Deliverable 6.3

Contribution to national and international technical standardisation committees regarding electric vehicle relevant standards

Prepared by:

Bart Benders, fka
benders@fka.de
Kim Winther, DTI
kwi@dti.dk

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Authors

	Name	Company
Key author	Bart Benders	fka
Further authors	Kim Winther	DTI

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List of Abbreviations

CCS	Combined Charging System
CEN	Comité Européen de Normalisation (European Committee for Standardisation)
CENELEC	Comité Européen de Normalisation Électrotechnique (European Committee for Electrotechnical Standardisation)
DIN	Deutsches Institut für Normung (German Institute for Standardisation)
DKE	Deutsche Kommission Elektrotechnik Elektronik Informationstechnik (German Commission for Electric, Electronic and Information technologies)
ECU	Electronic Control Unit
EMC	Electromagnetic Compatibility
ETSI	European Telecommunications Standards Institute
EU	European Union
EUDC	Extra-urban Drving Cycle
EV	Electric Vehicle
fka	Forschungsgesellschaft Kraftfahrwesen mbH
ICE	Internal combustion engine
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineering
ISO	International Organisation for Standardisation
ITU	International Telecommunication Union
NEDC	New European Driving Cycle
NERC	North American Electric Reliability Corporation
OEM	Original Equipment Manufacturer
SAE	Society of Automotive Engineers
SC	Subcommittee for standardisation
SOH	State Of Health
SORDS	Standardized On-Road Driving Schedule
TC	Technical Committee for standardisation
TEPCO	Tokyo Electric Power Company
UDC	Urban Driving Cycle
UNECE	United Nations Economic Commission for Europe

US	United States
WLTC	Worldwide Light-duty Test Cycle
WLTP	Worldwide harmonized Light vehicle Test Procedures
WG	Working Group
WP	Work Package
WTO	World Trade Organisation

1 Executive Summary

Goal of the work reported here was to identify gaps in standardization regarding EV technology and to bring proposals to national and international standardization groups.

Based on the standardisation analysis performed as part of work package (WP) 7 of Green eMotion, domains of capital importance regarding EV technology were extracted:

- EV: different connectors and charging modes
- Charging points: different socket outlets and charging modes
- Identification/Communication: different communication architectures
- Consumption analysis procedures: non-realistic results

Based on the catalogue of existing standards described in D7.1[1], the Forschungsgesellschaft Kraftfahrwesen mbH (fka) developed a more detailed and clear catalogue regarding EVs in cooperation with WP6 partners. An extract of this catalogue is depicted in Figure 3.1.

A main issue regarding connectors are the dimension of differences which the couplers have already reached. Not only diversity in design of the plug-in types is causing inhibition, totally different technical implementations obviate the possibility of using simplified adapters.

A major outcome is also the perception and proof that the definition and determination of the range and thus the energy consumption of an EV is critical and not sufficient. Common methodologies to describe the absolute range (for an EV, but also for combustion engine driven vehicles) as well as the energy consumption per 100 km aren't realistic especially since there is no single value that can represent all conditions.

Within WP6 of Green eMotion a new testing methodology was defined to give a more balanced picture on these values with regard to different weather and driving conditions. The outcomes of these developments are discussed/under discussion with the ISO/TC 22/SC 21/WG 2 "Definitions and methods of measurement of vehicle performance and of energy consumption" and an active contribution was delivered as described in this document.

It can be concluded that the standardisation processes will be off course still a topic after Green eMotion. Critical gaps were identified and even addressed with proposals for improvements towards ISO. This can be asserted as a success, definitely due to the fact that still there is discussion on these proposals and so the usefulness is proven.

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[1] Available at http://www.greenemotion-project.eu/dissemination/deliverables-standards.php

2 Introduction

2.1 Scope and structure of this report

Goal of the work reported here was to identify gaps in standardization regarding EV technology and to bring proposals to national and international standardization groups.

Within chapter 2 a generic description and explanation is given on how WP6 can contribute to standardisation and in which technical area. The “standardisation framework” for the EV, which is the main content of WP6, is displayed and also a contribution to other WPs regarding standardisation is described.

In the next section some standardisation topics, which the WP6 team thinks are critical due to the fact that there is a gap in the standardisation landscape, standards aren’t complete or not sufficient/correct, are listed and described.

Section 4 then describes the actions which are taken/could be taken out of WP6 to contribute to better or new standards.

The last two chapters then describe the outcomes and conclusions of the work, as well as the next steps which could be taken in the future, so after the Green eMotion project.

2.2 Standardisation bodies

In this section the standardisation landscape, relevant for WP6, will be described briefly to get an overview on this complex and sometimes non transparent area. For the definition of the work towards a productive contribution to the standardisation landscape, a proper schematic localization should be made to reduce the research field.

Engineering standards regarding EVs are concerning electro-techniques, telecommunication and general standardisation. Due to the overlap, the implementation progress of EVs in the world market is inhibited. Results are e.g. high costs which have negative consequences for the success of EV technology. A standardisation bodies’ structure from the German point of vision is depicted in Figure 2.1.

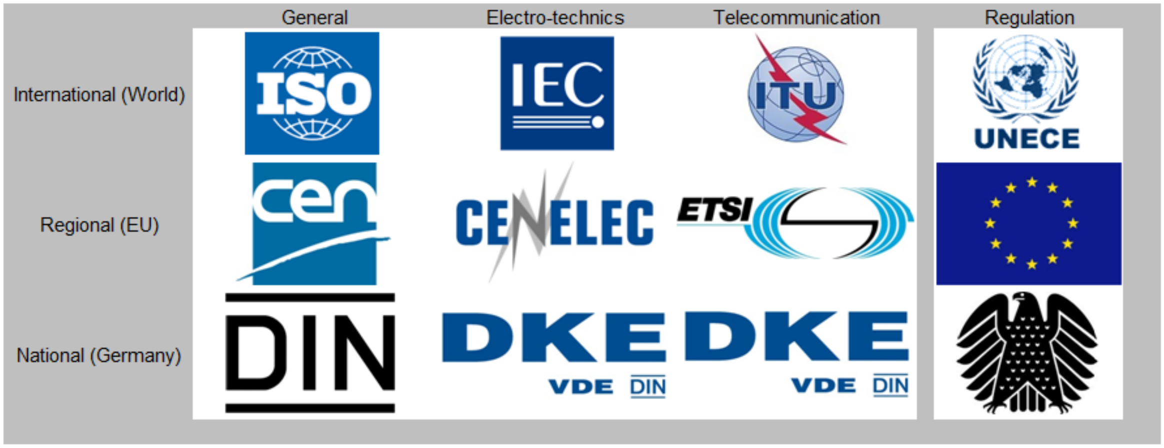

Figure 2.1: Structure of standardisation organisations for EV technology

The development of standards is divided into several technical groups, e.g. general, electro-techniques and telecommunication, as depicted in Figure 2.1, to ensure its improvement – topic specialists are guaranteeing a development of standards in a industry related way.

National standardisation organisations, e.g. DIN or DKE in Germany, arrange national standardisations to improve the economic growth within a country and especially to set their country apart from other countries regarding the level of technical quality. Moreover, national organisations prevent the import of products into the national market, if these are not conforming to national standards. Although these organisations were founded as national institutions and still work nationally, national organisations nowadays also play an important role in regional or international committees by providing the all important links to WGs from international organisations and set up national mirror committees. Inside these international committees, national organisations represent their national standardisations. National committees are restricted by the national legislation.

Political alliances, e.g. as the EU, afford one common standardisation organisation, as CEN, CENELEC or ETSI, for every specific standardisation topic to minimise differences regarding standardisation between member states. They are also representing the member states in global organisations regarding standardisation to achieve implementation of their regional standards into international agreements.

International standardisation organisations, e.g. ISO, IEC or ITU, ensure worldwide standardisation regarding any product on the world market due to globalisation. International WGs are supported by national institutes and regional organisations. They are regularised by the UNECE to achieve worldwide standardisation and to avoid inhibition on intercontinental markets.

Other standardisation bodies with a strong impact are IEEE in Europe or SAE and NERC in the US.

2.3 Development process of standards

The development process of standards begins with a standardisation request, in most cases from companies or organisations, but also from private persons, for a product or a service at standardisation organisations, e.g. at the DIN in Berlin. After a verification of the standardisation organisation regarding the national or international interest for the requested standard, a committee is founded. Committee members are companies, institutes, organisations, etc. which will be affected by the results of the requested standardisation process. In case of international standardisation processes, the WGs, consisting of experts from national standardisation organisations, get involved. After the agreement, a draft standard is published. If complaints are filed, consultants proof the qualification. Justifiable complaints must be considered resulting in overwork of the standard's draft version. Final versions must be accepted by the founded committee with a defined majority, e.g. all members in case of national standardisation committees of the DIN or 2/3 of the members in case of international ISO standards. International standards actually are optional. The World Trade Organisation (WTO) is currently trying to achieve a duty of assuming international standards. Within the EU, member states committed themselves to the acceptance of European standards. Deviating national standards are automatically getting invalid and must be overworked or abolished. The standardisation process of one standard requires about 3 years in average.

Standardisation in general is a common methodology to improve the international economic growth. Standards must always be established after general principles of standardisation: Transparency, impartiality, consensus, efficiency, relevance and consistency.

The principle of transparency contains an easily accessible information and procedure for all interested parties. Every standard must be developed in a way of impartiality to guarantee equality of opportunities. Consensus implies the united agreement of all relevant partners. Standardisation in general must achieve efficiency and relevance based on the market's needs. Moreover, the most important characteristic of standards is consistency due to the fact that standardisation builds the basis of uninhibited international growth of the economy.

2.4 Standardisation in Green eMotion

Standardisation and the resulting issues in case of lacking standardisation have been analysed in Green eMotion WP7. For the mass rollout of EVs, international standardisation plays a crucial role. Matching capabilities, e.g. the technical matching of plugs, and communication capabilities, e.g. the smooth communication between application programming interfaces (interoperability), of numerous electrical components must be ensured, especially during the charge, between different electrical components and between different OEMs components.

The Green eMotion WP7 in general devotes itself to a development harmonisation of standards in order to improve international acceptance of EVs, to advance EV technology and to achieve a region-wide coverage charging station network. Within WP7, standards and standardisation issues are analysed, influenced by the work done in WP6 among others.

D7.1[2] described interoperability issues in the EV standardisation process. In conclusion, several standards, concerning EV technology in general, vehicles, charging points, smart grid/connection to the grid, communication/identification and the billing service/payment system/roaming, are not covered at all. Others have gaps or are multiple covered with confliction between different specific topics' standards (general, telecommunication, electro-techniques) or different areas' standards (international, regional, national).

D7.2 examined these standardisation issues based on the catalogue of standards and the conclusions from D7.1. Concluding D7.2, technology and standards for international success of EV technology are available, but essential international standardisation decisions for an international mass rollout of EVs have not been made. Work in D7.2 identified the main issues regarding EVs and charging processes, whose standardisation progress is a fundamental precondition for the development of a successful international market for EV technology.

D7.3 is based on the input from D7.1 and D7.2 regarding standardisation issues. Within D7.3, results of other WPs, e.g. D6.1[3] regarding consumption analysis procedures, are picked up. Other work from WP6 regarding battery recuperation and compliance on communication is also considered. D7.3 conclusion is, based on the analysis of WP6, that official driving cycles' testing procedures for measurement of range and consumption are insufficient. Battery recuperation still needs improvements. Interoperability, especially communication within EV's components and between EVs and charging stations, often depends on different manufacturers' components resulting in technical issues due to not adequate covering standards.

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[2] All work package 7 deliverables (D7.x) are available at http://www.greenemotion-project.eu/dissemination-/deliverables-standards.php

[3] Available at http://www.greenemotion-project.eu/dissemination/deliverables-evaluations-demonstrations.php

3 Standardisation issues identified out of WP6

WP6 has demonstrated the huge variability of range and consumption under different driving conditions, reported in D6.2[4]. The variability between north and south of Europe has also been verified. Thus, it seems evident that no single value can be regarded as true for all cases.

3.1 Standardisation on the vehicle level

Based on the standardisation analysis in WP7, domains of capital importance regarding EV technology are derived for WP6:

- EV: different connectors and charging modes
- Charging points: different socket outlets and charging modes
- Identification/Communication: different communication architectures
- Consumption analysis procedures: non-realistic results

Lacking standardisation regarding EV's connectors and charging modes is reason for charging points having to provide different socket outlets and charging modes as result, especially AC and DC charging require various connecting systems. Moreover, manufacturer's private charging point installations do usually not consider competitor's plug-ins. For an overview on the different plugs, see chapter 3.2.1.

Besides, work carried out in D6.1 and experiences gained during the Green eMotion WP6 activities demonstrate a high demand on realistic consumption analysis procedures, as analysed in D7.3. Actually prescribed driving cycles like the NEDC enforce distrust in EV technology – results regarding range and consumption per 100 km are not realistic. Whereas maximal EV ranges are not comparable to vehicles with ICE anyway, customers feel misled while experiencing the differences between tested and realistic EV ranges. For a detailed analysis of driving cycles, see chapter 3.2.2.

Based on the catalogue of existing standards described in D7.1, the Forschungsgesellschaft Kraftfahrwesen mbH (fka) developed a more detailed and clear catalogue regarding EVs in cooperation with WP6 partners. An extract of this catalogue is depicted in Figure 3.1.

[4] Available February 2015 at http://www.greenemotion-project.eu/dissemination/deliverables-evaluations-demonstrations.php

Relevance Electric Vehicle	Classification	Standard	Title	Content
1	Drive Train - Communication	IEC/TS 62351-6	Power systems management and associated information exchange - Data and communications security -- Part 6: Security for IEC 61850	This part of IEC 62351 specifies messages, procedures and algorithms for securing the operation of all protocols based on or derived from the standard IEC 60870-5: Telecontrol equipment and systems - Part 5: Transmission protocols. This specification applies to at least those protocols listed in Table 1.
2	High Voltage - EMC	ISO 10605	Test methods for electrical disturbances from electrostatic discharge	This International Standard specifies the electrostatic discharge (ESD) test methods necessary to evaluate electronic modules intended for vehicle use. It applies to discharges in the following cases: ESD in assembly, ESD caused by service staff, ESD caused by occupants, ESD applied to the device under test (DUT) can directly influence the DUT.
3	High Voltage - Safety	ISO 10924-1	Road vehicles - Circuit breakers - Part 1: Definitions and general test requirements	This part of ISO 10924 defines terms and specifies general test requirements for circuit breakers for use in road vehicles with a nominal voltage of 12 V or 24 V. This part of ISO 10924 is intended to be used in conjunction with other parts of ISO 10924. This part of ISO 10924 is not applicable to circuit breaker holders (electrical centres or fuse-holders) used in vehicles.
3	High Voltage - Safety	ISO 10924-4	Road vehicles - Circuit breakers - Part 4: Medium circuit breakers with tabs (blade type), Form CB15	This part of ISO 10924 specifies medium circuit breakers with tabs (Blade type), Form CB15, for use in road vehicles. It establishes, for this circuit breaker form, the rated current, test procedures, performance requirements and dimensions. This part of ISO 10924 is intended to be used in conjunction with ISO 10924-1 and with ISO 10924-2.
2	Drive Train - EMC	ISO 11452-1	Component test methods for electrical disturbances from narrowband radiated electromagnetic energy -- Part 1: General principles and terminology	This part of ISO 11452 specifies general conditions, defines terms, gives practical guidelines and establishes the basic principles of the component tests used in the other parts of ISO 11452 for determining the immunity of electronic components of passenger cars and commercial vehicles to electrical disturbances from narrowband radiated electromagnetic energy, regardless of the vehicle propulsion system (e.g. spark-ignition engine, diesel engine, electric motor).
2	Drive Train - EMC	ISO 11452-2	Component test methods for electrical disturbances from narrowband radiated electromagnetic energy -- Part 2: Absorber-lined shielded enclosure	Specifies test methods and procedures for testing electromagnetic immunity (off-vehicle radiation sources) of electronic components for passenger cars and commercial vehicles regardless of the propulsion system (e.g. spark-ignition engine, diesel engine, electric motor). To perform this test method, the electronic module along with the wiring harness (prototype or standard test harness) and peripheral devices are subjected to the electromagnetic disturbance generated inside an absorberlined chamber. The electromagnetic disturbances considered in this part of ISO 11452 are limited to continuous narrowband electromagnetic fields. Immunity measurements of complete vehicles are generally only possible by the vehicle manufacturer. The reasons, for example, are the high costs of an absorber-lined chamber, preserving the secrey of prototypes, or the large number of different vehicle models. Therefore, for research, development and quality control, a laboratory measuring method is used by the manufacturer. Part 1 of ISO 11452 gives general information, definitions, practical use and basic principles of the test procedure.
1	Vehicle - General	ISO 11748-1	Technical documentation of electrical and electronic systems - Part 1: Content of exchanged documents	Gives guidelines for the content and structure of technical documentation of on-board electronic control systems used in road vehicles. It provides a checklist of technical data elements to be considered when creating technical documentation.
1	Vehicle - General	ISO 11748-2	Technical documentation of electrical and electronic systems - Part 2: Documentation agreement	Gives guidelines for the structure and content of the documentation agreement established between partners in the development of on-board electronic control systems used in road vehicles. The documetation agreement describes the exchange of documents between the partners and is specific to a given development. Provides a framework for any such agreement.
1	Vehicle - General	ISO 11748-3	Technical documentation of electrical and electronic systems - Part 3: Application example	This part of ISO 11748 provides an application example of the guidelines and specifications for technical documentation given in ISO 11748-1 and ISO 11748-2. The example is based on the standard generalized markup language (SGML), which is specified in ISO 8879.

Figure 3.1: Sample from the WP6 catalogue for EV standards

This catalogue for EV standards by the fka and WP6 partners contains all EV concerning and published standards by all standardisation organisations. A total of 277 relevant standards have been identified. The standards and their titles are listed in columns 3 and 4. Their content is explained in column 5 and its relevance for EV technology is rated in column 1 (1 – red: minimum relevance; 2 – yellow: medium relevance; 3 – green: maximum relevance). The number of standards categorized as relevant is 168.

In addition, these standards have been categorised in column 2 in order to facilitate a classification related overview on standards. Classifications and sub-classifications are shown in Figure 3.2.

Classification	Sub-classifications
General	Safety
Vehicle	General, Performance, Testing
Drive Train	General, Power electronics, Power converters, Communication, EMC
Battery	General, Safety, Packaging, Handling, Perfomance, Disposal, Testing
High Voltage	General, Safety, Charge, Plugs, Wires, EMC, Testing
Charging System	General, Safety, Plugs, Communication, Inductive charge
Functional Safety	
Diagnosis	
Certification	Functional Safety, Crash

Figure 3.2: Classifications and sub-classifications in the WP6 catalogue for EV standards

Due to the overlap of several categories, some standards have been attached to more than one single classification/sub-classification in order to facilitate the searching request and to have a better category related overview.

3.2 Identified issues

Gap analysis of the catalogue for EV standards by the fka and WP6 partners in chapter 3.1 identified issues regarding standardisation of EVs. These issues affect charging capabilities and consumption procedure analysis, are discussed in chapters 3.2.1 and 3.2.2.

3.2.1 Charging issues and plug discussion

Electrical connectors and charging modes for EV technology are regulated by international standards. To demonstrate the lack of standardisation regarding the charge of EVs, an overview of the plugs currently in circulation is given in this chapter.

The couplers support different charging modes – four modes do exist. Modes 1, 2 and 3 are AC charges varying in their amperage. Mode 1 charge reaches amperages up to 16 A, Mode 2 up to 32 A and Mode 3 up to 250 A. Mode 4 implies DC charging with amperages up to 400 A.

The SAE J1772-2009, or IEC 62196 Type 1, as depicted in Figure 3.3, manufactured by Yazaki among other manufacturers in 2009, is a five pin charging plug for single-phase Mode 1, 2 and 3 AC charges as a development of the SAE J1772-2001 standard. The SAE J1772-2009 coupler itself defines two charging levels: Level 1 at a voltage of 120 V and Level 2 at 240 V. So, it is capable of Mode 1 charging in Level 1 resulting in a maximal transferred power of 1.92 kW, a Mode 2 charge in Level 2 resulting in 7.68 kW and a Mode 3 charge in Level 2 reaching 19.2 kW (Mode 3 charge from IEC 62196 Type 1 is limited to 80 A not reaching the 250 A limit). The former SAE J1772-2001 coupler was limited to Mode 2 charge. AC three-phase current and DC charge are not available.

IEC 62196 Type 1		
Mode 1	Voltage	120 V
	Current	16 A
	Power	1.92 kW
	Phase	1
Mode 2	Voltage	240 V
	Current	32 A
	Power	7.68 kW
	Phase	1
Mode 3	Voltage	240 V
	Current	80 A
	Power	19.2 kW
	Phase	1

Figure 3.3: IEC 62196 Type 1 plug-in and socket

In order to imply Mode 4 DC charge to the SAE J1772-2009, or IEC 62196 Type 1 mentioned above, it can be enhanced to a Combo 1 or CCS Type 1, adding two further pins below the standard Type 1 connector, as shown in Figure 3.4, which socket also matches with a standard Type 1 Yazaki plug for AC charge. In case of CCS Type 1, DC charge with up to 90 kW is possible.

Figure 3.4: Combo 1 plug-in and socket

The VDE-AR-E 2623-2-2 or IEC 62196 Type 2, as depicted in Figure 3.5, originally manufactured by Mennekes is a seven pin connector upgrade for the requirements of the EV market based on the five pin IEC 60309 standardised CEEplus couplers for single- or three-phase AC charge and low DC charge by adding two more pins. The Type 2 Mennekes coupler affords Mode 1, 2, 3 and 4 charges. Single-phase charges at a voltage of 230 V consequently achieve a maximal power of 3.68 kW in Mode 1 charge, 7.36 kW in Mode 2 charge and 14.49 kW at Mode 3 charge (Mode 3 charge from IEC 62196 Type 2 is limited to 63 A not reaching the 250 A limit of Mode 3). Three-phase charges at a voltage of 400 V reach a maximal power of 11.04 kW in Mode 1 charge, 22.08 kW in Mode 2 charge and 43.47 kW in Mode 3 charge (limited to 63 A as mentioned above). Type 2 Mennekes couplers also support low DC Mode 4 charge with powers up to 38 kW.

IEC 62196 Type 2					
Mode 1	Voltage Current Power Phase	230 V 16 A 3.68 kW 1	Mode 1	Voltage Current Power Phase	400 V 16 A 11.04 kW 3
Mode 2	Voltage Current Power Phase	230 V 32 A 7.36 kW 1	Mode 2	Voltage Current Power Phase	400 V 32 A 22.08 kW 3
Mode 3	Voltage Current Power Phase	230 V 63 A 14.49 kW 1	Mode 3	Voltage Current Power Phase	400 V 63 A 43.47 kW 3

Figure 3.5: IEC 62196 Type 2 plug-in and socket

Implementing high DC charge to a VDE-AR-E 2623-2-2 or IEC 62196 Type 2 requires two additional pins below the connector, as depicted in Figure 3.6, called Combo 2 or CCS Type 2. The Combo 2 socket is also matching to Type 2 Mennekes plug-ins for AC and low DC charge. CCS Type 2 affords DC charges with powers up to 170 kW at a maximum voltage of 850 V and a maximum current of 200 A.

Figure 3.6: Combo 2 plug-in and socket

The EV Plug Alliance connector or IEC 62196 Type 3, as shown in Figure 3.7, is derived from SCAME couplers affording single- and three-phase AC charge and is produced by the EV plug alliance, consisting of several leading European manufacturers. In addition to IEC 62196 Type 2, shutters automatically keep electrical components hidden if not plugged. IEC 62196 Type 3 couplers only support Mode 1 and 2 charges. So, 230 V single-phase charges achieve 3.68 kW in Mode 1 and 7.36 kW in Mode 2. 400 V three-phase charges reach higher powers of 11.04 kW in Mode 1 and 22.08 kW in Mode 2. Neither DC charging of the IEC 62196 Type 3 itself nor an upgrade to a CCS for DC charging is possible.

IEC 62196 Type 3					
Mode 1	Voltage Current Power Phase	230 V 16 A 3.68 kW 1	Mode 1	Voltage Current Power Phase	400 V 16 A 11.04 kW 3
Mode 2	Voltage Current Power Phase	230 V 32 A 7.36 kW 1	Mode 2	Voltage Current Power Phase	400 V 32 A 22.08 kW 3

Figure 3.7: IEC 62196 Type 3 plug-in and socket

CHAdeMO, as depicted in Figure 3.8, is a pure DC charging coupler released in 2010 from TEPCO in cooperation with several Japanese EV manufacturers. CHAdeMO charging requires voltages of at least 200 V to maximal 600 V and achieves maximal Mode 4 amperages of 400 A. This is resulting in a maximal possible power of 240 kW.

Figure 3.8: CHAdeMO plug-in and socket

Tesla Motors developed another different electric coupler for the US market, as depicted in Figure 3.9. Tesla's EVs, e.g. the Model S, can be 230 V single-phase charged achieving 3.68 kW power in Mode 1 or three-phase charged achieving 11.04 kW in Mode 1 with 16 A in case of one implemented on-board charger. Tesla Motors' additional implementation of another second on-board charger is doubling the maximal power by enabling Mode 2 charge of 32 A. Power results during a 230 V single-phase charge are 7.36 kW in Mode 2 or 22.08 kW in a 400 V three-phase charge. Maximal AC power limits regarding capacities and amperages of the charging system itself are not released. EVs from Tesla Motors can be Mode 4 DC charged with powers up to 135 kW.

Tesla Motors					
Mode 1	Voltage Current Power Phase	230 V 16 A 3.68 kW 1	Mode 1	Voltage Current Power Phase	400 V 16 A 11.04 kW 3
Mode 2	Voltage Current Power Phase	230 V 32 A 7.36 kW 1	Mode 2	Voltage Current Power Phase	400 V 32 A 22.08 kW 3

Figure 3.9: Tesla Motors plug-in and socket

In summary, chapter 3.2.1 illustrates the dimension of differences which the couplers have already reached. Not only diversity in design of the plug-in types is causing inhibition, totally different technical implementations obviate the possibility of using simplified adapters.

3.2.2 Consumption analysis procedures

Every market on the world prescribes a testing methodology for consumption analysis of vehicles. International accepted consumption analysis procedures do not exist. As a result, manufacturers have to spend financial resources in different certifications and adaptations to the market's prescriptions. In this section, several driving cycles are analysed to validate the procedures and the consumption analysis results.

3.2.2.1 New European Driving Cycle

The New European Driving Cycle (NEDC) is consisting of the Urban Driving Cycle (UDC) from 1970, also known as city cycle, and the Extra-urban Driving Cycle (EUDC) from 1990, also known as highway cycle, as depicted in Figure 3.10, to measure the energy consumption of vehicles. The NEDC is used for vehicles with ICE and EVs.

Test procedure must be performed on a roller test bench with a cold engine in between 20 °C – 30 °C in the absence of wind and all auxiliaries, e.g. climate compressor, radio, etc., turned off.

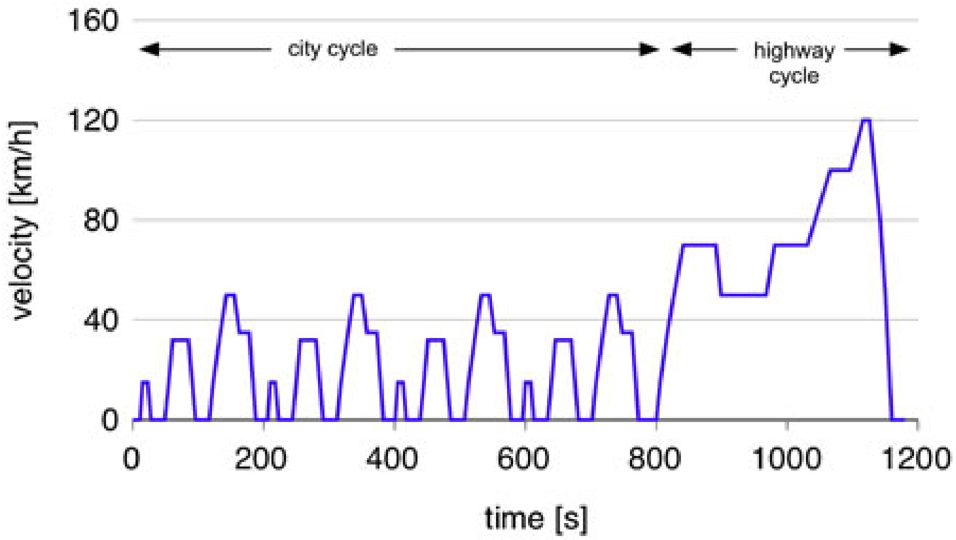

Figure 3.10: New European Driving Cycle

The first part of the UDC starts with an 11 sec pause after the engine start. Afterwards, the vehicle accelerates to 15 km/h within 4 sec maintaining the speed for 8 sec and braking to a full stop within 5 sec again pausing for 21 sec. The second part, starting at 49 sec, accelerates the vehicle to 32 km/h within 12 sec maintaining speed for 24 sec and braking to a full stop within 12 sec with a following pause of 21 sec. The third and last part, beginning at 117 sec, starts with an acceleration to 50 km/h within 26 sec, continuing at constant speed for 12 sec, decelerating to 35 km/h within 8 sec, maintaining speed for 13 sec and finally breaking to a full stop within 12 sec and pausing for another 7 sec resulting in a cycle time of 195 sec. This cycle is repeated four times resulting in an overall cycle time of 780 sec (13 min) over a theoretical distance of 3976 m with an average velocity of 18.35 km/h.

The EUDC starts with a 20 sec stop. Afterwards, the vehicle is accelerated to 70 km/h within 41 sec maintaining the speed for 50 sec, then decelerating to 50 km/h within 8 sec driving at steady speed for 69 sec and accelerating again up to 70 km/h within 13 sec holding constant speed for 50 sec, followed by an acceleration to 100 km/h within 35 sec driving at constant velocity for 30 sec. Finally, the vehicles is accelerated to 120 km/h within 20 sec for driving at constant speed for 10 sec and then braked to a full stop in 34 sec for standing still another 20 sec. This cycle duration is 400 sec (6 min 40 sec) over a theoretical distance of 6956 m with an average speed of 62.6 km/h.

The combination of both the UDC and the EUDC is the basis for the calculation of the vehicles total consumption.

Based on optimal circumstances, the test procedure's results are significantly different from practical consumption values due to the following influences:

1. Auxiliaries' consumptions are not considered. EV's heater or climate compressor consumptions in case of ambient temperatures deviating from 25 °C consume big amounts of energy (see D6.2).
2. Roller bench tests disregard the external wind speed and direction relative to the direction of travel, hills, turns etc., influencing vehicles in the outdoor.
3. Airflow effects are not realistic because they are only simulated for warm weather conditions with no external wind.

Moreover, the represented driving performance is not realistic because:

1. Average speed is much lower than typical European driving. Accelerating and braking processes are driven too slow resulting in low consumptions, e.g. acceleration to 50 km/h in 26 sec in part 3 of the UDC does not reflect practical situations.
2. High speed tests above 100 km/h only occur 37.84 sec of an 1180 sec test procedure. That is 3.21 % of the whole test. Especially for EVs - which consumption rises exponentially with higher velocity (see D6.2) - the consideration of high speed consumption values is essential.
3. The vehicle is standing still for 280 sec during the whole test, which makes about 23.73 % of the process time.

Despite of non-realistic consumption results, the NEDC is currently prescribed to OEMs inside of the EU. Realistic vehicle consumption analysis, especially regarding EV technology, would be a good possibility to achieve customer satisfaction, due to the fact, that distrust in range expectance is another main reason for customers not to purchase EVs. However the main message should be that range and consumption is never constant.

3.2.2.2 Worldwide Harmonized Light Vehicles Test Procedures

The driving cycles from the Worldwide Harmonized Light Vehicles Test Procedures (WLTP) are in development under guidelines of the UNECE. Final version is expected by October 2015. The WLTP actually includes three driving cycles called Worldwide Light-duty Test Cycles (WLTC) in order to test vehicles depending on their power-to-weight ratio. In case EVs cannot attain the prescribed acceleration and maximum speed values within WLTC procedure, the vehicles must be driven with fully activated accelerator pedal until reaching the required driving curve. These circumstances do not void the test procedure, but deviations from the driving cycle shall be recorded.

WLTP is also performed on roller test benches with auxiliaries turned off. Due to WLTC procedures' complexity, accelerations are not described as detailed as in the NEDC in this document.

Vehicles tested in WLTC Class 1 have power-to-weight ratio below 22 W/kg (very small urban vehicle). It consists of a low and a medium part to analyse consumption of Class 1 vehicles. WLTC Class 1 test is depicted in Figure 3.11.

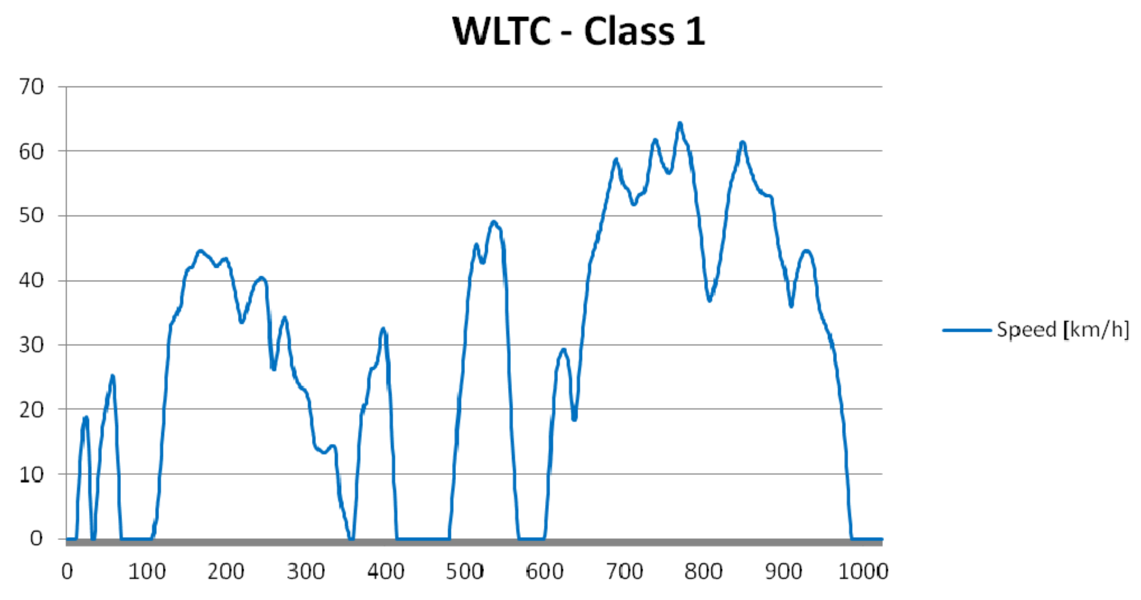

Figure 3.11: Worldwide Light-duty Test Cycle – Class 1

The WLTC Class 1 low part has duration of 589 sec covering a distance of 3333 m. Stop duration is 152 sec, which is about 25.81% of the whole test procedure. Maximal speed is 49.1 km/h; Average speed without stops is 27.46 km/h and 20.37 km/h with stops.
WLTC Class 1 medium part has duration of 433 sec on a distance of 4767 m with stop duration of 47 sec. That is about 10.85% of the whole medium part duration. Maximal speed is 64.4 km/h; Average speed without stops is 44.46 km/h and 39.63 km/h with stops.
As a result, the WLTC Class 1 test procedure has duration of 1022 sec with stop duration of 199 sec, this corresponds to a percentage of 19.47%. Distance covered is 8100 m; Average speed is 35.43 km/h without stops and 28.53 km/h with stops.

WLTC Class 2 is testing vehicles with power-to-weight ratio between 22 W/kg and 34 W/kg (small urban car, not suitable for highway travel). The process has low, medium, high and extra high parts for consumption analysis. WLTC Class 2 test procedure is shown in Figure 3.12

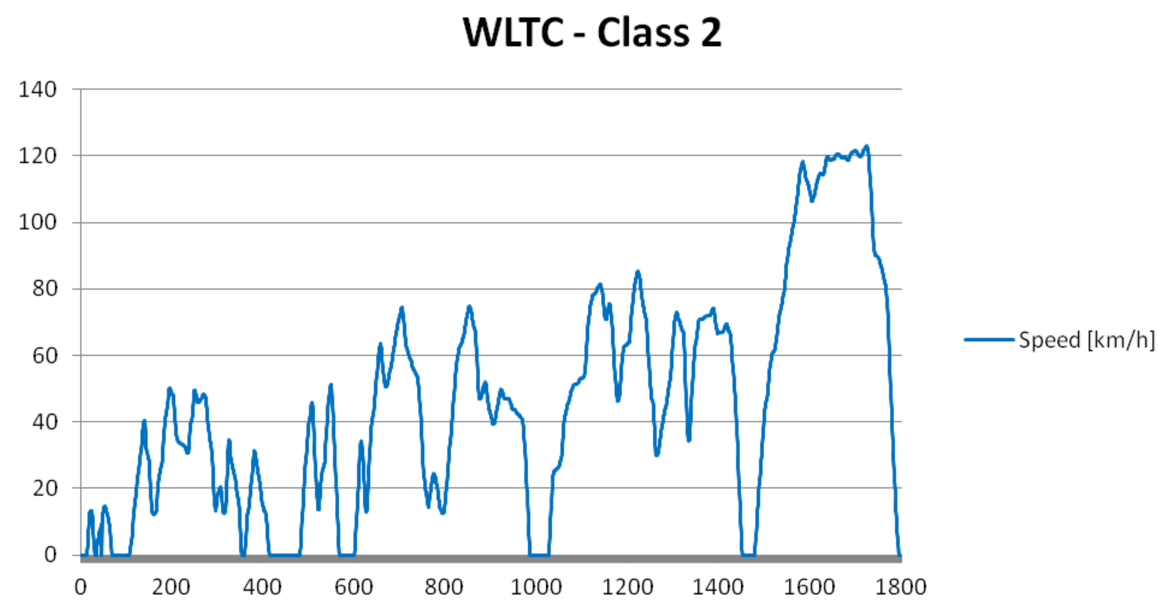

Figure 3.12: Worldwide Light-duty Test Cycle – Class 2

WLTC Class 2 low part has duration of 589 sec while covering distance of 3097 m. Stop duration is 151 sec, which is about 25,64% of the whole low part. Maximum speed is 50.2 km/h; Average speed is 25.46 km/h without stops and 18.93 km/h with stops.

The medium part of WLTC Class 2 has duration of 433 sec on a distance of 4738 m. During the medium part, tested vehicles are stopped for 48 sec, which is about 11.09% of the test procedure. Maximal reached speed is 74.7 km/h; Average speed without stops is 44.30 km/h and 39.39 km/h with stops.

The WLTC Class 2 high part's duration is 455 sec with a covered distance of 6792 m. Stop duration of the high part is 30 sec. That is about 6.59% of the tested procedure. Maximum speed is 85.2 km/h; Average speed is 57.53 km/h without stops and 53.74 km/h with stops.

Extra-high part of WLTC Class 2 has duration of 323 sec covering distance of 8019 m. Stop duration is 7 sec, which is about 2.17%. Maximum speed is 123.1 km/h; Average speed without stops is 91.36 km/h and 89.38 km/h with stops.

The whole WLTC Class 2 test procedure has duration of 1800 sec and covers a distance of 22646 m. Stop duration is 236 sec, which is about 13.11% of the whole Class 2 driving cycle. Average speed is 52.13 km/h without stops and 45.29 km/h with stops.

Class 3 of the WLTC is testing vehicles with power-to-weight ratio above 34 W/kg (small passenger car barely capable of highway travel). WLTC Class 3 also has low, medium, high and extra-high parts, but it is separated at the speed limit of 120 km/h. Medium and high parts are different for vehicles with speed limits underneath 120 km/h to vehicles with speed limits above 120 km/h. WLTC Class 3a for vehicles with speed limits underneath 120 km/h is depicted in Figure 3.13; WLTC Class 3b for vehicles with speed limits above 120 km/h is shown in Figure 3.14. Differences between Class 3a and Class 3b cycle are small.

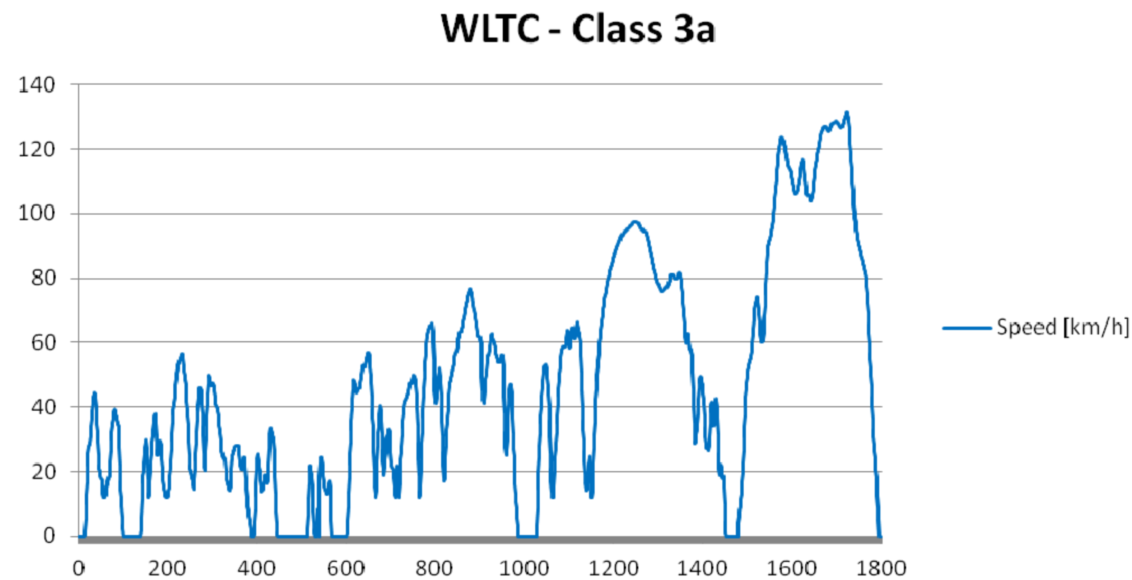

Figure 3.13: Worldwide Light-duty Test Cycle – Class 3a

The difference between Class 3b and class 3a is obtained by a downscaling factor which is a function of the relation between maximum required power of the cycle parts where downscaling is to be applied and the rated power of the vehicle. Thus the graph for 3a cannot be accurately reproduced without knowledge of the vehicle to be tested. Figure 3.13 is just an example.

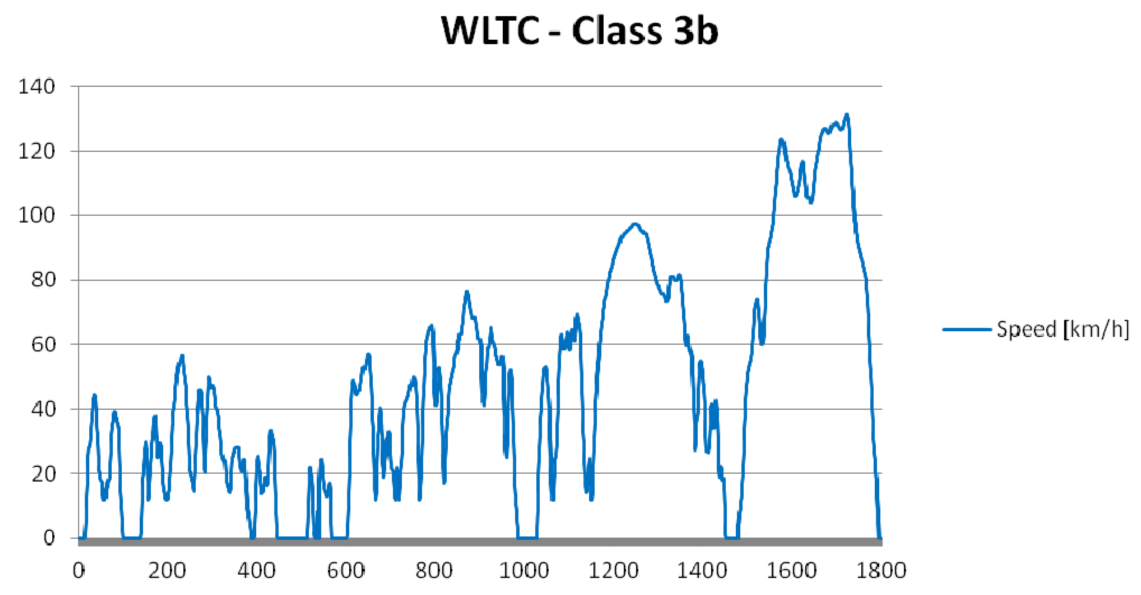

Figure 3.14: Worldwide Light-duty Test Cycle – Class 3b

WLTC Class 3 low part has duration of 589 sec while covering distance of 3091 m. Stop duration is 150 sec, which is about 25.47% of the whole low part. Maximum speed is 56.5 km/h; Average speed is 25.35 km/h without stops and 18.89 km/h with stops.

Medium part of WLTC Class 3a has duration of 433 sec on a covered distance of 4721 m. During the medium part, the vehicle has stop duration of 48 sec. That is 11.09% of the procedure. Maximum speed is 76.6 km/h; Average speed is 44.14 km/h without stops and 39.25 km/h with stops.

The other medium part of WLTC Class 3b also has duration of 433 sec and covers a distance of 4756 m. Stop duration is 48 sec as in medium part Class 3a, which is 11.09% of the test's duration. Maximal reached velocity is also 76.6 km/h; Average speed without stops is 44.47 km/h and 39.54 km/h with stops.

The high part of WLTC Class 3a takes a time of 455 sec while covering a distance of 7123 m. Stop duration is 30 sec, which is about 6.59% of the high part's duration. Maximum speed is 97.4 km/h; Average speed without stops is 60.34 km/h and 56.36 km/h with stops.

WLTC Class 3b high part also has duration of 455 sec and covers a distance of 7162 m. Stop duration, as in WLTC Class 3a, is 30 sec resulting in 6.59% of the test. Maximal velocity is 97.4 km/h; Average speed is 60.66 km/h without stops and 56.66 km/h with stops.

Finally, the extra-high part of WLTC Class 3 vehicles takes 323 sec on a covered distance of 8254 m. Vehicles are stopped for 7 sec, which is about 2.17%. Maximal reached speed is 131.3 km/h resulting in an average speed of 94.03 km/h without stops and 92.00 km/h with stops.
WLTC Class 3 testing procedure has overall duration of 1800 sec, covering a distance of 23189 m in Class 3a and 23263 m in Class 3b. Stop duration of the whole test is 235 sec in both Class 3a and 3b test, resulting in a percentage of 13.06%. Average speed without stops is 53.34 km/h and 46.38 km/h with stops in Class 3a test. Class 3b test procedure has an average speed of 53.51 km/h without stops and 46.53 km/h with stops.

The represented driving performance of the WLTP, as in the NEDC, is not realistic since:

1. Average speeds, acceleration and braking processes are driven too slow resulting in low consumption, e.g. WLTC Class 3 extra-high part acceleration to 50.5 km/h within 22 sec does not reflect practical situations.
2. High speeds above 100 km/h are barely tested. In WLTC Class 3 these parts only occur 181 sec of 1800 sec test duration, which is 10.06% of the procedure. This is about three times as long as in the NEDC, but still not enough, especially for EV relevant test results due to exponentially rising consumption with higher speeds.
3. Stop durations, which are about half of the time compared to the NEDC, are still too long, e.g. 13.06% in WLTC Class 3.

Although climate influences on the vehicles shall be considered by simulation in the WLTP roller bench tests, deactivated auxiliaries and its testing procedures are still not reflecting realistic driving performances – lower consumption values, compared to real on-road experiences, will be the result. In addition, extra driving cycles for alternative energies, e.g. electric energy, are not intended. Achieving realistic outcomes in a consumption analysis shall be the aim, so further work on WLTP until its possible release in October 2015 is still required.

3.3 Conclusion

Results from WP6 and WP7 give an overview on the actual state of standardisation, the inaccuracy of official driving cycles and other EV related issues. Especially, the necessity of international commitments in case of standardisation and realistic methods for consumption analysis, as described in chapter 3.2, should be achieved, to establish confidence in EV technology and to afford a mass rollout of EVs in the world market. In addition, lacking and unreliable infrastructure in charging stations is another main reason for the inhibition of mass EV rollout.

To get to this level of maturity, the WP6 team took actions, especially with regard to testing methodologies, as explained in Section 4.

4 Standardisation actions/work done/planned

4.1 Out of 3.2.1 (Charging issues and plug discussion)

Regarding the charging issues and plug discussion, it is hard for the WP6 team to contribute directly and active towards standardisation actions. However, in cooperation with the WP7 team the gaps and possible standardisation solutions were mapped. In addition, it can be stated that the standardisation landscape of this specific topic was very dynamic over the Green eMotion project timeline. A direct result out of Green eMotion therefore cannot be identified directly, however, contribution to the standardisation bodies and discussion with, can be marked as building block for the accelerated process. After the Green eMotion project, the work has to be continued and the section 3 therefore already gives a perfect overview on the state of the art at the end of the Green eMotion project.

4.2 Out of 3.2.2 (Consumption analysis procedures)

From driving on the test track at different speeds, the WP6 team determined that EV consumption is highly dependent on the average speed. Furthermore, the use of electric heating in the cars had major impact on consumption. While driving in the Nordic climate in the special out-door driving cycle defined by the WP6 team, ranges of less than half the official range stated by the NEDC test were figured.

Even though range and consumption figures don't match the official numbers, overall energy efficiency of EV's in most situations is actually quite high. Thus, the difference must be attributed to the test method and not the vehicle.

For further description of the SORDS cycle please refer to section 5.1 of D6.1. For a description of the results please see D6.2.

The internationally accepted standard for testing EV range and consumption is ISO 8714:2002 "Electric road vehicles -- Reference energy consumption and range -- Test procedures for passenger cars and light commercial vehicles". The current version of the standard was released on 2002 and reviewed in 2014.

ISO 8714 basically uses the same driving cycles as the legislative type approval schemes in each region (Japan, Europe and USA). This means for Europe, that NEDC is to be used. Since we already established that NEDC does not yield results representative the expectations of European drivers, the WP6 team would like to discuss the future use of NEDC in ISO 8714.

During the 2014 review, the standard was not changed. The WP6 team was not in time to propose a different driving cycle at this point. The reason for this is that our outdoor driving cycle (SORDS) is not yet developed to a state where it can be part of an international standard. First the method has to be validated thoroughly and commonly accepted by experts in the industry. Experimental methods cannot be accepted as international standards.

Furthermore, it is the clear conclusion form WP6, that consumption figures vary strongly with driving conditions, the load in the car and the operation of brakes to achieve maximum regenerative effect. Thus, it is not possible **with any driving cycle** to achieve a universally correct consumption figure. The real world consumption will always be subject to the individual conditions such as weather, speed limits and driver skills.

As a consequence, WP6 team does not claim SORDS to be any more correct than any other driving cycle. The SORDS merely has the advantage that is allows testing in a variety of outdoor conditions without the need for expensive roller bench dynamometers.

In connection with the 2014 review of ISO 8714, the WP6 team did make contact with the international committee in charge (ISO/TC22/SC21/WG2 Definitions and methods of measurement of vehicle performance and of energy consumption). DTI was already a member of this committee, so it was appropriate to send a proposal via the Danish Standards Institute.

The first draft was discussed on the Danish mirror committee S-454 in March 2014. The document was designated S-454n082_INF_Proposal for a range correction.

Subsequently, the document was forwarded to the secretary of ISO/TC22/SC21/WG2. Since there was no committee meetings scheduled at the time, the proposal was discussed within the Japanese mirror committee (based at JARI). A comprehensive review and evaluation of the proposal along with a number of questions for clarification was returned to the DTI in June 2014.

Based on the Japanese comment a second proposal was developed and this was returned to the committee in late July 2014. A response was received in November 2014. The committee had now decided on a meeting date in March 2015. This would be an opportunity to present and further explain the proposal to the committee. However, it lies beyond the finalisation date for Green emotion project so WP6 could not confirm the intention of participating in the meeting.

The WP6 proposal does not imply SORDS as a new testing cycle. Instead the proposal is treat the range of electric vehicles as a variable, which it properly is. The formula suggested for EV range is:

$$RANGE = \frac{CAPACITY \cdot SOC}{\frac{VLFC}{PABE} + \frac{AUX}{SPEED}}$$

- where

- RANGE = Actual driving range [km]
- CAPACITY = Actual battery capacity [kWh]
- SOC = State of charge [-]
- PABE*) = **P**owertrain **A**nd (regenerative) **B**raking **E**fficiency [%]
- VLFC*) = **V**ehicle **L**imited **F**uel **C**onsumption [kWh/100km]
- AUX = Auxiliary loads (heating and AC) [kW]
- SPEED = Average travelling speed [km/h]

The idea is that speed and auxiliary loads which are the main reasons for deviation can be set according to the actual conditions, not fixed by a certain drive cycle. If tests are done according to e.g. NEDC indoor then this result would be transferrable to other conditions, e.g. “winter driving on German highway”, “city driving in Spain”.

Both proposals Version 1 and Version 2 are attached as appendices to this report.

5 Next steps and cooperation with other WPs

5.1 Analysis of inter WP activities

Due to the fact that the Green eMotion consortium compromises a lot of technical experts in various areas of the electric mobility landscape, different workshops and the methodology description in WP7 have been constructive steps towards a productive inter WP cooperation. WP6 mainly focuses on the EV and therefore the content out of WP6 is different from other WPs. However, due to the usage of the same methodology a, in principle, methodological equal gap analysis was possible in different technical areas and an analysis of critical issues could be executed in the same way. This inter WP cooperation can be listed as a success and WP6 therefore can be seen as a methodology trial out of WP7 with the EV as main actor.

5.2 Next steps

Regarding standardisation of plugs, the EU agreed on the Type 2 Mennekes connection system in March 2014. Within the EU, electric charging shall be provided within cities and regions close to cities until 2020. An upcoming step regarding standardisation will be an international agreement on a single plug connection system for AC and DC charge as a basis for the development of infrastructure of a power station network for electric charges.

Moreover, the necessity of realistic consumption analysis procedures is required due to growing criticism. In addition, an international standard for consumption analysis procedures beware OEMs of different certifications which are required for different national markets. Besides, the costs arising from the vehicles' adaption to other markets' standards could be prevented. UNECE's final version of the WLTP is expected by October 2015. Within the EU, the European Parliament discusses whether the WLTP shall already become operative in January 2017. Other countries, e.g. Japan, China or India, also accept the WLTP in general, although several modifications are still requested. The equivalent committee in the US already militated against the introduction of the WLTP in the US market due to lacking consideration of engines with alternative energy. For an international agreement and realistic consumption analysis, the procedures of the WLTP have to be reworked and/or further cycle classes have to be added, e.g. for electric and hybrid vehicles.

6 Conclusions

Within this document, the analysis (out of WP6) of major constrictions regarding standardisation for the EV are identified and described. In cooperation with WP7, the basic analysis of gaps for standardisation activities within electric mobility was done. Within WP6, this analysis for the EV was deepened and a gap analysis matrix was build up as described in chapter 3.

Certainly, several areas show standardisation gaps for EVs, however, for the WP6 team, the most applicable gap, also considering the content of D6.1 and D6.2, is the standardised methodology of testing EVs. Analysis procedures are not realistic and definitely not suitable for giving realistic information on the energy consumption of a vehicle. Here, the WP6 team took action and developed a testing methodology which was presented to the ISO/TC 22/SC 21/WG 2 “Definitions and methods of measurement of vehicle performance and of energy consumption“ to open the discussion on possible adjustments to be made in the future. This is still an ongoing process which is described in Section 4 and will be work item also after the Green eMotion project.

In addition to this, the charging plug was also identified as “standardisation required” afflicted. The charging plug as described in section 3 shows a throughout detailed evolution within the Green eMotion project timeline. The developments done are described in detail and show a successful, but still not finalised, way towards standardisation.

From section 5, it can be concluded that the standardisation processes will be off course still a topic after Green eMotion, however critical gaps were identified and even addressed with proposals for improvements towards ISO. This can be asserted as a success, definitely due to the fact that still there is discussion on these proposals and so the usefulness is proven.

As a last conclusion, it must be stated that the way in which the different technical partners worked together within WP6, as well as between different WPs, composed a very impressive group of experts which led to a very professional working methodology on several standardisation topics.

7 Appendices

7.1 Version one of standardisation proposal for ISO 8714

Electric Vehicles

Task 6.3: Proposal for a range correction method

The problem…

The range of an electric car varies a lot according to weather and driving habits
European certification test figures do not reflect real world driving
=> Very difficult to predict the actual range
=> Uncertainty about usability of electric cars

Summary of the Nissan's results using EPA L4 test cycle operating the Leaf under different real-world scenarios[illegible]

Driving condition	Speed		Temperature		Total Drive Duration	Range		Air conditioner
	mph	km/h	°F	°C		mi	km	
Cruising (ideal condition)	38	61	68	20	3 hr 38 min	138	222	Off
City traffic	24	39	77	25	4 hr 23 min	105	169	Off
Highway	55	89	95	35	1 hr 16 min	70	110	n use
Winter, stop-and-go traffic	15	24	14	−10	4 hr 08 min	62	100	Heater on
Heavy stop-and-go traffic	6	10	86	30	7 hr 50 min	47	76	n use
EPA five-cycle tests[illegible]	n.a					73	117	Varying
NEDC							175	

The solution…

A simple 3-stage model:

1. The battery (capacity vs temperature)
2. The road (speed, accelerations, wind resistance, rolling resistance)
3. The car (powertrain and braking efficiency, heating and A/C)

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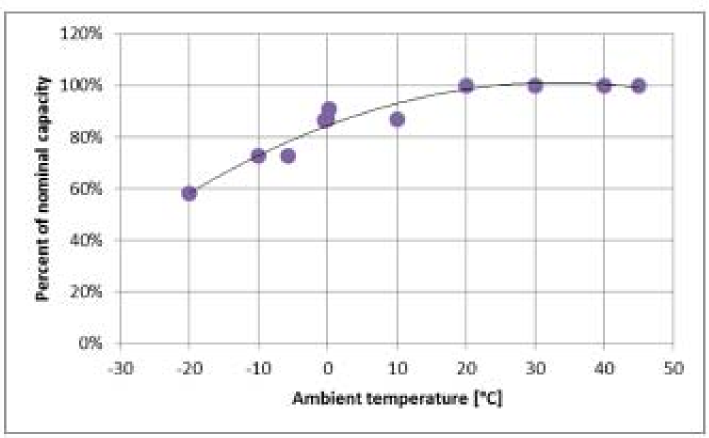
1) The battery



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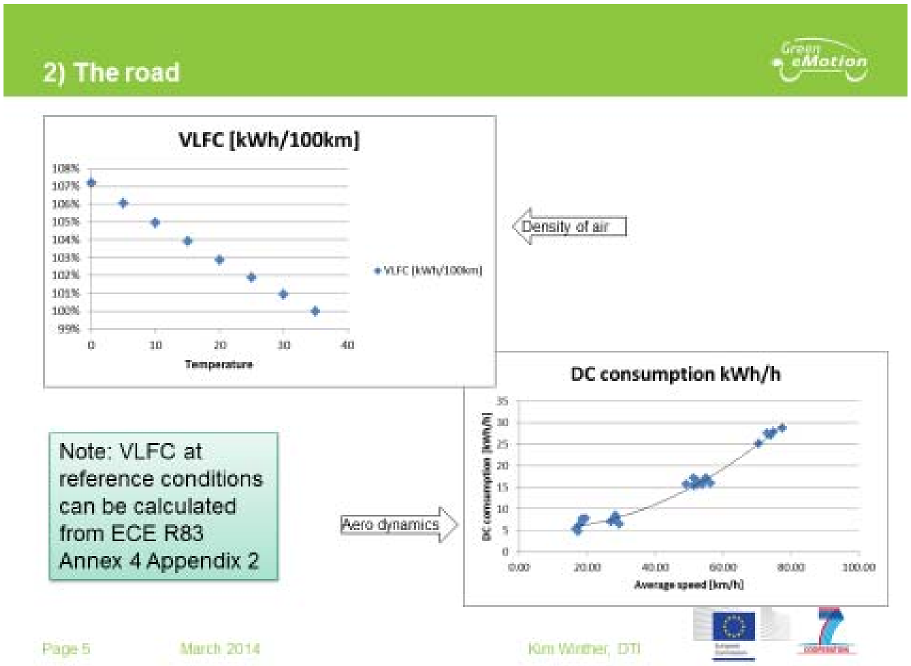
2) The road
VLFC [kWh/100km]
Temperature
VLFC [kWh/100km]
Density of air
Note: VLFC at reference conditions can be calculated from ECE R83 Annex 4 Appendix 2
Aero dynamics
DC consumption kWh/h
DC consumption [kWh/h]
Average speed [km/h]
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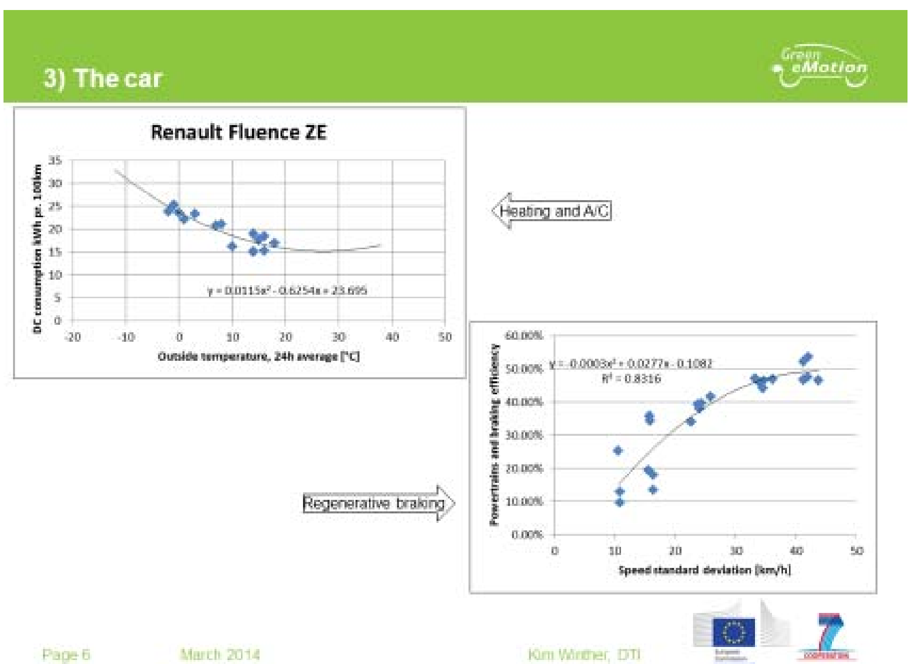
3) The car
Renault Fluence ZE
DC consumption kWh pr. 100km
y = 0.0115x² - 0.6254x + 23.695
Outside temperature, 24h average [°C]
Heating and A/C
Powertrains and braking efficiency
y = -0.0003x² + 0.0277x - 0.1082
R² = 0.8316
Speed standard deviation [km/h]
Regenerative braking
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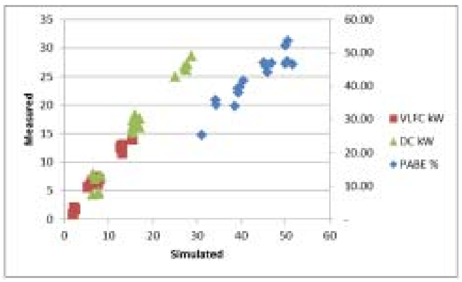
Formulae

	Approximation
Capacity	$0,85 + 0,001{*}t - 0,00015{*}t^2$
VLFC	$0,96 + 0,0022 * \text{mean}(v)^2$
PABE	$24,5 + 0,26 * \text{stddev}(v)$



Mean error: 6,5%

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7.2 Version two of standardisation proposal for ISO 8714

Electric Vehicles

Task 6.3: Proposal for a range correction method

What we propose

A general formulation of EV range can be written as:

$$RANGE = \frac{CAPACITY \cdot SOC}{\frac{VLFC}{PABE} + \frac{AUX}{SPEED}}$$

- where

- RANGE = Actual driving range [km]
- CAPACITY = Actual battery capacity [kWh]
- SOC = State of charge [-]
- PABE*) = **P**owertrain **A**nd (regenerative) **B**raking **E**fficiency [%]
- VLFC*) = **V**ehicle **L**imited **F**uel **C**onsumption [kWh/100km]
- AUX = Auxiliary loads (heating and AC) [kW]
- SPEED = Average travelling speed [km/h]

*) The expressions VLFC and PABE are convenient analytical quantities proposed by Hochgraf and Duoba at Oak Ridge National Laboratory 2010

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Problem statement

The real world range of an electric car varies a lot according to weather and driving style.

ISO 8714 - like most standardized vehicle tests - uses fixed laboratory conditions.
ISO 8714 driving range do therefore not reflect real world driving. This means:

=> It is difficult to predict the actual range
=> Uncertainty about usability of electric cars

Summary of the Nissan's results using EPA L4 test cycle operating the Leaf under different real-world scenarios

Driving condition	Speed		Temperature		Total Drive Duration	Range		Air conditioner
	mph	km/h	°F	°C		mi	km	
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Highway	55	89	95	35	1 hr 16 min	70	110	In use
Winter, stop-and-go traffic	15	24	14	−10	4 hr 08 min	62	100	Heater on
Heavy stop-and-go traffic	6	10	86	30	7 hr 50 min	47	76	In use
EPA five-cycle tests	n.a.					73	117	Varying
ISO 8714 (for Europe)							175	

Too large variation

The battery capacity

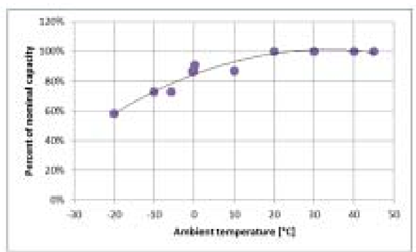
The battery capacity available for use includes:

- Actual battery capacity
- State of charge

In most cases SOC will be 100% at the beginning of a trip.

At standard test conditions, the nominal battery capacity will be stated.

In most cases actual battery capacity is slightly lower than nominal but never above.



The unit for battery capacity is [kWh].

At non-standard conditions the battery capacity varies mainly with ambient temperature (see illustration above).

Explanation of VLFC

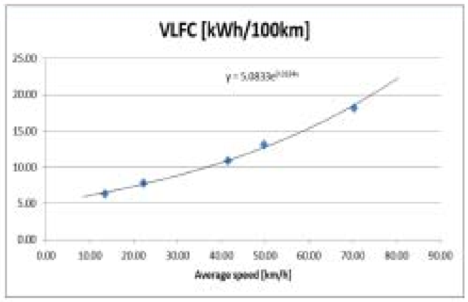
Vehicle Limited Fuel Consumption includes:

- Wind resistance
- Rolling resistance
- Potential energy stored by elevation
- Kinetic energy stored

In most cases potential and kinetic energy stored will be zero (vehicle returns to standstill at its original position). Thus:

VLFC = ∫ Wind resistance + ∫ Rolling resistance

The unit for VLFC is [kWh/100km]



At non-standard conditions VLFC varies mainly with driving speed, weight of vehicle, wind conditions and air density. The figure shows VLFC at slightly windy conditions with varying speed.

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Explanation of PABE

The Powertrain And Braking Efficiency includes:

- Electric motor efficiency
- Inverter efficiency
- Mechanical losses
- Regenerative braking effectiveness

The unit for PABE is per cent [%].

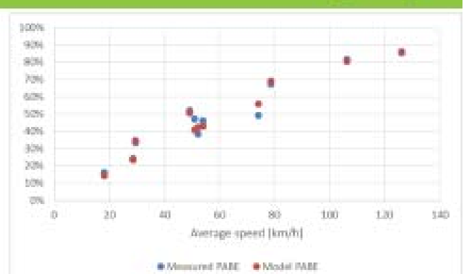
At standard test conditions PABE can be determined from the following relation:

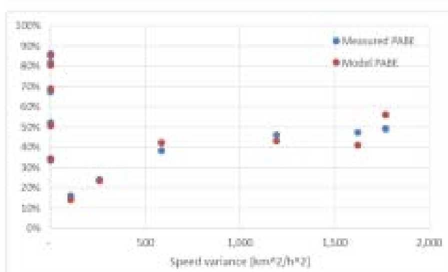
PABE=VLFC/(Consumption-AUX)

- where in most test conditions AUX will be close to zero, thus

PABE=VLFC/Consumption

At non-standard conditions PABE varies with speed and speed variance. See illustrations.





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Explanation of Auxiliary loads

Auxiliary loads include electric loads such as:

- Heating
- Air conditioning
- 12 V DC/DC converter
- Other electrical loads, brake vacuum pump etc.

Auxiliary loads increase the total power consumption of the vehicle, thus shortens the available range.

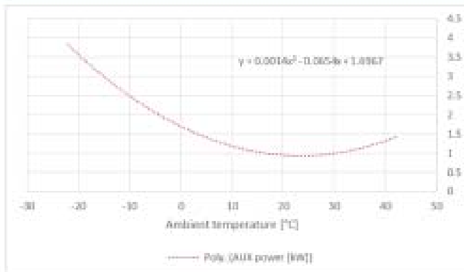
At standard test conditions, AUX will be close to zero because no heating or AC is used.

The best way to measure AUX in real conditions is with the vehicle stationary or rolling in neutral gear in which case:

AUX = Consumption

The unit for AUX consumption is [kW].

For the units to fit in the equation we divide this by average speed.



Heating and AC load depends mainly on ambient temperature.

The initial warming-up period is significant for shorter trips, but has less impact on the total range because the cabin temperature will be stable in 2-3 minutes.

Initial warming can therefore be neglected.

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How to determine the factors?

BATTERY CAPACITY is normally a known quantity but our work shows that it should be corrected to actual ambient air temperature. The battery pack manufacturer can state a temperature dependency, otherwise an empirical formula can be used.

VLFC can be determined accurately in all conditions by means of basic formulae for wind and rolling resistance or by road load target coefficients A, B and C following EPA Test Car List Data. In our work we also included weather data (wind speed, direction, air temperature) to obtain higher accuracy.

PABE can be accurately determined from ISO 8714 or any other test where energy in and outputs are known. At non-standard conditions however PABE does vary with speed. Our studies show that speed variation is also a key variable. An empirical formula is also available from our work.

AUX consumption can be determined from a heat loss calculation or by an empirical relation. We found that ambient temperature is the key variable.

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Empirical formulas to be used (if no other information exists)

	Approximation
PABE [%]	0,0112 * v – 0,000038 * v^2 - 0,01 * ln(σ(v))
VLFC [kWh/100km]	∫ *wind resistance* + ∫ *rolling resistance* *Or* 5.0833 * exp(0.0184*v)
Capacity [kWh]	C_{nom} * (0,85 + 0,01*t - 0,00015*t^2)
AUX [kW]	1,6967 - 0,0654*t + 0,0014*t^2

- *v is average speed [km/h]*
- *σ is variance [km^2/h^2]*
- *t is ambient temperature [°C]*
- *C_{nom} is nominal battery capacity [kWh]*

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Calculation of actual driving range - example

This example represents a highly dynamic driving style in cold weather.

CAPACITY:
Nominal capacity: 22 kWh
Correction factor at 5°C: 0,90375
Actual temperature: 5°
Actual capacity: 19,88 kWh

VLFC:
Average speed: 60 km/h
Actual VLFC: 15,33 kWh/100km

PABE:
Speed variance: 600 km^2/h^2
Actual PABE: 47%

AUX: at 5°: 1,4 kW

Actual range: 19,88 / (15,33 / 47 + 1,4 / 60) = 57 km

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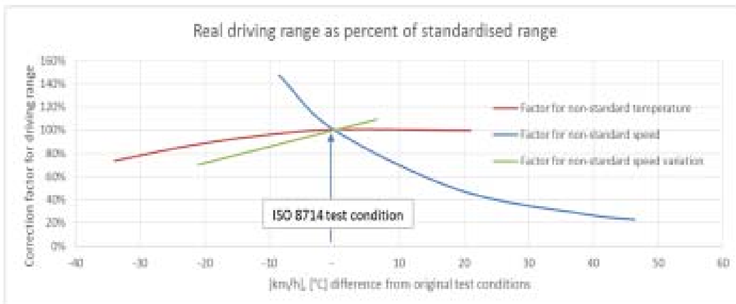
Sensitivity analysis

The figure below shows the relative impact on range if average speed, speed variation or ambient temperature is changed from standard test conditions.



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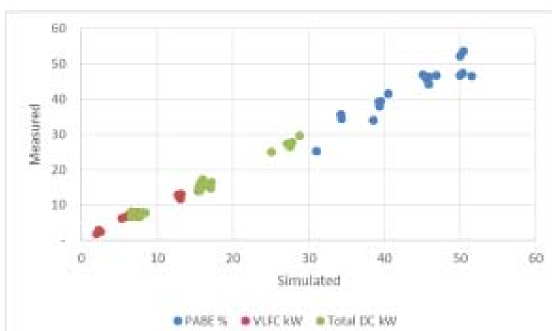
Our results

Our test results show good correlation with empirical values for VLFC, PABE and real consumption.



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