The 27th INTERNATIONAL ELECTRIC VEHICLE SYMPOSIUM & EXHIBITION
BARCELONA
17th-20th November 2013

Plug-to-wheel energy balance

Results of a two years experience behind the wheel of electric vehicles

Dr Ir Laurent De Vroey – Laborelec

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Context

- "Together for less CO_2", June 2011:

  10 commitments of Electrabel, among which green mobility: pilot project

- Objectives:
  - Gain skills and competences in the new EV business
  - Develop EV value propositions for B2B and B2C customers, partially based on technical insight from EV monitoring

- 10 Peugeot iOn used by Electrabel/Laborelec employees as principal car or as pool/service cars, 5 with full monitoring

- First EV project with 2 years results in Belgium

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Laborelec in a nutshel

Technical competence centre and laboratory:

- Experts in Electrical Power
  - Generation, T&D and Energy End-Use
  - Reliable, Clean and Efficient Energy
- 255 researchers and technical specialists
- Offices in
  - Belgium
  - the Netherlands
  - Germany
  - United Arab Emirates
  - Chile

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Laborelec EV activity

- EV monitoring (~ 90 vehicles)
  - Electrabel/Cofely/Fabricom
  - RTER (Rotterdam Test Elektrisch Rijden)
- Normative follow-up
- Support to product development
  - Electrabel CarPlug
- Test of battery ageing and charging solutions
- Techological watch

EVS 27

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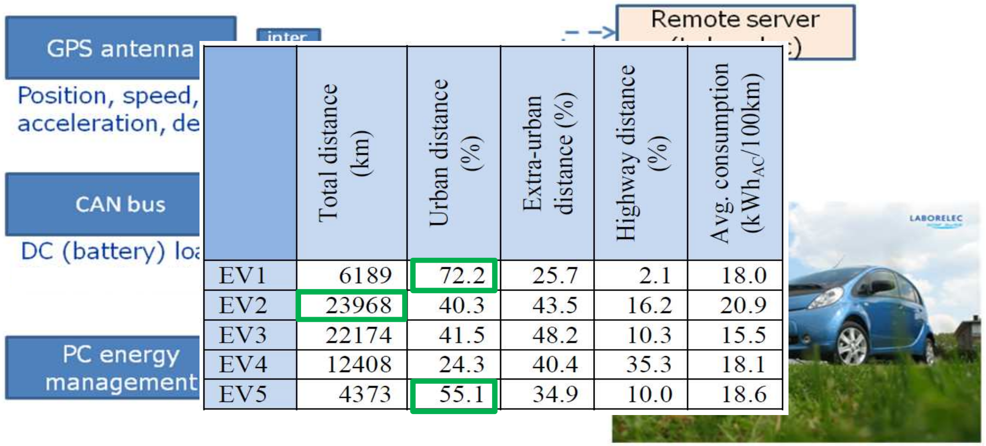
2 years monitoring of 5 EVs in the Brussels area

- Monitoring system by Laborelec

- 2 years continuous monitoring
- 5 Peugeot iOn
- 7 users
  - 5 personal cars (leasing)
  - 2 service / company pool cars



	Total distance (km)	Urban distance (%)	Extra-urban distance (%)	Highway distance (%)	Avg. consumption ($kWh_{AC}/100km$)
EV1	6189	72.2	25.7	2.1	18.0
EV2	23968	40.3	43.5	16.2	20.9
EV3	22174	41.5	48.2	10.3	15.5
EV4	12408	24.3	40.4	35.3	18.1
EV5	4373	55.1	34.9	10.0	18.6

Year 1												Year 2												
2011						2012												2013						
Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul

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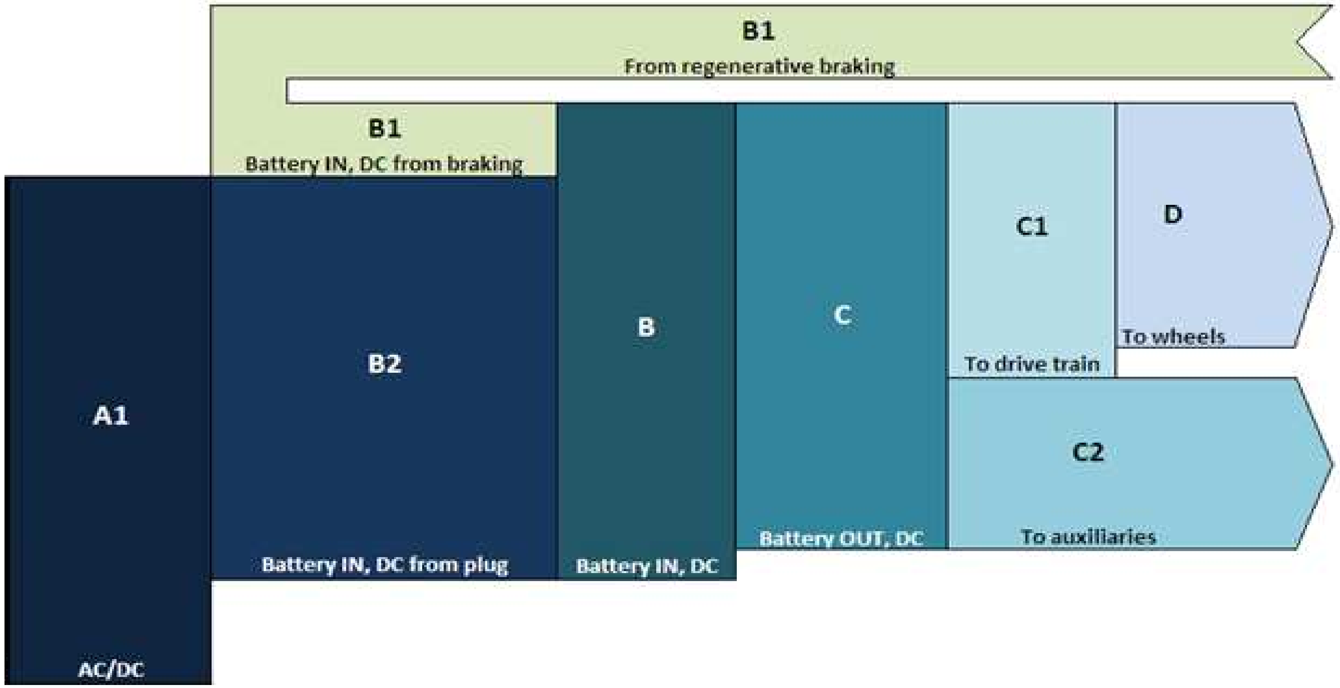
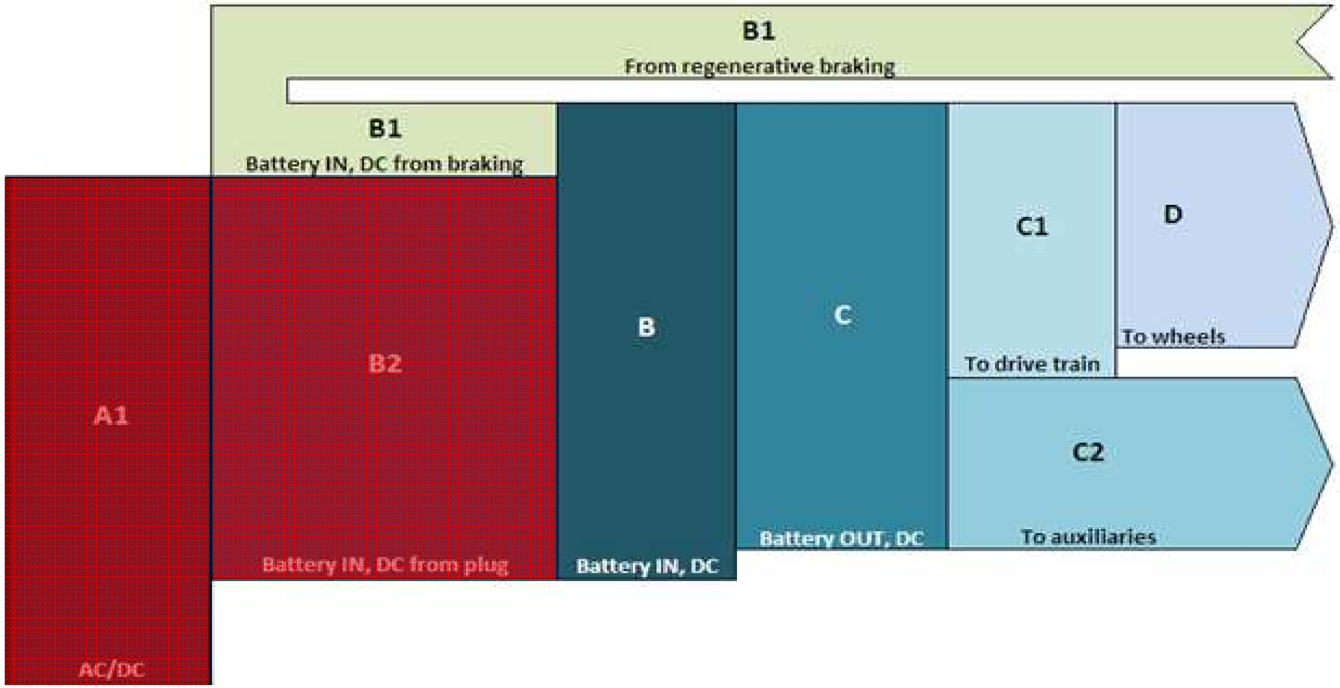
Energy balance
The Sankey diagram



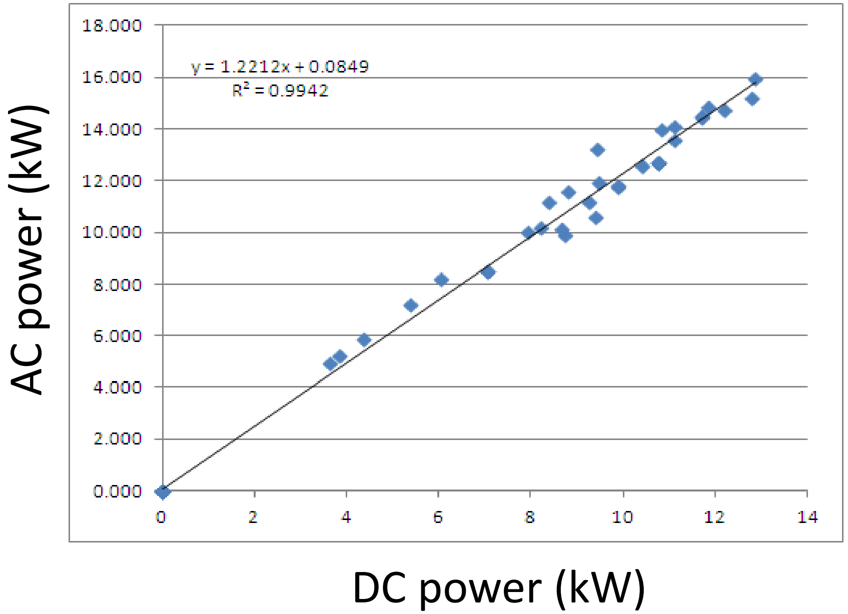
AC/DC efficiency



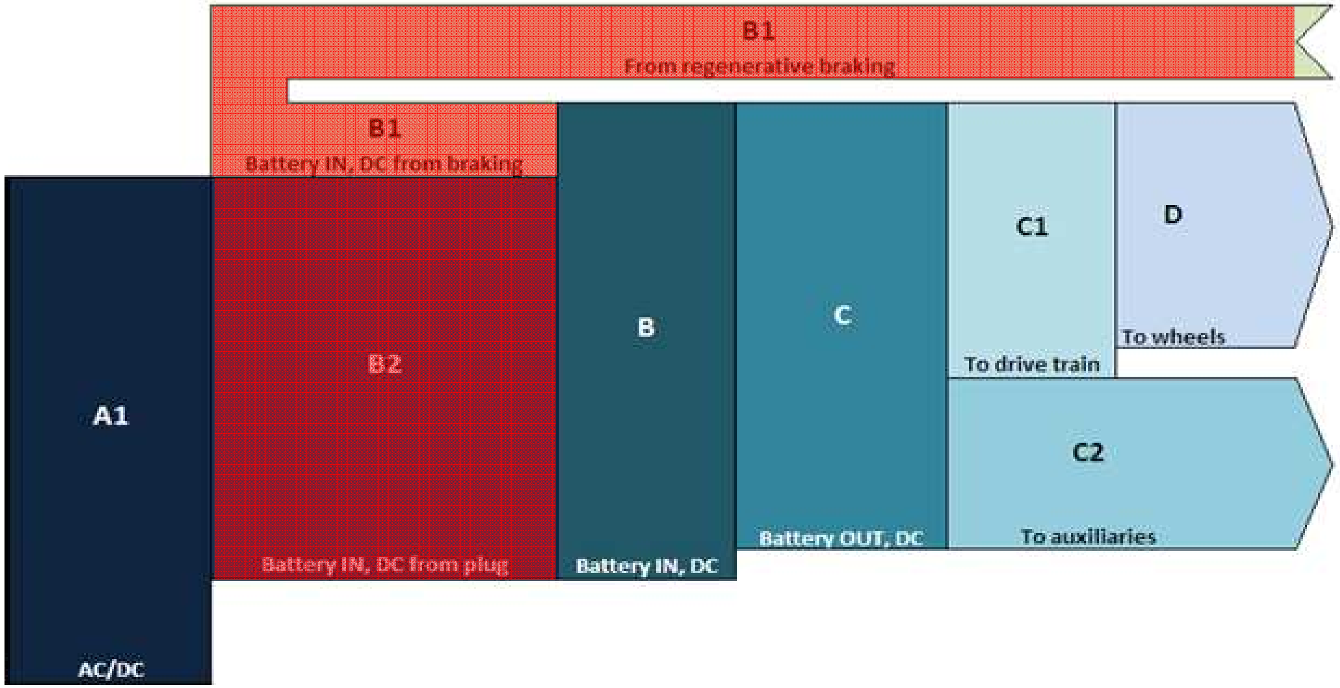
AC/DC efficiency

- AC/DC efficiency 82%
- Note: most of the not converted AC energy is used by the battery management system during the charging sequence

→ auxiliary consumption during charging

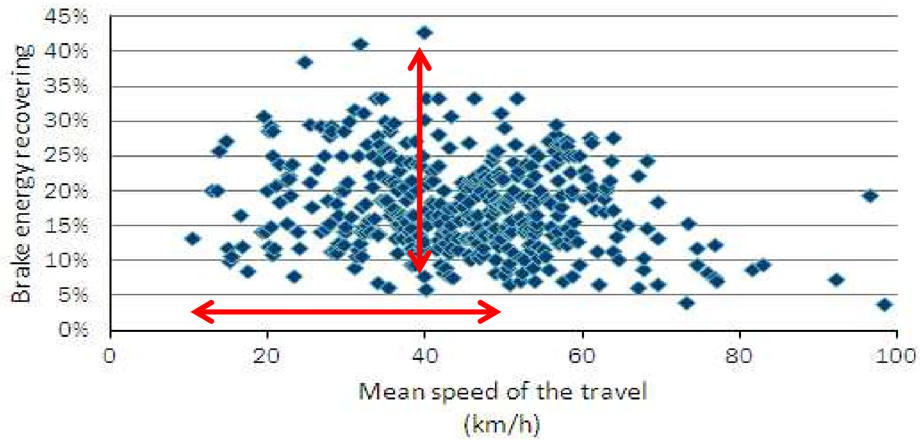


Regenerative braking



Regenerative braking

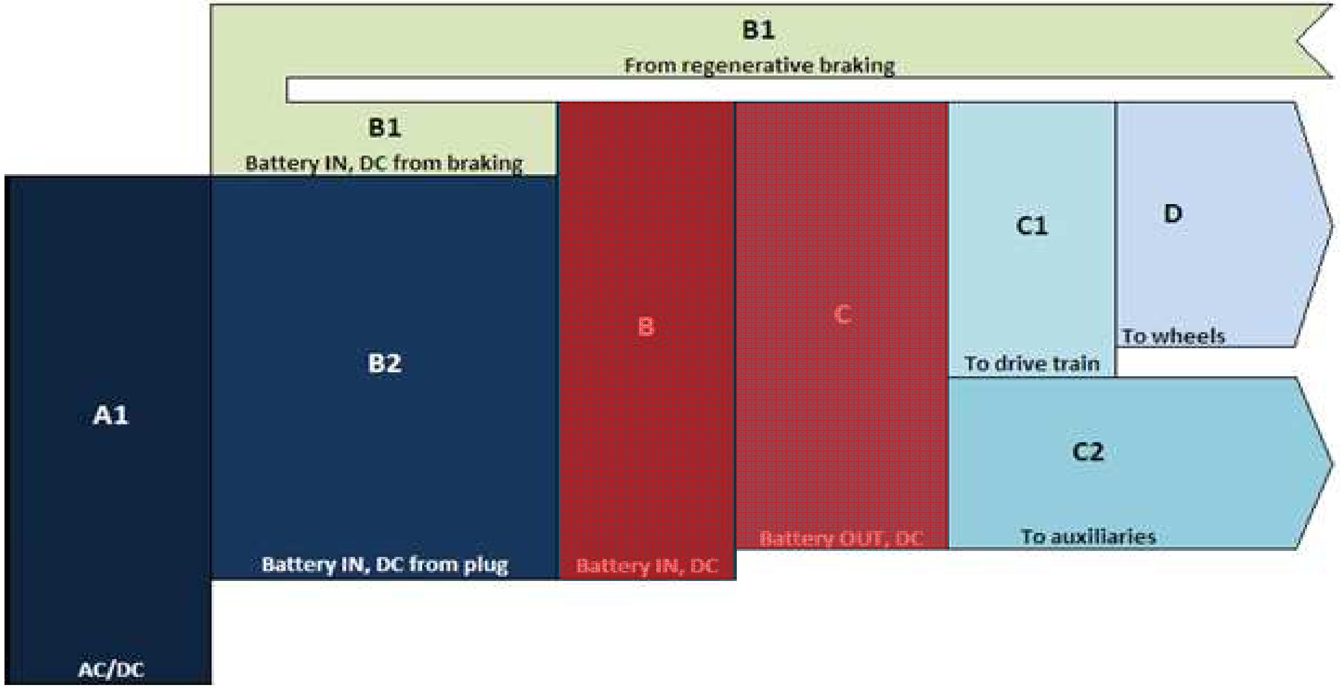
Regenerative braking % = energy to battery / energy from battery, during trips



- Mostly in urban trips
- Wide range: 5..40%
- Direct, important impact on (urban) consumption

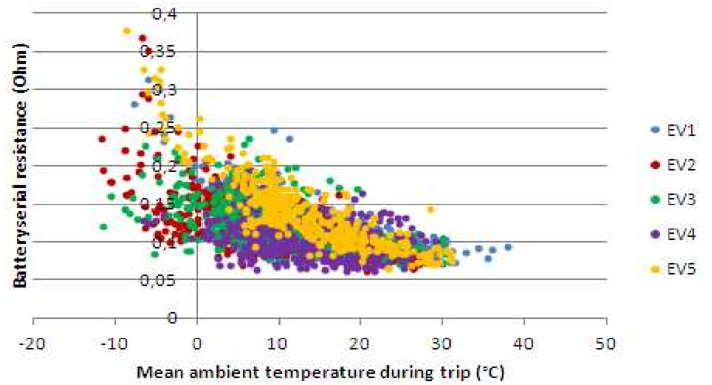
	Regenerative braking
EV1	16.9%
EV2	16.9%
EV3	16.8%
EV4	13.1%
EV5	19.3%

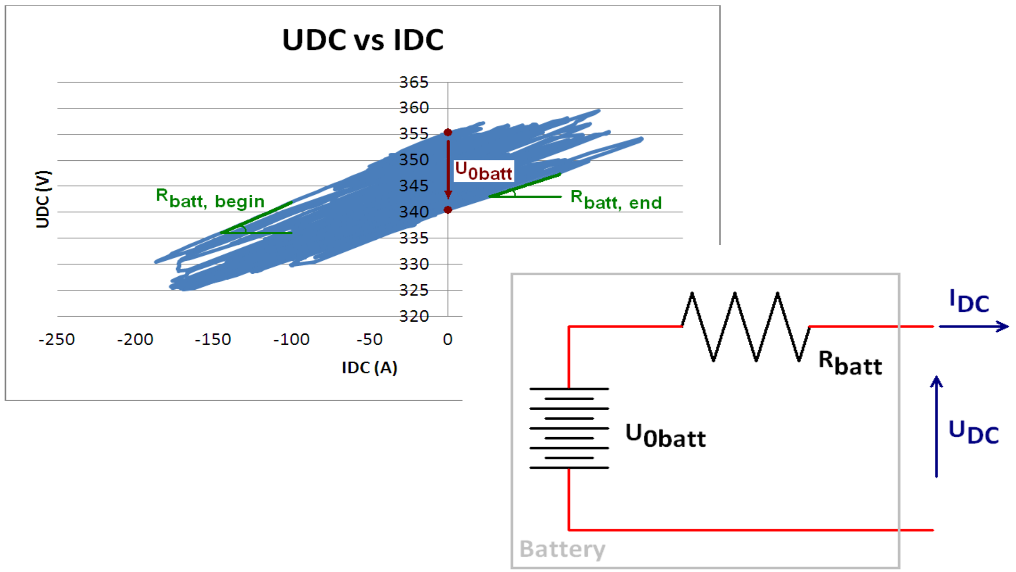
Battery efficiency



Battery efficiency

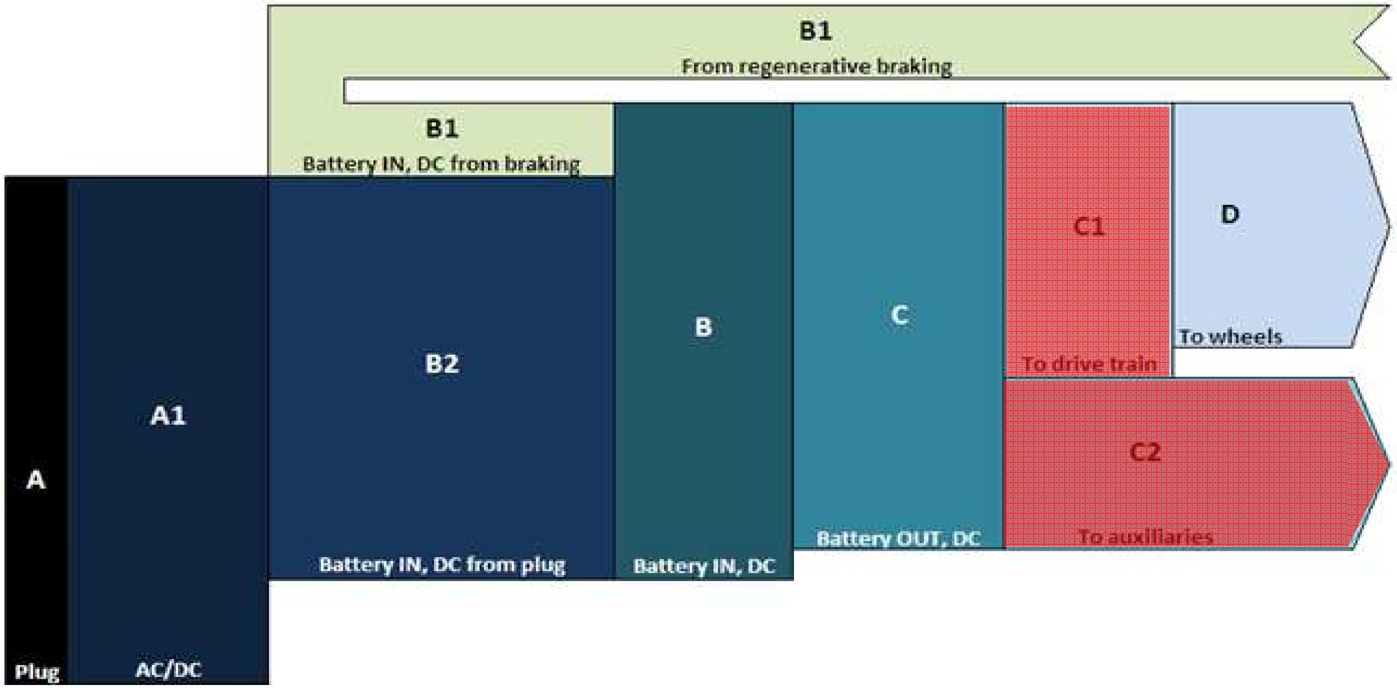
- Battery losses proportional to R_{batt} and I_{DC}^2
- I profile measured for each trip
- R calculated for each trip





	Avg. battery resistance (Ohm)	Avg. charging losses (%)	Avg. discharging losses (%)	Avg. battery efficiency (%)
EV1	0.122	0.2	2.6	97.2
EV2	0.127	0.2	3.5	96.3
EV3	0.124	0.2	2.0	97.8
EV4	0.115	0.2	2.4	97.4
EV5	0.130	0.2	3.4	96.4

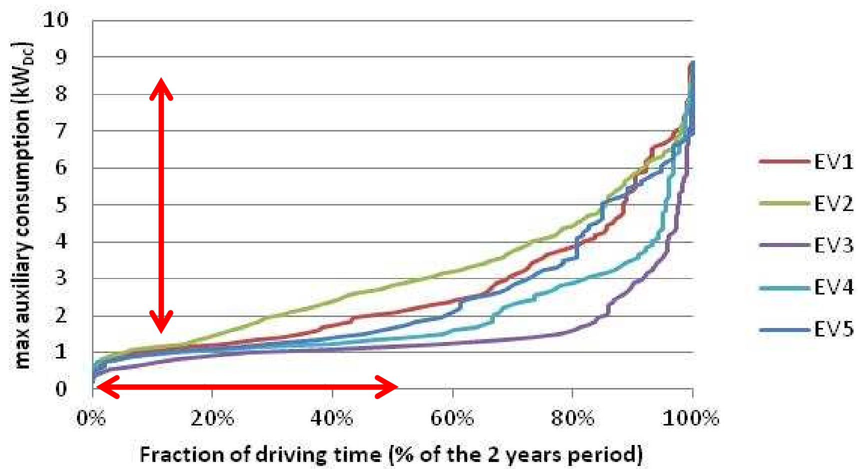
Auxiliary consumption



Auxiliary consumption

Auxiliary consumption = power measured when no speed and no acceleration

→ heating, cooling, battery management system, vacuum pump, light,…

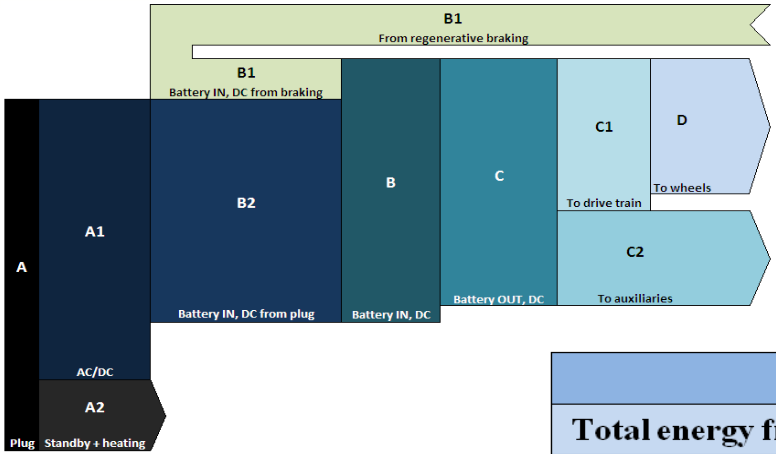


- Between 0.8kW and 8.5kW
- 50% of the year < 1.5kW in average

- Auxiliary consumption can be a significant part of the total, with strong differences between cars

	Mean auxiliaries (kW_{DC})	Auxiliaries vs global consumption (%)
EV1	2.6	42
EV2	3.1	38
EV3	1.5	23
EV4	2.0	24
EV5	2.4	38

Sankey diagram - synthesis



		EV1	EV2	EV3	EV4	EV5
Total energy from plug, AC	**A**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Plug to car, AC	*A1*	100.0	100.0	100.0	100.0	100.0
Standby and pre-heating, AC	*A2*	0.0	0.0	0.0	0.0	0.0
Battery IN, DC	**B**	**98.1**	**97.9**	**98.1**	**94.0**	**100.7**
Battery IN, DC from braking	*B1*	16.1	15.9	16.1	12.0	18.7
Battery IN, DC from plug	*B2*	82.0	82.0	82.0	82.0	82.0
Battery OUT, DC	**C**	**95.4**	**94.3**	**96.0**	**91.5**	**97.1**
Battery OUT, DC to drive train	*C1*	55.3	58.5	74.4	69.6	60.7
Battery OUT, DC to auxiliaries	*C2*	40.1	35.8	21.6	22.0	36.4
Energy to wheels	**D**	**47.0**	**49.7**	**63.2**	**59.1**	**51.6**

Conclusions

- A broad range of values is obtained for the 2 years average plug-to-wheel efficiency.
- The relative consumption of the auxiliaries is of significant importance in the total energy balance.
- A yearly well-to-wheel efficiency between 21 and 29% is obtained[1]. This is slightly better than the values for a conventional car (between 14 and 26% annual efficiency), but can still be significantly improved, namely by improving the auxiliary consumption.
- Because of the higher relative importance of the auxiliaries at lower speed, cars with a higher urban use show a globally lower plug-to-wheel efficiency. This is an important result when considering the urban trips as the primary segment for EVs, and should encourage the EV manufacturers to focus on the reduction of auxiliary consumption.

[1] Based on theoretical efficiency of EU elec production mix