Energy Consumption

Fuel and electricity (energy) consumption by different powertrains (conventional, PHEV, and BEV) are compared in Figure 1. One can notice that the U. S. cycle, even though it is less aggressive than the WLTC, leads to higher vehicle energy consumption, especially for electrified vehicles, because of its real-world adjustment factor. The right-hand axis of Figure 1 shows the relative difference in energy consumption in the U. S. combined cycle vs. the WLTC by each vehicle type.

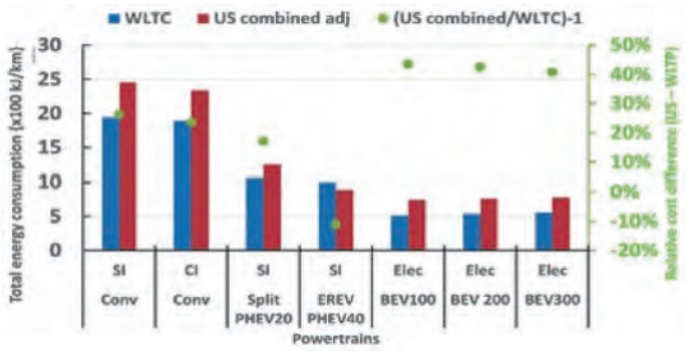

Figure 1 Energy consumption comparison by powertrain and driving cycle

Energy Costs Figure 2 shows the cost metric in Europe (using the WLTC as reference) and in the United States (with the U. S. combined adjusted cycle as reference). Mainly because of higher European energy prices (cf. Table 1), the cost of the energy per kilometre travelled is higher in Europe than in the United States.

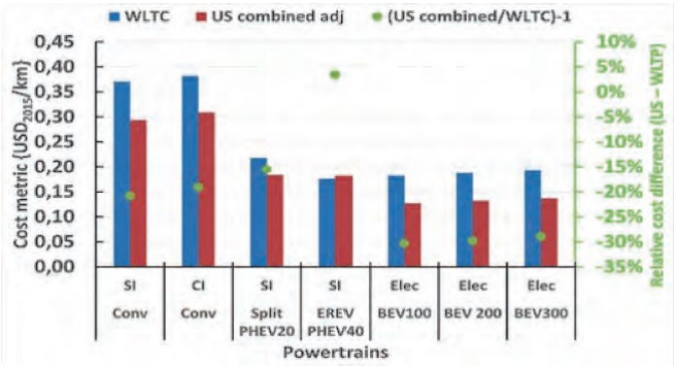

Figure 2 Cost metric comparison by powertrain and driving cycle

To properly compare the overall cost of ownership between the United States and Germany, we need to include the manufacturing cost, the maintenance cost over the years, taxes, and fees. These are shown in Figure 3 for Germany and Figure 4 for the United States. Negative costs (incentives) are shown below the axis and the total resulting RCO is shown as a filled, red circle.

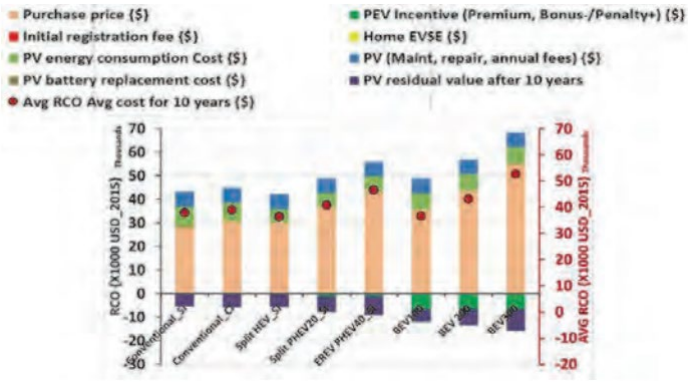

Figure 3 RCO comparison between powertrains for 10 years of ownership in Germany using the WLTC as reference

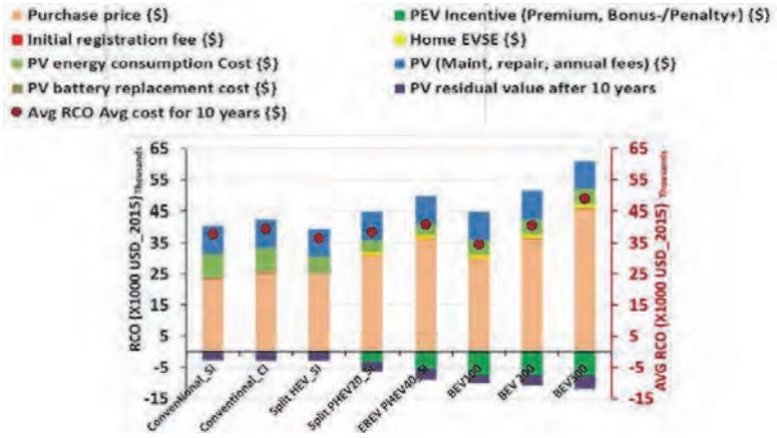

Figure 4 RCO comparison between powertrains for 10 years of ownership in the United States using the U.S. combined adjusted driving cycle as reference

For an ownership period of 10 years, only the BEV100 in both Germany and the United States seems to be cost competitive with conventionally powered cars when using the current market price as reference (cf. Figures. 3 and 4). However, as shown in Figure 5, even though the U. S. driving cycle leads to higher energy consumption for electrified vehicles compared to the WLTC, fuel savings by PEVs are higher in Germany than in the United States, because of the high price of fuel.

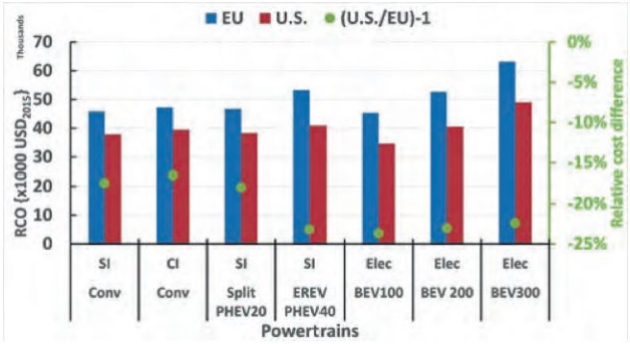

Figure 5 RCO comparison between the United States and Germany for 10 years of ownership

Impacts of Other Factors

We evaluated the effect of different factors on the competitiveness of PEVs on the U. S. and German markets.

Manufacturing Cost

The battery manufacturing cost has a direct impact on the selling price of the vehicle and hence on the customer purchase decision. The heat maps below (Tables 4 and 5) display the RCO by powertrain for a range of manufacturing battery costs. The colour of each cell in the table indicates whether the RCO is higher (red) or lower (green) in comparison to the others. Values in Tables 4 and 5 are based on the annual distance, discount rate, and fuel prices shown in Table 1. Tables 4 and 5 show that the PEVs become more competitive as the battery cost decreases. For instance, the BEV300 becomes even more economical in the United States than conventional vehicles at 100 USD2015/kWh or less, for an ownership period of 10 years.

Table 1 RCO by battery cost and powertrain for 10 years of ownership in the United States using the U.S. combined adjusted driving cycle as reference

		Conventional	Conventional	Split PHEV20	EREV PHEV40	BEV100	BEV 200	BEV300
Variable 1		SI	CI	SI	SI	Elec	Elec	Elec
Battery costs (USD_2015/kWh)	400	37,841	39,467	38,279	41,523	39,643	49,002	62,414
	300	37,841	39,467	36,876	38,949	36,270	43,355	53,472
	200	37,841	39,467	35,474	36,376	32,896	37,708	44,530
	100	37,841	39,467	34,873	34,378	29,523	32,061	35,588
	50	37,841	39,467	34,873	34,378	27,836	29,238	31,117

Table 2 RCO by battery cost and powertrain for 10 years of ownership in Germany using the WLTC as reference

		Conventional	Conventional	Split PHEV20	EREV PHEV40	BEV100	BEV 200	BEV300
Variable 1		SI	CI	SI	SI	Elec	Elec	Elec
Battery costs (USD_2015/kWh)	400	35,734	37,582	37,064	43,543	41,207	51,541	66,357
	300	35,734	37,582	35,531	40,728	37,518	45,366	56,578
	200	35,734	37,582	33,997	37,914	33,829	39,191	46,799
	100	35,734	37,582	33,340	35,729	30,140	33,015	37,021
	50	35,734	37,582	33,340	35,729	28,295	29,928	32,131

Annual Distance Travelled

As expected, the annual distance travelled by the customer will have a direct impact on the cost competitiveness between different powertrains (cf. Figure 6); higher annual distance travel plays in favour of the PEVs. For instance, in the United States, at around 24,000 km/year for 10 years of ownership, the PHEV20 and BEV100 become more economical than the conventional spark ignition (SI) vehicle (Table 6). In Germany, largely owing to the higher fuel and electricity prices, the PHEV20 becomes competitive at higher distances travelled than in the United States (cf. Tables 6 and 7).

Table 3 RCO by annual distance travelled and powertrain for 10 years of ownership in the United States using the U.S. combined adjusted driving cycle as reference

		Conventional	Conventional	Split PHEV20	EREV PHEV40	BEV100	BEV 200	BEV300
Variable 1		SI	CI	SI	SI	Elec	Elec	Elec
Annual VKT (Km)	40,233	53,695	55,285	52,059	54,129	47,547	54,522	64,172
	32,186	47,112	48,779	46,503	48,956	42,379	48,968	58,331
	24,140	39,385	41,019	39,648	42,226	35,882	41,937	50,556
	16,093	31,660	33,260	32,842	35,502	29,386	34,908	42,781
	8,047	23,936	25,502	26,243	28,822	22,891	27,879	35,007

Table 4 RCO by annual distance travelled and powertrain for 10 years of ownership in Germany using the WLTC as reference

		Conventional	Conventional	Split PHEV20	EREV PHEV40	BEV100	BEV 200	BEV300
Variable 1		SI	CI	SI	SI	Elec	Elec	Elec
Annual VKT (Km)	40,233	65,514	65,916	62,098	69,968	58,991	69,494	81,625
	32,186	57,323	58,260	55,559	63,002	54,235	62,480	74,159
	24,140	47,769	49,109	47,375	54,082	46,021	53,541	64,216
	16,093	38,217	39,960	39,192	45,161	37,808	44,602	54,274
	8,047	28,667	30,813	31,009	36,223	29,597	35,665	44,333

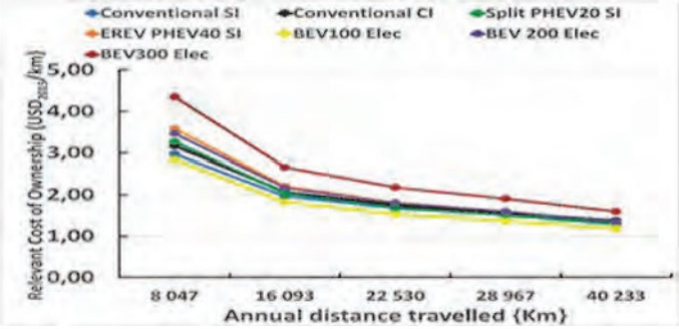

Figure 6 RCO by annual distance travelled and powertrain for 10 years of ownership in the

Energy Price

The impact of fuel price is far more important in Europe. Table 8 shows the impact of a potential fuel price evolution in Germany. At a gasoline price of 2.38 USD2015/litre (9.01 USD2015/gallon), the PHEV20 and the BEV100 will become more economical than conventional cars. The electricity price also plays a role in the overall cost for the owner of a PEV, as shown in Table 9. At electricity prices as low as 0.08 USD2015/kWh, the PHEV20 and the BEV200 become cost competitive over an ownership period of 10 years. However, the RCO of the PHEV40 or the BEV300 are higher than for conventional cars even at an electricity rate as low as 0.08 USD2015/kWh. If carbon emissions are priced, and the cost is reflected in higher fuel prices, this will tend to favour lower-carbon emitting PEVs, especially BEVs.

Table 5 RCO by fuel price and powertrain for 10 years of ownership in Germany using the WLTC as reference

		Conventional	Conventional	Split PHEV20	EREV PHEV40	BEV100	BEV 200	BEV300		
Variable 1		SI	CI	SI	SI	Elec	Elec	Elec		Variable 2
Gasoline price (USD_2015/Liter)	2.38	40,793	42,383	38,938	44,243	35,673	42,278	51,689	2.38	Diesel price (USD_2015/Liter)
	1.98	38,450	40,258	38,070	43,592	35,673	42,278	51,689	1.98	
	1.32	34,544	36,716	36,624	42,509	35,673	42,278	51,689	1.32	
	0.92	32,201	34,591	35,756	41,859	35,673	42,278	51,689	0.92	
	0.26	28,296	31,049	34,309	40,775	35,673	42,278	51,689	0.26	

Table 6 RCO by fuel price and powertrain for 10 years of ownership in Germany using the WLTC as reference

		Conventional	Conventional	Split PHEV20	EREV PHEV40	BEV100	BEV 200	BEV300
Variable 1		SI	CI	SI	SI	Elec	Elec	Elec
Electricity price ($/kWh)	0.4	35,734	37,582	37,083	42,868	35,725	42,332	51,745
	0.32	35,734	37,582	36,572	42,086	34,341	40,899	50,253
	0.24	35,734	37,582	36,060	41,303	32,957	39,465	48,761
	0.16	35,734	37,582	35,548	40,520	31,573	38,031	47,269
	0.08	35,734	37,582	35,037	39,737	30,190	36,598	45,777

For the combination of factors considered here (Table 1), the U. S. gasoline price must reach 1.32 USD2015/litre (5.0 USD2015/ gallon) for most PEVs to become cost competitive (cf. Table 10).

Table 7 RCO by fuel price and powertrain for 10 years of ownership in the United States using the U.S. combined adjusted driving cycle as reference

		Conventional	Conventional	Split PHEV20	EREV PHEV40	BEV100	BEV 200	BEV300
Variable 1		SI	CI	SI	SI	Elec	Elec	Elec
Gasoline price (USD_2015/Liter)	2.38	58,279	39,467	44,623	44,764	34,583	40,532	49,001
	1.98	53,517	39,467	43,145	43,859	34,583	40,532	49,001
	1.32	45,581	39,467	40,681	42,351	34,583	40,532	49,001
	0.92	40,819	39,467	39,203	41,445	34,583	40,532	49,001
	0.26	32,882	39,467	36,739	39,937	34,583	40,532	49,001

Incentives Influence

Incentives have a significant impact on the relevant cost of ownership. Therefore, we applied hypothetical variations on the initial value to enhance their impact on the RCO. Four different cases were applied in this study:

- Suppression of the incentive (0 % of the current incentive's values applied);
- Reduction of 50 % of the current value of the incentives;
- No change in the incentive (100 % of the current values applied);
- A hypothetical case of an increase of 50 % of the incentive (150 % of the current incentive's values applied).

Tables 11 and 12 below display the new RCO according to the incentive variation and the geographical area. They show how much the incentive influences the RCO of electrified vehicles. Indeed, if the incentive is suppressed in the U. S., the RCO for the BEV100 will decrease by almost 10 % and by 7 % for the Split PHEV20. If PEV incentives are decreased or eliminated, this can be expected to reduce PEV market share.

Table 8 RCO by incentives variation and powertrain for 10 years of ownership in the United States using the U.S. combined adjusted driving cycle as reference

		Conventional	Conventional	Split PHEV20	EREV PHEV40	BEV100	BEV 200	BEV300
Variable 1		SI	CI	SI	SI	Elec	Elec	Elec
Incentive (% of current value)	0%	37,841	39,467	40,986	45,539	41,226	47,175	55,644
	50%	37,841	39,467	39,632	43,209	37,905	43,853	52,323
	100%	37,841	39,467	38,279	40,879	34,583	40,532	49,001
	150%	37,841	39,467	36,925	38,549	31,261	37,210	45,679

Table 9 RCO by incentives variation and powertrain for 10 years of ownership in Germany using the WLTC as reference

		Conventional	Conventional	Split PHEV20	EREV PHEV40	BEV100	BEV 200	BEV300
Variable 1		SI	CI	SI	SI	Elec	Elec	Elec
Incentive (% of current value)	0%	35,734	37,582	39,630	45,405	39,095	45,700	55,111
	50%	35,734	37,582	38,347	44,122	37,384	43,989	53,400
	100%	35,734	37,582	37,064	42,839	35,673	42,278	51,689
	150%	35,734	37,582	35,781	41,556	33,962	40,567	49,978

Combination of Factors

We examined ranges of factors to determine what combinations enable BEVs to be cost-competitive with conventional SI vehicles. The ratio of the RCO of a BEV200 to that of a conventional SI vehicle under different assumptions is shown in Figures 7 and 8. Those figures display the contours of a constant RCOBEV200/RCOConvSI ratio for ranges of battery costs and annual distance travelled for three different electricity prices. All other parameters remain constant (as given in Tables 1, 2, and 3).

In Germany, mainly due to the high fuel cost for conventional vehicles, at high annual distance travelled, the BEV200 can be competitive with conventional vehicles (Figure 7). Furthermore, the electricity price will also have an impact on both the cost ratio between BEV200 and conventional SI, and on the way the annual VKT and battery cost will affect this ratio. Indeed, (cf. contours outlined in red in Figures 7 and 8) the slope of the RCOBEV200/RCOConvSI lines increases as electricity price decreases and the difference in the energy cost per kilometre increases. As shown in Figure 8, at high electricity prices (0.35 USD2015/kWh in the United States) while other parameters remain constant, the slope of contours become negative, since the energy cost per kilometre for the BEV is higher than that of the conventional vehicle, and the RCO ratio increases with annual distance travelled.

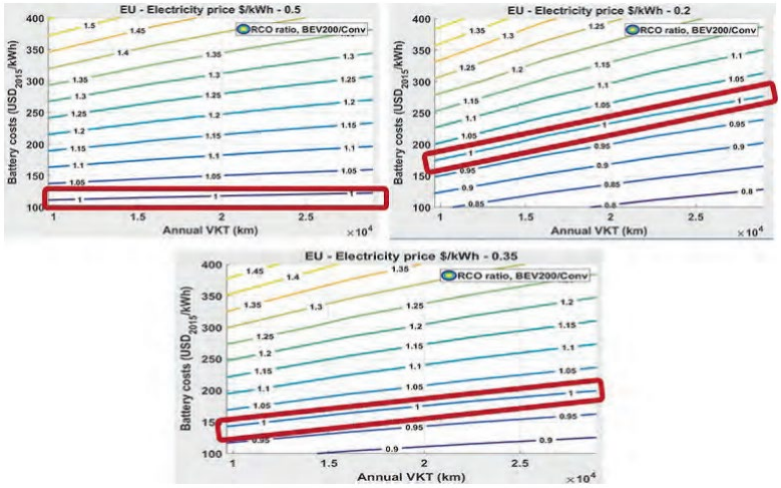

Figure 7 RCO ratio between BEV200 and conventional SI by annual distance travelled, battery cost, and electricity price, for 10 years of ownership in Germany using WLTC as reference

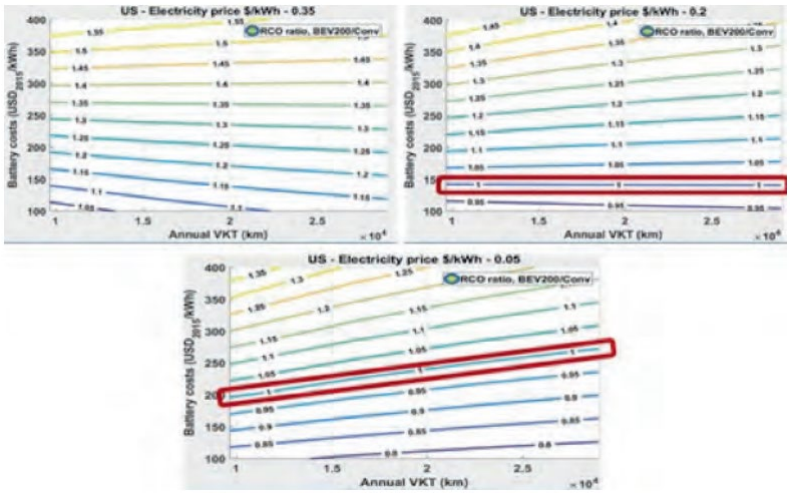

Figure 8 RCO ratio between BEV200 and conventional SI by annual distance travelled, battery cost, and electricity price, for 10 years of ownership in the United States using the U. S. combined adjusted driving cycle as reference