electrique, model year 1996/1997 and Renault Express Electrique, model year 1996.

- The most frequently used type of battery in EVs June 1999 was the flooded NiCd battery (68%).

- The number of onroad EVs, including passenger cars, trucks, buses and motor cycles, increased from 262 in June 1996, to 591 in June 1999.

- In 1998, the largest proportion of EVs was owned by companies (61%) followed by municipalities (county councils) (22%). Of the total number of motor vehicles in Sweden (about 4,200,000 passenger cars, trucks, buses and motorcycles), most (77%) are privately owned.

- The three most common types of EV were the Renault Clio (35%), the Citroèn Berlingo (17%) and the Renault Express (10%) (June 1999).

- Charging and driving data from four Renault Clio Electrique has been analysed to examine whether there is a correlation between the energy usage per km and other quantities. The two statistically secure correlations found shows that the energy usage per km decreases with an increase in the driven distans between charges as well as with an increase in the average speed. No statistically secure correlation could be found between the energy usage per km and the ambient temperature down to -3°C. How the driving style influences on the energy usage per km has not been possible to analyse with data from the Mobibox system. An experience from measuring the driving range though indicates that a Reanult Clio Electrique may use approximately 29 % less energy per km when used in moderate citydriving compared to sporty citydrivning.

- The average annual driving distance of all the EVs in the survey in 1999 was 5951 km. The electric vehicle which was driven most during the period 1996-1999 was a Renault Clio, which covered an annual distance of 20,656 km in 1997.

- The amount of energy expended (the amount taken from the power grid), based on 13 Renault Clios (excluding the car heater) varied from 2.2 to 3.8 kWh/10 km, with an average of 2.9 kWh/10 km.

- The LEVE database can be supplemented with information on other alternative vehicles. Collecting data from different kinds of vehicle technologies in one place would facilitate the comparison of different techniques, for example, the effects on the environment of methanol-driven vehicles.

- A very important issue is that future projects should test and verify measuring systems *before* its application.

- Through cooperation with related projects in other countries, LEVE would increase its knowledge on EVs. Possible partners are the Swiss Mendrisio project and the French project (Eléctricité de France).

REFERAT (Syfte, Metod, Resultat)

Institutionen för Industriell Elektroteknik och Automation (IEA) vid LTH sköter sedan början av 1996 på uppdrag av Kommunikationsforskningsberedningen (KFB) uppbyggnad och drift av en databas med information om pågående elfordonsaktiviteter i Sverige. Databasen omfattar de aktiviteter som sker i elbilsprojekten Elbilar i Göteborg, Elbilar i Skåne, Batteribytesprojektet, FUSE (Fortsatt Utvärdering av SEHCCs Elbilar, teknikupphandlingsprojektet) och Miljöbilar i Stockholm (ZEUS, Zero and low Emission vehicles in Urban Society).

I denna slutrapport sammanfattas erfarenheterna från uppbyggnad och drift av databasen under tiden februari 1996 till december 1999. Målet är att upprätta en fungerande databas för utvärdering av el- och elhybridfordon i Sverige.

Databasen innehåller detaljrik information om erfarenheterna från flera års elbilsanvändning i Sverige (t.ex. 220 miljoner (!) "körningar" med elbilar). Två typer av mätsystemen har använts varav det mer komplexa ej fungerat tillfredsställande. För det enklare systemet har orsaken för utebliven data orsakats främst av mänskliga faktorer.

Slutsatser från utvärderingen:
- För de 30 Reanult Clio Electrique i undersökningen gällande elfordonsrelaterade problem/fel har antalet problem/fel minskat under 1998 jämfört med 1997. En stor andel av problemen/felen under det första året var isolationsproblem. En åtgärd för att förbättra isolationen har varit att montera en skyddslist vilken förättrat skyddet mot stänk underifrån bilen. De ågärden förklarar en stor del av minskningen av problemen/felen.

- De enda elfordonsrelaterade problemen/felen för de 9 Peugeot 106 Electrique har gällt traktionsbatterierna. Systemkomponenterna i Peugeot 106 Electrique verkar vara mer utvecklade än de som används i Renault Clio Electrique, årsmodell 1996/1997 och Renault Express Electrique, årsmodell 1996.

- Den mest förekommande batteritypen i elfordonen juni 1999 var öppna NiCd-batterier (68%).

- Elfordonsbeståndet i Sverige vad gäller personbilar, lastbilar, bussar och MC har ökat från 262 juni 1996 till 591 juni 1999.

- Under 1998 ägdes de flesta elfordon av företag (61%) och kommuner (22%), medan hela fordonsflottan (totalt ca 4,2 miljoner personbilar/lastbilar/bussar/MC) dominerades av privatägda fordon (77%).

- De 3 vanligast förekommande elfordonstyperna var, juni 1999, Renault Clio (35%), Citroën Berlingo (17%) och Renault Express (10%).

- Energianvändning har analyserats relativt storheterna körsträcka mellan laddningar, medelhastighet och yttertemperatur för fyra Renault Clios. De två statistiskt säkrade trenderna visar att energianvändning per km minskar vid ökad körsträcka mellan laddningar samt vid högre medelhastigheter. Något samband mellan energianvändning per km och yttertemperatur ner till -3°C har ej kunnat påvisas. En

ytterligare intressant storhet som tyvärr ej kunnat analyseras ur befintlig mätdata från Mobibox mätsystem är körstilens (accelerationer/retardationer) inverkan på energianvändning då Mobibox ej loggar accelerationer/retardationer. En *indikation* på körstilens inverkan är dock att en Renault Clio Electrique kan ha i storleksordningen 29 % lägre energianvändning per km vid mjuk stadskörning i jämförelse med hård stadskörning.

- Den årliga körsträckan för samtliga elbilar inom projekten var 5951 km under 1999. Det fordon, en Renault Clio, som hade högst årlig körsträcka kördes 20656 km under 1997.

- Uppmätta värden på energianvändnigen (exklusive eventuell energi för uppvärmning av kupén) för 13 Renault Clio varierar från 2,2 till 3,8 kWh/10 km. Medelvärde var 2,9 kWh/10 km.

- LEVA databasen kan kompletteras med information för andra miljöfordon. Att samla in sådan information på ett och samma ställe ger möjligheter att jämföra olika alternativ, tex metanoldrivna fordons miljöpåverkan.

- En mycket viktig lärdom för framtida projekt är att en verifiering och test i verklig drift av tänkbart mätsystem bör göras före användning.

- Genom samarbete med relaterade projekt utomlands kan LEVE öka kunskapen om elfordon. Tänkbara samarbetspartner skulle t.ex. kunna vara Mendrisioprojektet i Schweiz och Eléctricité de France i Frankrike

Contents

Introduction

At the beginning of 1996, The Department of Electrical Engineering and Automation at the Lund Institute of Technology, Sweden, was charged by the KFB with constructing and maintaining a database containing information on current electric vehicle activities in Sweden. This project is entitled LEVE: Lund Electric Vehicle Evaluation. The database includes data from the demonstration projects: Electric Vehicles in Scania, Electric Vehicles in Gothenburg, The Battery Exchange Project in Stockholm, FUSE (Continued evaluation of SEHCC's[1] electric vehicles) and ZEUS, Zero- and low-Emission vehicles in Urban Society, in Stockholm.

This report summarises the results and findings of the construction and running of the database during the period February 1996 to December 1999. The aim was to construct a well-functioning database for the evaluation of electric and hybrid vehicles in Sweden. Some data analysis has also been carried out within LEVE.

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[1] SEHCC, Swedish Electric/Hybrid Car Consortium

Collection of Data

Demonstration projects in connection with LEVE

Five demonstration projects have been connected with LEVE. The number of vehicles involved in June 1999 is given in parentheses for each project.

Electric Vehicles in Scania
Seventy-three passenger cars and courier's vans: Peugeot 106 Electric (10), Citroèn Berlingo (36), Renault Clio Electrique (12), Renault Express Electrique (12), Peugeot Partner Electric (2) and Toyota RAV4-EV (1).

Electric Vehicles in Gothenburg
Sixty-four passenger cars and courier's vans: Peugeot 106 Electric (3) Citroèn Berlingo (6), Renault Clio Electrique (21), Renault Express Electrique (29) and Peugeot Partner Electric (5).

Battery Exchange Project in Stockholm
Renault Express Electrique (5).

FUSE
Continued evaluation of SEHCC's[2] electric vehicles. Twenty so-called zero-series cars and a number (30) of the 120 main series cars, all Renault Clio.

ZEUS
Zero- and low-Emission vehicles in Urban Society. In Stockholm, the ZEUS project has involved about 52 EVs: Peugeot 106 Electric (1), Citroèn Berlingo (2), Renault Clio Electrique (37, of which 9 are included in the FUSE project), Renault Express Electrique (5) and the Fiat 600 Eletta (7).

Other vehicles
The database also includes driving data from 5 combustion-engine vehicles, as control vehicles for comparison, which have been used to deliver material in the building sector in Stockholm. Driving and charging data were collected from an onboard measuring system in a Toyota RAV4-EV from the end of October, 1998.

Measuring systems

Two measuring systems have thus far been used in the projects: Mobibox and Mobicap made by Mobilsystem AB. The parameters measured are, for example, driving distance, the energy taken from the grid during battery charging, the mean velocity and the ambient temperature. A detailed list of all the parameters measured can be found in Appendix 1. The data are normally checked to ensure that they are reasonable before being imported into the LEVE database.

Data collected in the database

One of the tasks of this project is to coordinate and harmonise the collection of data from the Swedish EV projects. The aim of this is to allow the data collected from

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[2] SEHCC, Swedish Electric/Hybrid Car Consortium

various EV projects to be compared. To this end, standardised input forms have been developed in the program Microsoft Access™. See, for example, Appendix 2. The following data were collected:

- the odometer reading, normally once per month
- data from onboard measuring systems
- questionnaires answered by drivers and service personnel
- driving journals

Flow of Information

Figure 1 gives a general view of how data are collected from the various EV projects, analysed and disseminated.

1. User	10. Transfer of information from the demonstration projects to the database
2. Measuring systems	
3. Service journals	11. Database
4. Data storage/transport media	12. Reports from the database
5. Questionnaires and driving journals	13. Results published on the LEVE home page
6. Activities in and experience from the projects	
7. Project evaluations	14. Provoked information from the database
8. Project reports	15. KFB reports, etc.
9. Provoked information from the projects	

Figure 1.   General view of the flow of information in the KFB Electric and Hybrid Vehicle Programme.

The Database

Design

Important questions that must be answered before a database can be constructed are: What kind of information is to be stored in the database? Who will the users be, and what do they intend to do with the information? Will they enter their own data, or merely use the data contained in the database?

The content of the database was determined together with representatives from KFB, and is illustrated in Figure 2.

Figure 2.   The content of the LEVE database.

As the demonstration projects connected to LEVE have access to the Microsoft database program Access™, this has been used to construct the database. The fact that data from the vehicle's onboard measuring system are stored in a separate FoxPro™ database has presented problems. This program makes use of predefined reports, which are useful, but it is not possible to construct one's own queries or reports. This problem has been overcome by creating links from MS Access™ to the FoxPro™ databases, as illustrated in Figure 3.

Figure 3.   Links between the MS Access™ (LEVE) and the FoxPro™ databases.

Another problem arose when the desire for the database to contain historical data from the National Road Administration's Vehicle Licensing Register was raised. This register contains information which changes with time. Therefore, it is stored in the LEVE database as a table called "AppearanceDate" containing information on vehicles and their owners at the time the data were downloaded from the vehicle register. This is usually done twice per year.

Those working in the various demonstration projects also wanted to be able to enter their own data into LEVE, i.e. the results of interviews, project activities, case studies, driving journals and problems related to EVs, so that they could also use the LEVE database. This led to special demands on the construction of the database. The problem was solved by restricting access to several tables in the LEVE database so that only personnel working on the LEVE project could update them. Professional help was obtained in solving specific database problems from Mats Svensson (Ref. 1) and Alberto Herrera (Ref. 2).

Structure of the database

It is always desirable to avoid storing the same information twice in a database. One of the reasons for this is that it is more efficient to update the information if it is only stored in one place. To avoid storing data more than once, one creates relations between tables containing different kinds of information. For example, information on inter- viewees is stored in one table, while the replies are stored in another. These interviews may have been carried out more than once. The structure of the LEVE database including the tables and relations as they are at present is given in Appendix 1.

Contents

Table 1 below provides information on the type and amount of data collected in the LEVE database to date.

Table 1.   Type and amount of data collected in the LEVE database.

Type of data	Amount of data	Comments
Driving journals	3838 records	Data for 219 vehicles, mostly km readings
Project activities	1 post	
Vehicle specifications	160 records	Specifications for each model for each year, for all manufacturers
Vehicle	746 records	The number of records refers to all vehicles on which information has been retrieved from the vehicle licensing register on any occasion (cars, vans, buses or motorcycles)
Historical data	2,421 records	1 post per vehicle for each occasion on which data were retrieved from the vehicle licensing register (normally twice per year)
Vehicle owner	486 records	Name, address…
Project	10 records	
Interviewees	207 records	An interviewee may have participated in several interviews/questionnaires
Results from the questionnaire "To future EV drivers"	52 records	
Results from the questionnaire "Drivers who have driven EVs"	191 records	
Results from the extra questionnaire "To decision-makers and those responsible for EVs"	10 records	
Service journal (faults, problems, service)	542 records	Data for 52 vehicles
Mobibox system	7,826 charging records 220,154,866 driving records	Data for 28 vehicles (not incl. data from the Battery Exchange Project). Charging records correspond to 14,636 kWh, driving records to 90,970 km. The energy meter (kWh) may not have been continuously connected.
Mobicap system	9,624 charging records 14,271 driving records	

In addition to the data listed in table 1, 6 case studies are presented on the LEVE homepage. Results from the questionnaire "To future hybrid van/truck drivers" (2 records) and the questionnaire "To drivers of hybrid vans/trucks"(2 records) are stored

on paper. Results from the questionnaire "EVs in private use" (10 records) are stored in Microsoft Excel™ format.

Validation of data

In order to identify incoming data of poor quality, they are first validated. In this way, faults can be detected and corrected, for example, a faulty speedometer. This validation is, however, only a coarse measure of the quality of the data.

The Mobicap system

Data from the Mobicap systems was evaluated weekly during the whole of 1998 (52 weeks), with the following results.

- Data were obtained for 40% of the weeks (15% within the validation limits, 25% outside).
- Data are lacking for 60% of the weeks (36% due to failure of the system, 20% due to human error, and 4% reason unknown).

Figure 4 shows the results of the validation of the data from 18 Mobicap systems.

Figure 4.   Results of the validation of data from 17 Mobicap systems during the 52 weeks of 1998.

The reason for the large amount of data classified as "Data missing, failure of system" is that several of the Mobicap systems had to be switched off for long periods of time as they caused problems in the running of the vehicles. Also, during downloading of data from a number of systems the unique identification number of the vehicle was changed to the default value 0000, making it impossible to identify from which vehicle the data had been collected.

Loss of data categorised as "Data missing, human error" was probably due to a combination of too infrequent downloading of data from the memory cards, poor

follow-up, and the fact that detailed logging of data filled the memory cards faster than anticipated.

"Data with errors" indicates that data were obtained for the week in question, but not all data fulfil the validation criterias, or that other errors were detected. For example, the temperature gauge had come loose (giving erroneous temperature data) or that the system had gone into off-line mode during part of the week.

The Mobicap system generates self-diagnostic records every two hours, and it is thus possible to determine the degree of functioning of the system. This is defined as the relation between the number of self-diagnostic records generated and full functioning, which is equivalent to 12 self-diagnostic records per 24 hours. From Figure 5 it can be seen that the Mobicap systems were in operation to a much greater degree in Gothenburg than in Malmö/Scania. This is probably the result of better follow-up in Gothenburg and the fact that an older program version was employed in Malmö/Scania by mistake. This led to the memory card being filled more rapidly than intended.

Figure 5.   Degree of functioning for 17 Mobicap systems from January to October 1998. The letters G, S and M after each vehicle refer to Gothenburg, SEHCC[3] and Malmö/Scania, respectively.

The Mobibox system
Data from forty-two Mobibox systems were evaluated during the whole of 1998 (52 weeks), with the following results.

• Data were obtained for 58% of the weeks (46% within the validation limits, 12% outside).
• Data are lacking for 42% of the weeks (4% due to failure of the system, 18% due to human error, and 20% reason unknown).

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[3] SEHCC, Swedish Electric/Hybrid Car Consortium

Figure 6 shows the results of the validation of data from the 42 Mobibox systems.

Figure 6.   *Results of the validation of data from 42 Mobibox systems tested during the 52 weeks of 1998.*

The largest share of "Data with errors" is due to a loose temperature sensor or energy gauge.

"Data missing, human error" is due to the fact that the system was not installed on time, or that the memory card became full.

Verification of the measuring systems

For differences between Mobibox and Mobicap systems, see Appendix 3.

The Mobicap system
At the start of the project, the accuracy of the more complex Mobicap system was not known. In order to determine the accuracy, the system has been verified. This was carried out by Semcon (Ref. 4). One of the Mobicap units was arbitrarily chosen for verification after having been used in an electric vehicle. The results show that at normal temperature (-20°C to 20°C) the system performed well when the vehicle was *not* in operation. When the vehicle was in operation on rollers (simulating the open road), it did not perform to the specifications for certain parameters, as can be seen in Table 2.

Table 2.   Performance and specifications of the Mobicap system.

Quantity measured	Value & accuracy of the control system	Greatest deviation in Mobicap data	Specification
Mean value of the **current from the battery** after 20 mins driving according to SS-EN 1986-1	74.75 ± 0.27 A	+ 21 A (+28%)	± 5 A
Mean value of the **voltage across the battery** during charging from 15% to 100% State of Charge (SOC)	136.87 ± 0.05 V	-8.91 V (-7%)	± 6 V
Energy to the engine while driving at approx. 40 A withdrawal for 5 mins	1,414,278 ± 3,540 Ws	+869,078 Ws (+61%)	± 9,000 Ws (± 30*tWs)
Energy to the service system while charging from 15% to 100% State of Charge (SOC)	2,971,694 ± 7,920 Ws	-74,547 Ws (-3%)	± 2,112 Ws (± 0.8*t Ws)
Energy to the battery (regeneration) after 20 mins driving according to SS-EN 1986-1	69,699 ± 960 Ws	-316,537 Ws (-450%)	± 36,000 Ws (± 30*t Ws)

The following conclusions were drawn from the verification of the Mobicap system.

- It is unnecessarily complex.
- It requires a great deal of maintenance.
- It measures extra parameters (energy flow and current through the vehicle) with poor accuracy.
- The parameters common to both systems (driving distance, energy taken form the grid when charging, ambient temperature, starting time, stopping time, mean velocity, max velocity) are measured with the same accuracy by both systems.

According to Semcon, the accuracy can be improved by moving the current shunts away from the engine house, reducing the scanning frequency of data collection, and by increasing the integration time. The two latter measures should provide a filter against high-frequency interference.

The Mobibox system
Projects using the Mobibox system have not verified it's accuracy.

Recommendations
LEVE recommends the Mobibox system over Mobicap as the reliability is greater and the parameters measured are sufficient for the evaluation of EVs (with the possible exception of high-speed charging and the measurement of the effect of the style of driving on the energy use). Bearing in mind the reliability of the two systems, it must be regarded as fortuitous that 42 vehicles were equipped with the Mobibox system and only 17 with Mobicap.

Maintenance of the database

In order to ensure that the data in the LEVE database are up to date regarding the existence of EVs in Sweden, data are downloaded from the National Vehicle Licensing Register twice per year. New data from the different EV projects is entered into the database by the following way:

1. A copy of the LEVE database is sent to the various project managers
2. New data is entered into the local copy
3. The database is returned to LEVE
4. The original LEVE database is updated
5. Copies of the updated LEVE database are sent to the various project managers
6. Steps 1-5 are repeated

Publication and External Activities

WWW

The project has its own home page (www.iea.lth.se/leve) where information is available to the public. The various projects, the vehicles, user categories, case studies, results etc., are described on the web site. On the page entitled "EVs in Sweden" the geographical distribution of EVs throughout Sweden can be seen, together with the increase in electric vehicles with time. Information on the number of kilometres driven by the cars is automatically updated on the page entitled "Project Cars" via a database connection using ASP (Active Server Pages). A diagram is automatically generated for each vehicle in the project, as shown in Figure 7. The vehicles are identified by code names, e.g. Clio-G49, which means a Renault Clio participating in the project Electric Vehicles in Gothenburg.

Figure 7.   *Distance driven by one of the electric vehicles as published on the LEVE web site. The statistics are automatically updated using ASP.*

Publication of reports

This report is one in a series of reports on the project which includes:
- A Database on Electric Vehicle use in Sweden, 1996-1997, KFB report 1998:29 (in Swedish).
- A Database on Electric Vehicle use in Sweden, January-October 1998, KFB report 1999:6 (in Swedish).
- A Database on Electric Vehicle use in Sweden, Final Report December 1999.

Other external activities

Below are some of the activities undertaken within the project in order to disseminate information.

- Exhibition together with The Swedish Transport and Communications Research Board at Miljöbil-96 in Stockholm, November 1996
- Participation in the Electric Vehicle Symposium EVS-13 in Osaka, Japan, October 1996
- Showcase together with The Swedish Transport and Communications Research Board at the Stockholm Motor Show, April 1997
- Participation in the Electric Vehicle Symposium EVS-14 in Orlando, USA, December 1997
- Participation in "Melarloppet" (EV race and presentation), May 1998
- Exhibition of the Toyota RAV4-EV for new students at the Department of Electrical Engineering and Automation at LTH, August 1998
- Showcase "Testsite Sweden" at EVS-15 in Brussels, September 1998
- A two-day seminar at The Swedish Transport and Communications Research Board, October 1998
- Participation in the seminar "Sverige på Elektrisk Väg" ("Sweden-on the electric road"), Lund, March 1999
- Presentation of the LEVE database at the General Meeting of ELFIR (Association for Electric Vehicles), at LTH, April 1999
- Showcase at EVS-16, Beijing, China, October 1999

Examples of interested parties who have recently contacted LEVE

- International magazines, regarding articles and advertisements
- Electric vehicle consultants, regarding the number of EVs in Scania
- Government authorities, regarding the total energy use of EVs in Sweden during 1997 and 1998
- Students on the ecological building engineering programme in Östersund, northern Sweden, regarding the lifetime, cost and recyclability of batteries, the effect of cold on batteries and the cost of EVs
- Analytical companies, regarding use of name and address information in the database as a mailing list
- A postgraduate student at the Chalmers University of Technology, Sweden, regarding the performance of the cars of today and tomorrow (2015) in kWh/km.
- Students in Stockholm, regarding a project on electric vehicles
- A postgraduate student in France, regarding what affects the development of batteries
- Reporters, regarding articles on environmental vehicle projects, magnetic fields, etc.
- Analytical companies, regarding environmental taxes on batteries, etc.
- Energy companies, regarding the driven distance and energy use of their EVs
- Energy companies, enquiring about the availability of the LEVE database on the Internet
- Scientists at Göteborg University, Sweden, regarding the prevalence of electric vehicles throughout the world
- A government authority, regarding brochures on electric vehicles

Compilation and Analysis of Data

In order to investigate the kind of information on electric vehicles of interest to various groups, 500 questionnaires were sent out in the summer of 1998 to EV owners, Swedish participants in the EVS-14 symposium in Orlando, Florida, USA, and transport and environmental departments of local authorities in Sweden. Of the 122 replies received, it was found that the information of interest was:

- What is likely to go wrong with an EV? Are faults more or less common in EVs than in corresponding petrol combustion engine vehicles?
- What is the vehicle range with fully charged batteries in the summer and the winter? Is the range shorter in the winter?
- What is available on the EV market today?

The questionnaire also allowed respondents to express desires for certain kinds of reports. This resulted in 50 requests from 39 respondents. These have been divided into six areas:

- The uses of EVs (17)
- The economics of EVs (12)
- The technology of EVs (9)
- The market for EVs (7)
- Safety issues (3)
- Environmental issues (2)

The numbers in parentheses indicate the number of respondents interested in such reports.

For those interested in using the LEVE database, an English user's manual has been produced including examples.

This chapter presents a number of reports based on the desires identified above.

Fault and service report

All service actions for all vehicles
The LEVE database contains service and fault reports of electric vehicles. Figure 8 shows what needed to be serviced, repaired or changed. The figure is based on data from the following vehicles:

- Twenty Renault Clio Electriques, during the period 27 June 1996 - 19 January 1999, included in the Electric Vehicles in Gothenburg project.
- Nine Peugeot 106 Electrics, for the period 7 June 1997 - 16 June 1999, 10 Renault Clio Electriques, during the period 19 April 1996 - 27 May 1999, and 12 Renault Express Electriques for the period 15 June 1995 – 15 June 1999, included in the Electric Vehicles in Scania project.

The most common service action was to fill up the batteries with water. The water in the NiCd traction battery must normally be filled up every 4000 km, so this is a routine service action and expected. The most common single source for unexpected problems was the onboard computer, which measures, among other things, the remaining capacity of the battery. The next most common type of repair was concerned with electric insulation and the car heater respectively.

Figure 8.   Service report for 51 EVs showing the type and number of faults, service.

Comments
The type of repair called "Others" includes repairs which do not fit into any of the other categories. Examples of these are: replacing windscreen wipers and tyres, problems with locks or the pump for the servo-brakes.

Amongst the 61 repairs categorised as UCL (vehicle computer), 23 were program upgrades, 16 units were replaced, and 11 were reprogrammed. Reasons for replacing the vehicle computer were: "Impossible to reverse the vehicle", "Poor drivability", "Erroneous battery capacity given", "Values not updated" and "French text". After

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updating 19 vehicles with UCL version 8, four UCLs were replaced, one was reprogrammed and .reseted. These problems did not occur with the Peugeot 106 Electric since this vehicle has another type of vehicle computer, not affected by these problems.

Regarding measures to improve the electric insulation, most involved cleaning the traction battery and mounting a guard to protect the battery from splashing from beneath the car. The guard was necessary due to the Swedish weather conditions requiring the use of salt on the roads in winter. The problem of poor insulation has not been completely solved by mounting the guard, but has been considerably reduced.

EV-related faults and problems
An important question is whether the fault frequency of EVs is higher or lower than the one of conventional vehicles. The number of vehicles and the timespan in this service survey have not been sufficient to draw conclusions based on statistical analysis.

To examine the number of faults specific to electric vehicles, standard service actions like refilling the battery were filtered away, as well as problems that also occur with petrol cars (lights, damages on chassi etc.). To upgrade the the vehicle computer (newer software version) does not necessarily indicate that the old software was malfunctioning. Upgrading of the vehicle computer was therefore also filtered away. The fault frequencies are shown for two following years to show a possible change in fault frequency in time. The results have been sorted by car model and model year and are presented in figures 9-12.
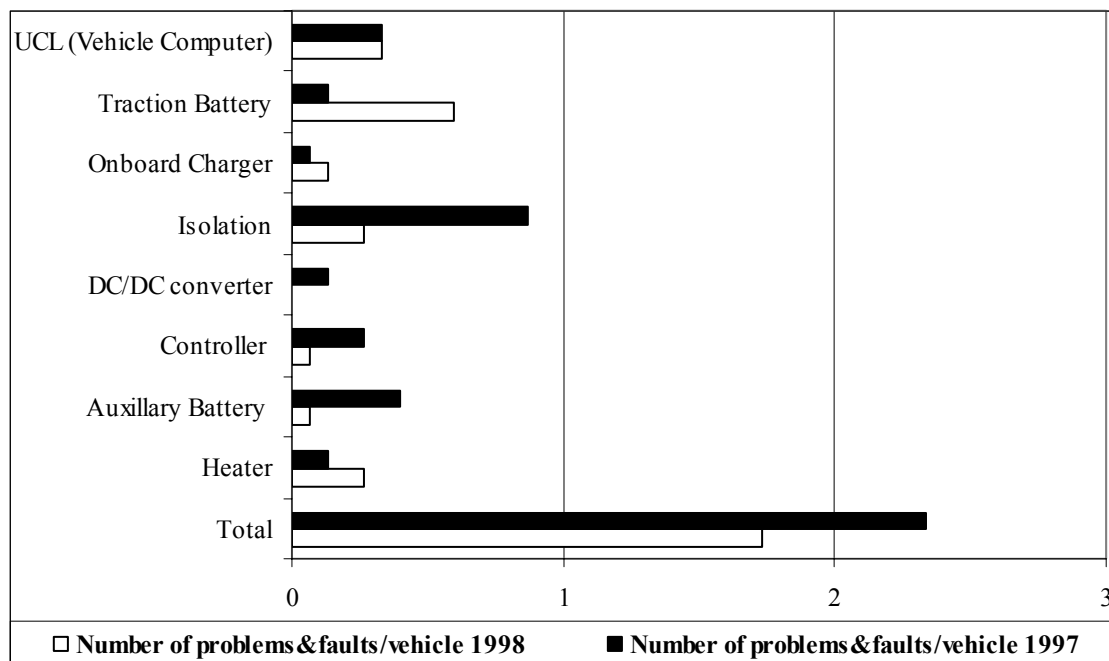

Figure 9: Number of EV-related faults per vehicle in 15 Renault Clio Electrique, model year 1996
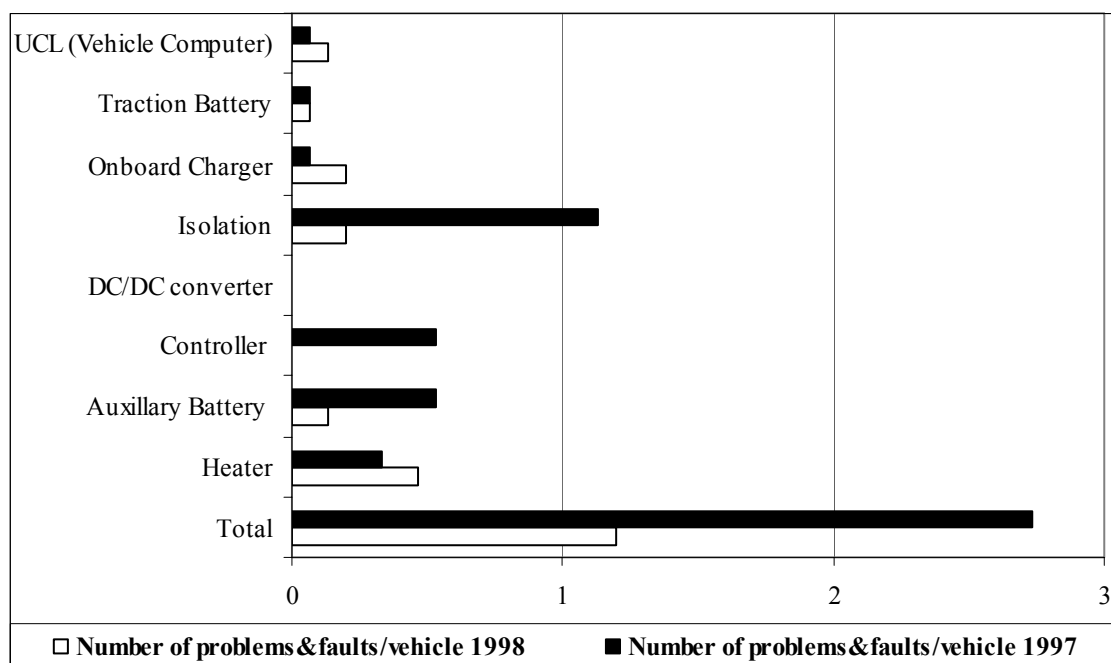
Figure 10: Number of EV-related faults per vehicle in 15 Renault Clio Electrique, model year 1997

Figure 11: Number of EV-related faults per vehicle in 9 Peugeot 106 Electrique, model year 1997

Figure 12: Number of EV-related faults per vehicle in 10 Renault Express Electrique, model year 1996

Conclusions:

For the 30 Renault Clio Electrique in the service survey, the number of problems&faults per year has decreased during 1998 compared with 1997. A large amount of the faults of the Renault Clio Electrique cars in the first year were due to insulation problems. Measures to improve the electric insulation mainly involved cleaning the traction battery and mounting a guard to protect the battery from splashing from beneath the car. This explains why this fault category decreased between the two years.

The only EV-related faults for the 9 Peugeot 106 Electrique concerned the traction batteries. The system components in Peugeot 106 Electrique appears to be more developed than those on in the Renault Clio Electrique, model year 1996/1997 and Renault Express Electrique, model year 1996.

The 10 Renault Express Electrique, model year 1996 has not experienced any traction battery problems. The traction battery in the Express has a higher rating (140 Ah) than those in the Peugeot 106 and the Renault Clio (100 Ah).

The number of EVs in Sweden from 1993 to 1999

Figure 13 shows the increase in the number of EVs in Sweden since 1993. The following vehicles have been included in the analysis: electric and electric hybrid vehicles in use and registered as passenger cars, vans/trucks, buses or motorcycles.

Figure 13.   Number of electric and hybrid vehicles registered in Sweden from 1993 to 1999. (Source: The National Vehicle Licensing Register)

Comments

The increase between January 1997 and June 1997 is mostly due to the technical procurement by the Swedish National Energy Administration (STEM).

Distribution of EVs according to district from January 1997 to June 1999

Figure 14 illustrates the change in the number of electric vehicles within each district of Sweden, from January 1997 to June 1999.

Figure 14. *Geographical distribution of electric and hybrid vehicles registered in Sweden as passenger cars, vans/trucks, buses or motorcycles. (Source: The National Vehicle Licensing Register)*

Types of batteries used in electric vehicles

Figure 15 shows the types of batteries used in EVs in Sweden. The following vehicles were included in the analysis: electric and electric hybrid vehicles in use and registered in June 1999 as passenger cars, vans/trucks, buses or motorcycles.

Figure 15.   Types of batteries used in electric and hybrid vehicles in Sweden, in June 1999. The analysis is based on 591 onroad vehicles. Batteries classified as unknown are those in older EVs and in cars converted to run on electricity, and are probably lead batteries. (Source: The National Vehicle Licensing Register)

Models of EVs registered

Figure 16 shows the numbers of EVs registered in June 1999 in Sweden according to model. Vehicles included in the analysis were those registered as passenger cars, vans/trucks, buses or motorcycles. Only models with at least three vehicles are included.

Figure 16.   The 17 most common models of electric and hybrid vehicles registered in Sweden in June 1999. (Source: The National Vehicle Licensing Register)

An EVs energy usage versus various quantities

Charging and driving data from four Renault Clio Electrique has been analysed to examine whether there is a correlation between the energy usage per km and other quantities. The energy usage refers to energy taken from the grid. The examined quantities are:

- Ambient temperature
- Average speed
- Driven distance between charging

Figure 17 to 19 shows the energy usage per km versus various quantities for the four Renault Clios.

Figure 17.   Energy usage per km versus ambient temperature

Figure 18.   Energy usage per km versus average speed

Figure 19. Energy usage per km versus the driven distance between charging

In figure 17 to 19 one can see that there are significant individual differences between the vehicles both conserning the diffusion of data and the trends. The trends are represented by linear regressions and drawn in the figures with grey lines. The black line in the three figures is the linear regression for the data for all vehicles.

Table 3 shows whether there are any correlations that can be statistically secured from the collected data. The table gives a 95% confidence interval for beta (the slope of the curve) as well as the p (probability) value of the test. If the interval does not cover zero (equals the statement that the p value is less than 0.05), the slope differs significantly from zero, i e the slope is statistically secured (Ref. 5). The interesting issue is if any of the quantities shows a significant trend for all the cars. The values that this condition are in **bold**.

Table 3.   p and beta values for all examined quantities determines if any correlation is statistically secure
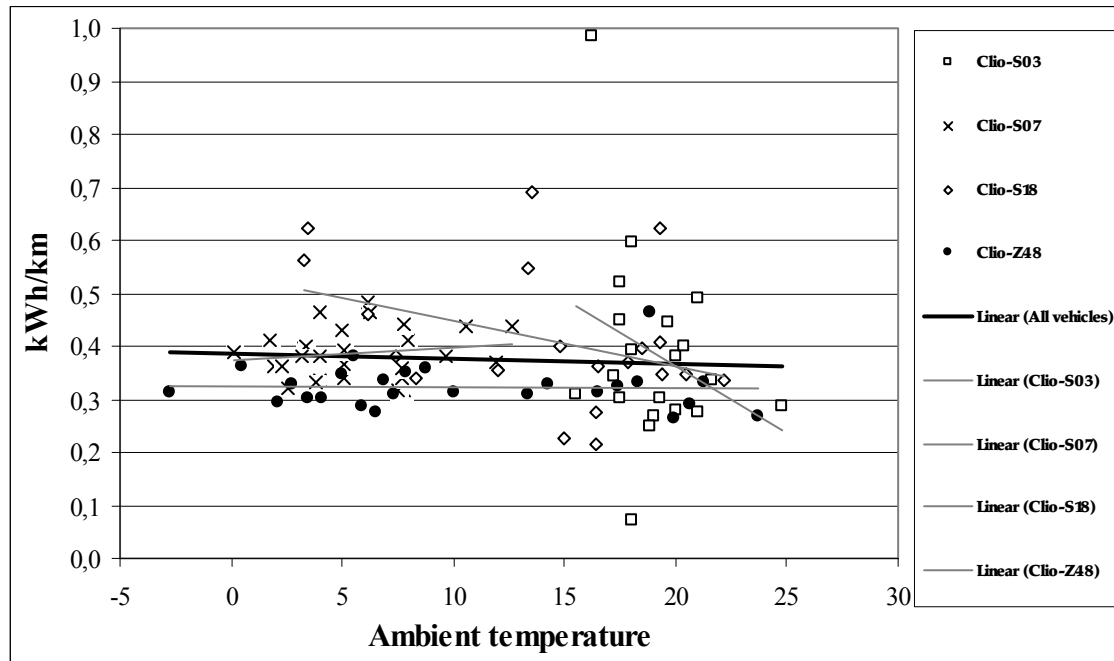
Parameter\ Vehicle	**Clio-S03**	**Clio-S07**	**Clio-S18**	**Clio-Z48**	**All Vehicles**
Data period	1998-06-08 to 1998-07-27	1998-10-27 to 1998-12-11	1998-04-22 to 1998-11-24	1998-11-15 to 1999-03-13	
Average speed	P: **0,0200** Beta*: **-0,0196** to **-0,0019**	P: **0,0028** Beta*: **-0,0130** to **-0,0030**	P: 0,6667 Beta*: -0,0119 to 0,0078	P: **0,0054** Beta*: **-0,0101** to **-0,0020**	P: **0,0001** Beta*: **-0,0104** to **-0,0041**
Ambient temperature	P: 0,2068 Beta*: -0,0662 to 0,0153	P: 0,4145 Beta*: -0,0035 to 0,0084	P: 0,1049 Beta*: -0,0193 to 0,0020	P: 0,8653 Beta*: -0,0026 to 0,0022	P: 0,6044 Beta*: -0,0042 to 0,002443

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Driven distance between charging	P: **0,0453** Beta*: **-0,0155** to **-0,0002**	P: **0,0076** Beta*: **-0,0048** to **-0,0008**	P: **0,0005** Beta*: **-0,0083** to **-0,0028**	P: **0,0008** Beta*: **-0,0036** to **-0,0011**	P: **0,0062** Beta*: **-0,0036** to **-0,0006**

The result shows that there is a statistically secure correlation between the energy usage per km and the driven distance between charging. The trend shows that the energy usage per km decreases with an increase in the driven distans between charges. For example, a vehicle driven three times further between charges (60 km compared to 20 km) uses 22% less energy per km. A possible explanation for this trend is the fact that the charging efficiency of the batteries decreases when almost fully charged (gassing in the equalising phase). An empty battery can thus be charged with a high efficiency under a longer period than a battery that is half full.

The result also shows for three out of the four vehicles, as well as for all vehiles together, that there is a statistically secure correlation between the energy usage per km and the average speed. The trend shows that the energy usage per km decreases with an increase in the average speed. For example, a vehicle driven at a three times higher average speed (30 km/h compared to 10 km/h)) uses 33% less energy per km. One explanation to this surprising trend is that city driving (low average speed) includes more stops and accelerations than highway driving (higher average speed). The data does not show the energy usage per km at constant speed. In such a case, the energy usage per km is expected to increase with an increase in speed.

No statistically secure correlation could be found between the energy usage per km and the ambient temperature down to -3°C.

How the driving style influences the energy usage per km has not been possible to analyse. An experience from measuring the driving range though indicates that a Reanult Clio Electrique may use approximately 40 % less energy per km when used in moderate citydriving compared to sporty citydrivning.

Users of EVs compared with users of conventional vehicles in Sweden

One of the aims of The Swedish Transport and Communications Research Board's programme for research, development and demonstration of electric and hybrid vehicles is to study the conditions for and consequences of the large-scale introduction of EVs.

In the summer of 1998, there were about 4.2 million passenger cars, trucks, lorries, buses and motorcycles in Sweden. Of these, 77% were owned privately, and 23% by companies and local authorities. It we, however, turn to the owners of the 189 EVs included in the programme, we find that only 4% is owned privately, the vast majority being owned by companies and local authorities. The distribution of ownership is illustrated in Figure 20. In order to be able to draw reasonably accurate conclusions regarding the effects of large-scale introduction of EVs, future studies should include an increased proportion of EVs in private ownership.

Figure 20. *The distribution of ownership of all vehicles registered in Sweden in July of 1998, all EVs and the 189 EVs included in the study.*

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User categories for the EVs included in the programme

Figure 21 shows the user categories for the 210 EVs included in the demonstration projects, January 1999.

Figure 21.   User categories for the 210 vehicles included in the demonstration projects in January 1999. Only users of at least two vehicles are shown.

Average driving distance of the vehicles in the demonstration projects, 1996 - 1999

Figures 22, 23, 24 and 25 show the minimum, maximum, average and median driving distances for the EVs during the years 1996, 1997, 1998 and 1999, respectively. Only vehicles with data on driving distance for at least 6 months of the relevant year were included in the analysis. Data from The Swedish Motor Vehicle Inspection Company regarding petrol-driven Renault Clios (1995 model) and Peugeot 106s (also 1995 model) are included for comparison.

Figure 22. *Minimum, maximum, average and median driving distances for the EVs in the demonstration projects during 1996, together with the corresponding data for petrol-driven Renault Clios and Peugeot 106s during 1997. (Sources: LEVE and The Swedish Consumer Agency)*

Figure 23. Minimum, maximum, average and median driving distances for the EVs in the demonstration projects during 1997, together with the corresponding data for petrol-driven Renault Clios and Peugeot 106s during 1997. (Sources: LEVE and The Swedish Consumer Agency)

Figure 24. *Minimum, maximum, average and median driving distances for the EVs in the demonstration projects during 1998, together with the corresponding data for petrol-driven Renault Clios and Peugeot 106s during 1997. (Sources: LEVE and The Swedish Consumer Agency)*

Figure 25. *Minimum, maximum, average and median driving distances for the EVs in the demonstration projects during 1999, together with the corresponding data for petrol-driven Renault Clios and Peugeot 106s during 1997. (Sources: LEVE and The Swedish Consumer Agency)*

Energy use per 10 km for 13 Renault Clios

The average, maximum, minimum and median energy use for 13 Renault Clio Electriques in the investigation is shown in Figure 26. The analysis is based on a total driving distance of 23,000 km, from 29 December 1997 to 25 January 1999.

Figure 26.   Energy use from the grid for 13 Renault Clio Electriques, over a period of about 1 year.

Comments

Energy measurements above do not include energy used by the car heater.
To give an approximate number on the peterol used per year fueling data has been collected for 13 Renault Clio Electriques over a period of about 1 year.
The result gave an average of 36, a maximum of 121, a minimum of 10 and a median of 26 litres per year.

Conclusions and Suggestions for Future Work

The LEVE database contains detailed information from several years' use of EVs in Sweden, including "hard" data (technical data and measurements) as well as "soft" data (replies to questionnaires and subjective opinions). These data can be analysed in many ways to produce various kinds of reports. The imagination of the user is the main limitation. The database constitutes a piece of electric vehicle history which can be used now and in the future for research and as the basis for planning future EV activities.

The strength of the database lies in its width. A weakness is, however, that not all the vehicles have the same extensive data, due mainly to technical problems with the complex Mobicap system, and poor maintenance of the simpler Mobibox system. Mobicap was found to be an unnecessarily complex system with insufficient reliability. Mobibox is to be recommended over Mobicap as its reliability is higher, and the data generated are sufficient for the purpose of analysing the performance of EVs. (Possible exceptions are the facility of fast charging and the possibility of measuring driving style.) In future projects, testing and verification of measuring systems should be carried out *before* its application.

Compared with the European database CEU-Task 1 (A Database for Information Exchange on Electric Vehicle Field Tests and Demonstration Programmes), LEVE is less detailed. The CEU contains, for example, information on the city, district etc., in which the car is used. On the other hand, the LEVE database is a complete database for EVs in Sweden - all vehicles are included and subjective data (obtained through interviews/questionnaires) are available in many cases, which the CEU database lacks. Another difference between the LEVE and CEU databases is that the input fields for test results are more detailed in the CEU database. Various test results can, however, be entered in the comments field in the Project Activity table of the LEVE database.

The LEVE database can, of course, be supplemented with information on natural-gas-driven and ethanol-driven vehicles. If this is to be done, a number of conventional control vehicles, also equipped with measuring systems, should be included for comparison. These should be studied in the same way as the EVs. It would be easy to extend LEVE to a knowledge and experience database for alternative vehicles in a broader sense. Collecting data from different kinds of vehicle technologies in one place would facilitate the comparison of different techniques, for example, the effects on the environment of methanol-driven vehicles.

In order to be able to satisfy demands regarding relevant analysis and reports, a clearer strategy for data collection should be developed. Methods of data collection, format, input routines, etc., should be coordinated in future projects in order to avoid duplication of work.

It is necessary to check the quality of the data before adding it to the LEVE database. Validation of data should be carried out in such a way that possible problems and errors can be corrected without undue delay. One way of achieving this is to use automatic data collection which, with the aid of GSM[4], collects data and sends them to a central computer for validation. Such systems may also make use of the global positioning system, GPS, which eliminates the need for mechanical or electronic distance-

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[4] GSM: Global System for Mobile Communications

measuring devices, which require individual calibration and which are prone to faults. In this way, it is possible to measure velocity with sufficient accuracy (using differential GPS) and distance.

Most of the data in the LEVE database are from the first generation of EVs. Newer, more modern vehicles, e.g. the Toyota RAV4-EV, have a significantly better performance than the vehicles which dominate the market today. If the latest generation of EVs can find a broader market, the pattern of use and degree of acceptance may change considerably. It is thus important to collect and analyse data from these vehicles.

Further suggestions for the continued use of the LEVE database include, making a map available on the Internet showing where it is possible to charge EVs, to perform further analysis, and to inspire regional projects to evaluate the next generation of EVs, for example taxis with a driving range of 150 - 200 km. Such a study would mean hard driving (in turn requiring good backup and support from the manufacturer), high exposure (with the possibility to register attitudes through an electronic questionnaire in the car, the results of which would be sent automatically to LEVE's central computer via GSM), and the possibility of informing a wider public. Such a taxi project would benefit from the possibility of fast charging. It would also be necessary to introduce a system of financing which guarantees taxi companies the same income from EVs as from conventional vehicles.

Through intensive cooperation with related projects in other countries, LEVE would, in the long term, increase our knowledge on EVs. Projects carried out in other countries could provide answers to questions not covered by the Swedish projects, and vice versa. Making use of data on EVs available in other countries constitutes an effective way of increasing our knowledge on EVs in Sweden. It would, however, be necessary to scrutinize the data critically, as it is not at all certain that all conditions are comparable to those in Sweden. Possible partners are the Swiss Mendrisio project and the French project (Eléctricité de France.) The EDF database is in the process of being constructed.

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      communication on data analysis.

2.   Alberto Herrera, Durodatek, Private communication on database techniques.

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      Testing of Two Renault Clio Electriques, Report MTC-9534S, 1996/6.

4.   Semcon, report entitled; Verification of Onboard Measuring Systems for Electric
      Vehicles, dated 1998-07-07. (In Swedish)

5.   Experimentell och industriell statistik, Lennart Olbjer. (In Swedish)

Appendices

Appendix 1. Parameters Stored by the Measuring Systems

Mobibox - the simpler measuring system
Driving distance
Energy taken from the grid during charging (not control vehicles)
Ambient temperature (not control vehicles)
Starting and stopping time
Time standing still (not control vehicles)
Max velocity (not control vehicles)
Average velocity

Mobicap - the more complex measuring system
Driving distance
Energy taken from the grid during charging
Voltage across, current and energy to and from the traction battery
Voltage across, current and energy to and from the engine regulator
Voltage across, current and energy to and from the service system
Battery temperature
Ambient temperature
Energy from the hybrid unit if fitted
Current to and from the electric motor
Max velocity
Average velocity
Starting and stopping time

In the Mobicap system it is possible to log data in different ways: when an event takes place, e.g. start and stop charging or driving (normal logging), or with a fix time interval of 30 seconds (detailed logging when charging) and of 2 seconds (detailed logging during driving).

Appendix 2. Input Form for the Fault/Problem/Service Journal

Fault/Problem/Service Journal

Fault, Problem and Service List
01 Auxiliary battery
02 Chassis or crash
03 Controller
04 DC/DC converter
05 Heater
06 Insulation
07 Onboard charger
08 Replacement car
10 Traction battery
11 UCL (Vehicle computer)
12 Water-filling
13 Lights
14 DAS (Data Acquisition System)
Other, please specify below

REGNO: HDA547

Repair shop name: Bilia/Göteborg

KT-nr: 0

Date in (yy-mm-dd): 1997-04-22

Date out (yy-mm-dd): 1997-04-22

Odometer Reading: 2852 km

Fault Category: 12 Water-filling

Fault Description:

Time required, total: 60 Minutes

Covered by guarantee: Nej

Cost (excl VAT): 703 SEK

Add Record

Appendix 3. Tables and Relations in the LEVE Database

VehicleSpec

Manufacturer
Type
Modelyear
FuelType
BatteryType
VehiclePhoto
VehicleSpecMEMO

Vehicle

REGNO
REGDate
VehicleCounter
Manufacturer
Type
ModelYear
ChassisNO
ChassisCode
ModelCode
GroupCode
REGTotalWeight
FORDBEN
DataBaseName
URL_to_Graph
URL_to_Case
VehicleMEMO

ApperanceDate

ApperanceDate
REGNO
REGDate
VehicleOwnerID
ProjectID
RegisteredAs
DeOrPreRegistered
CommercialTraffic
Leasing
PurchaseDate
KFBEvaluation
VehicleUser
UserType
UserCategory
ApperanceDateMEMO

VehicleOwner

VehicleOwnerID
VehicleOwnerName
CountyCode
Address
PostCode
City
Phone
Fax
VehicleOwnerMemo

County

CountyCode
Couty

ProjectActivity

ActivityID
ProjectID
ActivtyName
ActivityDescription
Purpose
Location
StartDate
StopDate
ActivityManagerFirstName
ActivityManagerLastName
InvolvedVehicles
InvolvedPersonsOrCompanies
Result
OtherInfo

DriverJournal

JournalDate
VehicleCounter
StartTime
StopTime
ODOReading
AhReadingBeforeCharge
kWhReading
DriverFirstName
DriverLastName
Usage
DriverJournalMEMO
AhReadingAfterCharge
Ahc

Project

ProjectID
ProjectName
ProjectManagerFirstName
ProjectManagerLastName
ProjectLOGO
ProjectLocation
ProjectMEMO

Case

CaseID
ProjectID
CaseText
CasePhoto
CaseStartDate
CaseStopDate
CaseMEMO

Fault_Problem_Service

VehicleCounter
RepairShop_Name
KT-nr
Date_In
Date_Out
ODOReading
Fault_Category
Covered_By_Guarantee
Time_required_Total
Cost_excl_VAT
Fault_Description

InterviewPerson

InterviewPersonID
ProjectID
InterviewPersonFirstName
InterviewPersonLastName
Sex
InterviewPersonYearOfBirth
InterviewPersonMEMO

Questionnaire1

InterviewDate
InterviewPersonID
ProjectID
VehicleCounter
F0Inmatare
F4Företag
F5Yrke
Svar på frågorna...
MEMO

Questionnaire2

InterviewDate
InterviewPersonID
ProjectID
VehicleCounter
F0Inmatare
F4Företag
F5Yrke
Svar på frågorna...
MEMO

Questionnaire3

InterviewDate
InterviewPersonID
ProjectID
VehicleCounter
F0Inmatare
F4Företag
F5Yrke
Svar på frågorna...
MEMO

Legend

Bold = Primary key
Underscore = Secondary key

|——— = Forced relation
O— = Non forced relation
☐ = Table only updateable by LEVE

Relation labels: Vehicle has, Appears on, Vehicle owned by, lives in, Vehicle belongs to, has, involves, Project has, Case belongs to, has

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Postal address: Box 5706, S-114 87 Stockholm, Sweden
Visiting address: Linnégatan 2, Stockholm
Phone: 08-459 17 00; Int: +46 8 459 17 00
Fax: 08-662 66 09; Int: +46 8 662 66 09
Internet Home page: www.kfb.se
E-mail: kfb@kfb.se

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