World Electric Vehicle Journal

MDPI

Article

Supplementary Material

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Table S1. General data

ID_param	Symbol	Parameter	Resource	Time type	Value	Unit	Reference
0000	m_bv	mass_base_vehicle		SoA	1000	kg	[1]
0000	m_bv	mass_base_vehicle		PoT	870	kg	[2]
0001	m_load	mass_load		ALL	80	kg	
0020	P_n_bv	nominal_power_base_vehicle		SoA	90	kW	[2]
0020	P_n_bv	nominal_power_base_vehicle		PoT	135	kW	[2]
0022	P_p_bv	peak_power_base_vehicle		SoA	150	kW	[3]
0022	P_p_bv	peak_power_base_vehicle		PoT	225	kW	[3]
0030	eta	efficiency	BE	SoA	0.28	%	[4]
0030	eta	efficiency	BE	PoT	0.32	%	[4]
0030	eta	efficiency	Gas	SoA	0.42	%	[5]
0030	eta	efficiency	Gas	PoT	0.47	%	[5] [6]
0030	eta	efficiency	HCo	SoA	0.35	%	[5][7]
0030	eta	efficiency	HCo	PoT	0.42	%	[5][6]
0030	eta	efficiency	HP	SoA	0.9	%	[8]
0030	eta	efficiency	HP	PoT	0.95	%	[9]
0030	eta	efficiency	Oil	SoA	0.37	%	[5][7]
0030	eta	efficiency	Oil	PoT	0.44	%	[5][6]
0030	eta	efficiency	PV	SoA	0.22	%	[10]
0030	eta	efficiency	PV	PoT	0.414	%	[11]
0030	eta	efficiency	U	SoA	0.3	%	[5]
0030	eta	efficiency	U	PoT	0.3	%	[5][6]
0030	eta	efficiency	WP	SoA	0.45	%	[10]
0030	eta	efficiency	WP	PoT	0.52	%	[10]
0060	LC_bv	lifecycle		ALL	10	years	[12]
0061	Mil_bv	mileage		ALL	15000	km/year	[12]
0070	A_front,bv	inflow_surface_base_vehicle		ALL	2	m2	[13]
0071	c_w,bv	drag_coefficient_base_vehicle		SoA	0.3		[14]
0071	c_w,bv	drag_coefficient_base_vehicle		PoT	0.24		[14]

0072	f_rr,bv	rolling_resistance_coefficient_base_vehicle		ALL	0.01		[13]
0073	e_i,bv	rotating_mass_surcharge factor		ALL	1.1		[15]
0074	roh_air	air_density		ALL	1.2	kg/m3	[16]
0075	G	g-force_earth		ALL	9.81	m/s2	[17]
1004	R_bv	resource_base_vehicle	Ste	SoA	526.6	kg	[18]
1004	R_bv	resource_base_vehicle	Fe	SoA	101.5	kg	
1004	R_bv	resource_base_vehicle	Al	SoA	102.2	kg	
1004	R_bv	resource_base_vehicle	Cu	SoA	1.3	kg	
1004	R_bv	resource_base_vehicle	Cot	SoA	12.8	kg	
1004	R_bv	resource_base_vehicle	Pla	SoA	223.5	kg	
1004	R_bv	resource_base_vehicle	Gla	SoA	29.6	kg	
1004	R_bv	resource_base_vehicle	Zn	SoA	2.5	kg	
1004	R_bv	resource_base_vehicle	Ste	PoT	458.2	kg	
1004	R_bv	resource_base_vehicle	Fe	PoT	88.3	kg	
1004	R_bv	resource_base_vehicle	Al	PoT	88.9	kg	
1004	R_bv	resource_base_vehicle	Cu	PoT	1.1	kg	
1004	R_bv	resource_base_vehicle	Cot	PoT	11.2	kg	
1004	R_bv	resource_base_vehicle	Pla	PoT	194.4	kg	
1004	R_bv	resource_base_vehicle	Gla	PoT	25.7	kg	
1004	R_bv	resource_base_vehicle	Zn	PoT	2.2	kg	
1005	x_ee	share_electric_energy_mix	BE	PoT	0.03039172	%	[19][20]
1005	x_ee	share_electric_energy_mix	Gas	SoA	0.23204150	%	[21]
1005	x_ee	share_electric_energy_mix	Gas	PoT	0.28486876	%	[19]
1005	x_ee	share_electric_energy_mix	HCo	SoA	0.38406868	%	[21]
1005	x_ee	share_electric_energy_mix	HCo	PoT	0.28512609	%	[19]
1005	x_ee	share_electric_energy_mix	HP	SoA	0.16701021	%	[21]
1005	x_ee	share_electric_energy_mix	HP	PoT	0.14967485	%	[19][20]
1005	x_ee	share_electric_energy_mix	Oil	SoA	0.03800680	%	[21]
1005	x_ee	share_electric_energy_mix	Oil	PoT	0.01286670	%	[19]
1005	x_ee	share_electric_energy_mix	OR	SoA	0.02334939	%	[21]
1005	x_ee	share_electric_energy_mix	PV	SoA	0.01313653	%	[21]
1005	x_ee	share_electric_energy_mix	PV	PoT	0.05501128	%	[19][20]
1005	x_ee	share_electric_energy_mix	U	SoA	0.10401860	%	[21]
1005	x_ee	share_electric_energy_mix	U	PoT	0.09778693	%	[19]
1005	x_ee	share_electric_energy_mix	WP	SoA	0.03836829	%	[21]
1005	x_ee	share_electric_energy_mix	WP	PoT	0.08427367	%	[19][20]
1012	(E/R_E)	Energy_per_resource_energy	BCo	ALL	2.56	kWh/kg	[22]
1012	(E/R_E)	Energy_per_resource_energy	Gas	ALL	12.4	kWh/kg	[23]
1012	(E/R_E)	Energy_per_resource_energy	HCo	ALL	8.33	kWh/kg	[22]

1012	(E/R_E)	Energy_per_resource_energy	Oil	ALL	11.6	kWh/kg	[23]
1012	(E/R_E)	Energy_per_resource_energy	U	ALL	24000000	kWh/kg	[24]
1300	x_res	resource_recycling_rate	Al	ALL	0.7684	%	[25]
1300	x_res	resource_recycling_rate	Cu	ALL	0.7684	%	[25]
1300	x_res	resource_recycling_rate	Li	ALL	0.01	%	[26]
1300	x_res	resource_recycling_rate	Pt	ALL	0.70	%	[26]
1300	x_res	resource_recycling_rate	Co	ALL	0.68	%	[26]
1300	x_res	resource_recycling_rate	Gla	ALL	0.822	%	[27]
1300	x_res	resource_recycling_rate	Cot	ALL	0.12	%	[28]
1300	x_res	resource_recycling_rate	Ga	ALL	0.01	%	[26]
1300	x_res	resource_recycling_rate	Ce	ALL	0.01	%	[26]
1300	x_res	resource_recycling_rate	Dy	ALL	0.01	%	[26]
1300	x_res	resource_recycling_rate	Tb	ALL	0.01	%	[26]
1300	x_res	resource_recycling_rate	Ste	ALL	0.8951	%	[25]
1300	x_res	resource_recycling_rate	Fe	ALL	0.8951	%	[25]
1300	x_res	resource_recycling_rate	Sn	ALL	0.7684	%	[25]
1300	x_res	resource_recycling_rate	Ge	ALL	0.385	%	[26]
1300	x_res	resource_recycling_rate	Au	ALL	0.775	%	[26]
1300	x_res	resource_recycling_rate	In	ALL	0.01	%	[26]
1300	x_res	resource_recycling_rate	Zn	ALL	0.7684	%	[25]
1300	x_res	resource_recycling_rate	Ni	ALL	0.7684	%	[25]
1300	x_res	resource_recycling_rate	La	ALL	0.01	%	[26]
1300	x_res	resource_recycling_rate	Mn	ALL	0.53	%	[26]
1300	x_res	resource_recycling_rate	Nd	ALL	0.01	%	[26]
1300	x_res	resource_recycling_rate	Te	ALL	0.01	%	[26]
1300	x_res	resource_recycling_rate	Cr	ALL	0.7684	%	[25]
1300	x_res	resource_recycling_rate	Pd	ALL	0.7	%	[26]
1300	x_res	resource_recycling_rate	Ag	ALL	0.775	%	[26]
1300	x_res	resource_recycling_rate	Si	ALL	0.9	%	[29]
1300	x_res	resource_recycling_rate	Ti	ALL	0.91	%	[26]
1300	x_res	resource_recycling_rate	Cd	ALL	0.15	%	[26]
1300	x_res	resource_recycling_rate	Pb	ALL	0.7684	%	[25]
1300	x_res	resource_recycling_rate	Gra	ALL	0	%	[30]
1300	x_res	resource_recycling_rate	Con	ALL	0.78	%	[25]
1300	x_res	resource_recycling_rate	Cem	ALL	0.78	%	[25]
1300	x_res	resource_recycling_rate	Pla	ALL	0.221	%	[25]
1400	x_res	resource_vehicle_recycling_rate	Al	ALL	0.9850	%	[31][32]
1400	x_res	resource_vehicle_recycling_rate	Cu	ALL	0.9850	%	[31][32]
1400	x_res	resource_vehicle_recycling_rate	La	ALL	0.01	%	[26]

1400	x_res	resource_vehicle_recycling_rate	Ag	ALL	0.775	%	[26]
1400	x_res	resource_vehicle_recycling_rate	Nd	ALL	0.01	%	[26]
1400	x_res	resource_vehicle_recycling_rate	Li	ALL	0.01	%	[26]
1400	x_res	resource_vehicle_recycling_rate	Ti	ALL	0.91	%	[26]
1400	x_res	resource_vehicle_recycling_rate	Te	ALL	0.01	%	[26]
1400	x_res	resource_vehicle_recycling_rate	Zn	ALL	0.985	%	[31][32]
1400	x_res	resource_vehicle_recycling_rate	Fe	ALL	0.985	%	[31][32]
1400	x_res	resource_vehicle_recycling_rate	Pb	ALL	0.7684	%	[25]
1400	x_res	resource_vehicle_recycling_rate	Ni	ALL	0.7684	%	[25]
1400	x_res	resource_vehicle_recycling_rate	Gra	ALL	0	%	[30]
1400	x_res	resource_vehicle_recycling_rate	Sn	ALL	0.985	%	[31][32]
1400	x_res	resource_vehicle_recycling_rate	Cr	ALL	0.7684	%	[25]
1400	x_res	resource_vehicle_recycling_rate	Mn	ALL	0.53	%	[26]
1400	x_res	resource_vehicle_recycling_rate	Pla	ALL	0.55	%	[31]
1400	x_res	resource_vehicle_recycling_rate	Pd	ALL	0.7	%	[26]
1400	x_res	resource_vehicle_recycling_rate	Gla	ALL	0.08	%	[33]
1400	x_res	resource_vehicle_recycling_rate	Pt	ALL	0.70	%	[26]
1400	x_res	resource_vehicle_recycling_rate	Cot	ALL	0.12	%	[28]
1400	x_res	resource_vehicle_recycling_rate	Co	ALL	0.68	%	[26]
1400	x_res	resource_vehicle_recycling_rate	Au	ALL	0.775	%	[26]
1400	x_res	resource_vehicle_recycling_rate	Ge	ALL	0.385	%	[26]
1400	x_res	resource_vehicle_recycling_rate	Ga	ALL	0.01	%	[26]
1400	x_res	resource_vehicle_recycling_rate	Ste	ALL	0.985	%	[31][32]
1400	x_res	resource_vehicle_recycling_rate	Tb	ALL	0.01	%	[26]
1400	x_res	resource_vehicle_recycling_rate	Dy	ALL	0.01	%	[26]
1400	x_res	resource_vehicle_recycling_rate	Ce	ALL	0.01	%	[26]
1400	x_res	resource_vehicle_recycling_rate	In	ALL	0.01	%	[26]
1400	x_res	resource_vehicle_recycling_rate	Cd	ALL	0.15	%	[26]
1799	(ghg/E_E)	GHG_emission_per_energy_electricity		SoA	540.8906228	g/kWh	[21][34][35][36][37][38]
1799	(ghg/E_E)	GHG_emission_per_energy_electricity		PoT	407.8802702	g/kWh	[19][20][34][35][36][37][38]
1800	R_av	resource_available	BCo	ALL	4741000000000	t	[39]
1800	R_av	resource_available	Ce	ALL	145810428	t	[40][41]
1800	R_av	resource_available	Pt	ALL	47000	t	[42][43][44]
1800	R_av	resource_available	Al	ALL	12500000000	t	[43]
1800	R_av	resource_available	Li	ALL	53000000	t	[43]
1800	R_av	resource_available	Co	ALL	145000000	t	[43]
1800	R_av	resource_available	HCo	ALL	18424000000000	t	[39]

1800	R_av	resource_available	Ni	ALL	300000000	t	[45]
1800	R_av	resource_available	Cd	ALL	570000000	t	[46]
1800	R_av	resource_available	Cr	ALL	12000000000	t	[46]
1800	R_av	resource_available	Fe	ALL	230000000000	t	[43]
1800	R_av	resource_available	In	ALL	95000	t	[43]
1800	R_av	resource_available	La	ALL	76263908	t	[40][41]
1800	R_av	resource_available	Mn	ALL	5990000000	t	[47]
1800	R_av	resource_available	Nd	ALL	49594650	t	[40][41]
1800	R_av	resource_available	Pd	ALL	51000	t	[44]
1800	R_av	resource_available	Gra	ALL	800000000	t	[43]
1800	R_av	resource_available	P	ALL	300000000000	t	[43]
1800	R_av	resource_available	Gas	ALL	672000000000	t	[39]
1800	R_av	resource_available	Cu	ALL	2100000000	t	[43]
1800	R_av	resource_available	U	ALL	11600000	t	[39]
1800	R_av	resource_available	Ga	ALL	3845000	t	[43]
1800	R_av	resource_available	Dy	ALL	1910449.4	t	[40][41]
1800	R_av	resource_available	Oil	ALL	689000000000	t	[39]
1800	R_av	resource_available	Pb	ALL	2000000000	t	[46]
2000	C_bv	cost_base_vehicle		ALL	15000	€	[12][48]
2020	x_c,sale,bv	resale_base_vehicle		ALL	0.1	%	[49]
3205	n_veh_p_g	vehicle_production_global		SoA	70567581		[50]
3205	n_veh_p_g	vehicle_production_global		PoT	152168184		[50][51]

Table S2. Location specific data using the example of Germany

ID_param	Symbol	Parameter	Resource	Time type	Value	Unit	Reference
30	eta	efficiency	BCo	SoA	0.391655636	%	[7][52]
30	eta	efficiency	BCo	PoT	0.47	%	[6]
30	eta	efficiency	BE	SoA	0.28	%	[4]
30	eta	efficiency	BE	PoT	0.32	%	[4]
30	eta	efficiency	Gas	SoA	0.573832757	%	[7][52]
30	eta	efficiency	Gas	PoT	0.62	%	[6]
30	eta	efficiency	HCo	SoA	0.425255113	%	[7][52]
30	eta	efficiency	HCo	PoT	0.5	%	[6]
30	eta	efficiency	HP	SoA	0.9	%	[8]
30	eta	efficiency	HP	PoT	0.95	%	[9]
30	eta	efficiency	Oil	SoA	0.413600164	%	[7][52]
30	eta	efficiency	Oil	PoT	0.48	%	[6]
30	eta	efficiency	PV	SoA	0.22	%	[10]
30	eta	efficiency	PV	PoT	0.414	%	[11]

30	eta	efficiency	U	SoA	0.329954712	%	[7][52]
30	eta	efficiency	U	PoT	0.333	%	[6]
30	eta	efficiency	WP	SoA	0.45	%	[10]
30	eta	efficiency	WP	PoT	0.52	%	[10]
1005	x_ee	share_electric_energy_mix	BCo	SoA	0.24267365	%	[53]
1005	x_ee	share_electric_energy_mix	BCo	PoT	0.01743265	%	[54]
1005	x_ee	share_electric_energy_mix	BE	SoA	0.08230131	%	[53]
1005	x_ee	share_electric_energy_mix	BE	PoT	0.07765452	%	[54]
1005	x_ee	share_electric_energy_mix	Gas	SoA	0.08197387	%	[53]
1005	x_ee	share_electric_energy_mix	Gas	PoT	0.21553090	%	[54]
1005	x_ee	share_electric_energy_mix	HCo	SoA	0.13346128	%	[53]
1005	x_ee	share_electric_energy_mix	HCo	PoT	0.03645008	%	[54]
1005	x_ee	share_electric_energy_mix	HP	SoA	0.03580128	%	[53]
1005	x_ee	share_electric_energy_mix	HP	PoT	0.03803487	%	[54]
1005	x_ee	share_electric_energy_mix	PV	SoA	0.08442829	%	[53]
1005	x_ee	share_electric_energy_mix	PV	PoT	0.10935024	%	[54]
1005	x_ee	share_electric_energy_mix	U	SoA	0.13336901	%	[53]
1005	x_ee	share_electric_energy_mix	U	PoT	0	%	[54]
1005	x_ee	share_electric_energy_mix	WP	SoA	0.20569130	%	[53]
1005	x_ee	share_electric_energy_mix	WP	PoT	0.50554675	%	[54]
1799	(ghg/E_E)	GHG_emission_per_energy_electricity		SoA	463.8433416	g/kWh	[34][35][36][37][38][53]
1799	(ghg/E_E)	GHG_emission_per_energy_electricity		PoT	157.91441036	g/kWh	[34][35][36][37][38][54]
2006	(C/E_E)	cost_per_energy_electricity		SoA	0.2986	€/kWh	[55]
2006	(C/E_E)	cost_per_energy_electricity		PoT	0.268	€/kWh	[6]
2007	(C/E_H2)	cost_per_energy_hydrogen		SoA	0.285	€/kWh	[56]
2007	(C/E_H2)	cost_per_energy_hydrogen		PoT	0.157	€/kWh	[57]
2008	(C/E_G)	cost_per_energy_gasoline		SoA	0.155	€/kWh	[23][58]
2008	(C/E_G)	cost_per_energy_gasoline		PoT	0.244	€/kWh	[6][23]
2009	(C/E_D)	cost_per_energy_diesel		SoA	0.116	€/kWh	[23][58]
2009	(C/E_D)	cost_per_energy_diesel		PoT	0.202	€/kWh	[6][23]
2010	x_C,E,adj	cost_adjustment_electricity		ALL	0.46	%	[59]
2011	x_C,H2,adj	cost_adjustment_hydrogen		ALL	0.84	%	
2012	x_C,G,adj	cost_adjustment_gasoline		ALL	0.361	%	[58]
2013	x_C,D,adj	cost_adjustment_diesel		ALL	0.433	%	[58]
3200	L_road	length_highway_road_network		ALL	12996	km	[60]
3201	DP_veh	design_driving_performance_vehicle		ALL	1.462520828	km/h	[61]

3202	n_veh	registered_vehicles		SoA	52895784		[62]
3202	n_veh	registered_vehicles		PoT	45863000		[6]
3204	*n_el*	average_electrified_lane		ALL	2.2917		[61]

Table S3. Technological data

ID_param	Symbol	Component	Parameter	Resource	Time type	Value	Unit	Reference
0030	eta	electricity_trans port	efficiency		SoA	0.94	%	[63]
0030	eta		efficiency		PoT	0.97	%	[64]
1001	(R/E)		resource_per_energy	Al	ALL	0.000150141	kg/kWh	[18][65][53][54]
1001	(R/E)		resource_per_energy	Cu	ALL	0.000281691	kg/kWh	
1001	(R/E)		resource_per_energy	Ste	ALL	0.000543517	kg/kWh	
1001	(R/E)		resource_per_energy	Wo	ALL	0.0000598252	kg/kWh	
1001	(R/E)		resource_per_energy	Con	ALL	0.00335517	kg/kWh	
1001	(R/E)		resource_per_energy	San	ALL	0.020830662	kg/kWh	
1001	(R/E)		resource_per_energy	Pla	ALL	0.000160966	kg/kWh	
1001	(R/E)		resource_per_energy	Pb	ALL	0.0000928778	kg/kWh	
0030	eta	electrolysis, compression, storage	efficiency		SoA	0.65	%	[66]
0030	eta		efficiency		PoT	0.85	%	[67]
1001	(R/E)		resource_per_energy	Al	ALL	0.00000180	kg/kWh	[68][23]
1001	(R/E)		resource_per_energy	Con	ALL	0.00000900	kg/kWh	
1001	(R/E)		resource_per_energy	Ste	ALL	0.00018002	kg/kWh	
1001	(R/E)		resource_per_energy	Ni	ALL	0.00001920	kg/kWh	
1001	(R/E)		resource_per_energy	Pla	ALL	0.00000150	kg/kWh	
1001	(R/E)		resource_per_energy	Cr	ALL	0.00000570	kg/kWh	
1105	E_aux/E		energy_auxiliary_per_energy		SoA	1.538461538	kWh/kWh	[66]
1105	E_aux/E		energy_auxiliary_per_energy		PoT	1.176470588	kWh/kWh	[67]
0030	eta	H2_distribution	efficiency		ALL	0.99	%	[69]
1001	(R/E)		resource_per_energy	Ste	ALL	0.0024	kg/kWh	[18]
1105	E_aux/E		energy_auxiliary_per_energy		ALL	0.0000000377538	kWh/kWh	[18]
1500	ghg_fac		GHG_emission_auxiliary_factor		SoA	477.89	g/kWh	[18]
1500	ghg_fac		GHG_emission_auxiliary_factor		PoT	381.19	g/kWh	[18]
30	eta	compression, storage, fueling	efficiency		ALL	0.935	%	[70]
60	LC_bv		lifecycle		ALL	10	years	[18]
1105	E_aux/E		energy_auxiliary_per_energy		ALL	0.03	kWh/kWh	[18]
1500	ghg_fac		GHG_emission_auxiliary_factor		SoA	483.92	g/kWh	[18]
1500	ghg_fac		GHG_emission_auxiliary_factor		PoT	386.05	g/kWh	[18]
2002	c/P		cost_per_performance		SoA	1892.4	€/kW	[23][69][71][72]
2002	c/P		cost_per_performance		PoT	1690.53	€/kW	[69][71][72]
21	P	charging	nominal_power		SoA	150	kW	[73]

21	P		nominal_power		PoT	350	kW	[73]
30	eta		efficiency		SoA	0.85	%	[74]
30	eta		efficiency		PoT	0.85	%	[74]
60	LC_bv		lifecycle		ALL	10	years	
1002	R/P		resource_per_performance	Cu	SoA	1.35	kg/kW	[18][73][75]
1002	R/P		resource_per_performance	Cu	PoT	1.317428571429	kg/kW	[18][73][75]
1002	R/P		resource_per_performance	In	SoA	0.0000000066667	kg/kW	[73][75]
1002	R/P		resource_per_performance	In	PoT	0.00000000231	kg/kW	[73][75]
1002	R/P		resource_per_performance	Ge	SoA	0.0000000066667	kg/kW	[73][75]
1002	R/P		resource_per_performance	Ge	PoT	0.00000000231	kg/kW	[73][75]
1002	R/P		resource_per_performance	Ga	SoA	0.0000000066667	kg/kW	[73][75]
1002	R/P		resource_per_performance	Ga	PoT	0.00000000231	kg/kW	[73][75]
1002	R/P		resource_per_performance	Ag	SoA	0.0000000066667	kg/kW	[73][75]
1002	R/P		resource_per_performance	Ag	PoT	0.00000000231	kg/kW	[73][75]
1002	R/P		resource_per_performance	Ste	SoA	3.0	kg/kW	[18]
1002	R/P		resource_per_performance	Ste	PoT	3.0	kg/kW	[18]
2002	c/P		cost_per_performance		SoA	212.50	€/kW	[73][76][77]
2002	c/P		cost_per_performance		PoT	61.63		[73][76][77]
30	eta		efficiency		SoA	0.63	%	[78]
30	eta		efficiency		PoT	0.9	%	[79][80]
60	LC_bv		lifecycle		ALL	30	years	[12]
1002	R/P		resource_per_performance	Ta	ALL	0.000002211	kg/kW	[81][82]
1002	R/P		resource_per_performance	Sb	ALL	0.000053422	kg/kW	[81][82]
1002	R/P		resource_per_performance	Pla	ALL	0.034263455	kg/kW	[81][82]
1002	R/P		resource_per_performance	Cu	ALL	1.3226580909091	kg/kW	[18][81][82]
1002	R/P		resource_per_performance	Fe	ALL	0.016394879	kg/kW	[81][82]
1002	R/P		resource_per_performance	Ste	ALL	3	kg/kW	[81][82]
1002	R/P		resource_per_performance	Sn	ALL	0.000202633	kg/kW	[18]
1002	R/P	E-road	resource_per_performance	Au	ALL	0.000001658	kg/kW	[81][82]
1002	R/P		resource_per_performance	Ag	ALL	0.000005895	kg/kW	[81][82]
1002	R/P		resource_per_performance	Al	ALL	0.1070272424242	kg/kW	[81][82]
1002	R/P		resource_per_performance	Pd	ALL	0.000000276	kg/kW	[81][82]
1003	R/L		resource_per_distance	Al	ALL	1700	kg/km	[61][65][80]
1003	R/L		resource_per_distance	Cu	ALL	10336	kg/km	[61][65][80] [83]
1003	R/L		resource_per_distance	San	ALL	235000	kg/km	[61][65][80]
1003	R/L		resource_per_distance	Pb	ALL	300	kg/km	[61][65][80]
1003	R/L		resource_per_distance	Pla	ALL	1000	kg/km	[61][65][80]
1003	R/L		resource_per_distance	Ste	ALL	400	kg/km	[61][65][80]
2003	c/L		cost_per_length		ALL	3240023,9	€/km	[84]

30	eta		efficiency		SoA	0.94	%	[2][85]
30	eta		efficiency		PoT	0.96	%	[2][85]
40	E/m		energy_density		SoA	0.135	kWh/kg	[2][85][86]
40	E/m		energy_density		PoT	0.175	kWh/kg	[2][85][86]
1001	(R/E)		resource_per_energy	Al	SoA	1.05148148148148	kg/kWh	[2][85][86] [87][88]
1001	(R/E)		resource_per_energy	Al	PoT	0.789	kg/kWh	
1001	(R/E)		resource_per_energy	Co	SoA	0.208148148148148	kg/kWh	
1001	(R/E)		resource_per_energy	Co	PoT	0.093	kg/kWh	
1001	(R/E)		resource_per_energy	Li	SoA	0.141851851851852	kg/kWh	
1001	(R/E)		resource_per_energy	Li	PoT	0.125	kg/kWh	
1001	(R/E)		resource_per_energy	Mn	SoA	0.342666	kg/kWh	
1001	(R/E)		resource_per_energy	Mn	PoT	0.159	kg/kWh	
1001	(R/E)		resource_per_energy	Cu	SoA	1.228	kg/kWh	
1001	(R/E)		resource_per_energy	Cu	PoT	0.741	kg/kWh	
1001	(R/E)		resource_per_energy	Ni	SoA	0.3426667	kg/kWh	
1001	(R/E)		resource_per_energy	Ni	PoT	0.317	kg/kWh	
1001	(R/E)		resource_per_energy	Fe	SoA	0.677333	kg/kWh	
1001	(R/E)		resource_per_energy	Fe	PoT	0.62	kg/kWh	
1001	(R/E)		resource_per_energy	P	SoA	0.069333	kg/kWh	
1001	(R/E)	battery	resource_per_energy	P	PoT	0.189	kg/kWh	
1001	(R/E)		resource_per_energy	Si	SoA	0.072	kg/kWh	
1001	(R/E)		resource_per_energy	Si	PoT	0.216	kg/kWh	
1001	(R/E)		resource_per_energy	Gra	SoA	1.36	kg/kWh	
1001	(R/E)		resource_per_energy	Gra	PoT	0.862	kg/kWh	
1101	EP/E		energy_production_per_energy		SoA	163	kWh/kWh	[89]
1101	EP/E		energy_production_per_energy		PoT	97	kWh/kWh	[90]
1300	x_res		resource_recycling_rate	Al	SoA	0.85	%	[87][91]
1300	x_res		resource_recycling_rate	Al	PoT	0.9	%	[87][91]
1300	x_res		resource_recycling_rate	Co	SoA	0.95	%	[87]
1300	x_res		resource_recycling_rate	Co	PoT	0.98	%	[87][92][93] [94][95]
1300	x_res		resource_recycling_rate	Li	SoA	0.8	%	[87][92][93] [94][95][96]
1300	x_res		resource_recycling_rate	Li	PoT	0.9	%	[87][92][93] [94][95][96]
1300	x_res		resource_recycling_rate	Mn	SoA	0.95	%	[87]
1300	x_res		resource_recycling_rate	Mn	PoT	0.98	%	[87][92][93] [94][95][96]
1300	x_res		resource_recycling_rate	Cu	SoA	0.9	%	[87] [91]

1300	x_res		resource_recycling_rate	Cu	PoT	0.95	%	[87][91][93]
1300	x_res		resource_recycling_rate	Ni	SoA	0.95	%	[87]
1300	x_res		resource_recycling_rate	Ni	PoT	0.96	%	[87][91][92] [93][95][96]
2001	C/E		cost_per_energy		SoA	202.5	€/kWh	[86][97]
2001	C/E		cost_per_energy		PoT	100	€/kWh	[86][97]
10	C		capacity		SoA	133.3	kWh	[14]
10	C		Capacity		PoT	177.8	kWh	[14]
30	eta		efficiency		ALL	0.90	%	[98]
40	E/m		energy_density		SoA	1.68	kWh/kg	[14][99]
40	E/m	H2_tank	energy_density		PoT	2.60	kWh/kg	[14][99]
1001	(R/E)		resource_per_energy	Pla	SoA	0.59564891	kg/kWh	[14][99]
1001	(R/E)		resource_per_energy	Pla	PoT	0.37007874	kg/kWh	[14][99]
2001	C/E		cost_per_energy		SoA	30.003	€/kWh	[23][97]
2001	C/E		cost_per_energy		PoT	9.00090009	€/kWh	[23][97]
30	eta		efficiency		SoA	0.91	%	[2][85]
30	eta		efficiency		PoT	0.95	%	[2][85]
31	eta_rec		efficiency__degr_recup		ALL	0.89	%	[99]
50	P/m		performance_density		SoA	2	kW/kg	[99]
50	P/m		performance_density		PoT	3	kW/kg	[99]
1002	R/P		resource_per_performance	Fe	SoA	0.3244495	kg/kW	
1002	R/P		resource_per_performance	Fe	PoT	0.2148256667	kg/kW	
1002	R/P		resource_per_performance	Al	SoA	0.9715	kg/kW	
1002	R/P		resource_per_performance	Al	PoT	0.0669666667	kg/kW	
1002	R/P		resource_per_performance	Nd	SoA	0.003564	kg/kW	[68][99][100] [101][102]
1002	R/P		resource_per_performance	Nd	PoT	0.001848	kg/kW	
1002	R/P	E-motor	resource_per_performance	Dy	SoA	0.001188	kg/kW	
1002	R/P		resource_per_performance	Dy	PoT	0.000616	kg/kW	
1002	R/P		resource_per_performance	Cu	SoA	0.0665	kg/kW	
1002	R/P		resource_per_performance	Cu	PoT	0.0443333333	kg/kW	
1102	EP/P		energy_production_per_performance		SoA	160	kWh/kW	[103]
1102	EP/P		energy_production_per_performance		PoT	95	kWh/kW	[103]
1300	x_res		resource_recycling_rate	Nd	ALL	0.9	%	[104]
1300	x_res		resource_recycling_rate	Cu	ALL	0.95	%	[87]
1300	x_res		resource_recycling_rate	Dy	ALL	0.90	%	[104]
1300	x_res		resource_recycling_rate	Al	ALL	0.9	%	[87]
2002	c/P		cost_per_performance		SoA	12.9	€/kW	[97]
2002	c/P		cost_per_performance		PoT	10	€/kW	[97]
21	P	PE	nominal_power		SoA	90	kW	[75]

21	P		nominal_power		PoT	150	kW	[75]
30	eta		efficiency		SoA	0.96	%	[2][85]
30	eta		efficiency		PoT	0.97	%	[2][85]
50	P/m		performance_density		SoA	3.6	kW/kg	[99]
50	P/m		performance_density		PoT	5	kW/kg	[99]
1002	R/P		resource_per_performance	Ge	SoA	0.0000005882	kg/kW	[75]
1002	R/P		resource_per_performance	Ge	PoT	0.0000004235	kg/kW	[75]
1002	R/P		resource_per_performance	Ag	SoA	0.0000705882	kg/kW	[75]
1002	R/P		resource_per_performance	Ag	PoT	0.0000508235	kg/kW	[75]
1002	R/P		resource_per_performance	Au	SoA	0.0000023529	kg/kW	[75]
1002	R/P		resource_per_performance	Au	PoT	0.0000016941	kg/kW	[75]
1002	R/P		resource_per_performance	Pd	SoA	0.0000009412	kg/kW	[75]
1002	R/P		resource_per_performance	Pd	PoT	0.0000006776	kg/kW	[75]
1002	R/P		resource_per_performance	Cu	SoA	0.0294117647058824	kg/kW	[75][99]
1002	R/P		resource_per_performance	Cu	PoT	0.0211764706	kg/kW	[75]
1002	R/P		resource_per_performance	In	SoA	0.0000005882	kg/kW	[75]
1002	R/P		resource_per_performance	In	PoT	0.0000004235	kg/kW	[75]
1002	R/P		resource_per_performance	Ga	SoA	0.000000588235294	kg/kW	[75]
1002	R/P		resource_per_performance	Ga	PoT	0.000000423538462	kg/kW	[75]
2002	c/P		cost_per_performance		SoA	4.5	€/kW	[97]
2002	c/P		cost_per_performance		PoT	3	€/kW	[97]
21	P	bz_system	nominal_power		SoA	74.1	kW	[14][105]
21	P		nominal_power		PoT	111.2	kW	[14][105]
30	eta		efficiency		SoA	0.525	%	[106]
30	eta		efficiency		PoT	0.60	%	[106]
50	P/m		performance_density		SoA	0.40	kW/kg	[99]
50	P/m		performance_density		PoT	0.65	kW/kg	[98]
1002	R/P		resource_per_performance	Ste	SoA	0.0005	kg/kW	[14][87][116][105]
1002	R/P		resource_per_performance	Ste	PoT	0.2798926237	kg/kW	[87][107]
1002	R/P		resource_per_performance	Gra	SoA	0.455	kg/kW	[14][87][116][105]
1002	R/P		resource_per_performance	Gra	PoT	0.0140056	kg/kW	[87][98]
1002	R/P		resource_per_performance	Pt	SoA	0.585	kg/kW	[87][107]
1002	R/P		resource_per_performance	Pt	PoT	0.0002	kg/kW	[87][107]
1002	R/P		resource_per_performance	Cu	SoA	0.1	kg/kW	[14][87][116][105]
1002	R/P		resource_per_performance	Cu	PoT	0.06151447246	kg/kW	[87][107]

1002	R/P		resource_per_performance	Al	SoA	0.02285714	kg/kW	[14][87][116][105]
1002	R/P		resource_per_performance	Al	PoT	0.2798926237	kg/kW	[87][107]
1102	EP/P		energy_production_per_performance		SoA	261.111	kWh/kW	[108]
1102	EP/P		energy_production_per_performance		PoT	206.66666	kWh/kW	[108]
1300	x_res		resource_recycling_rate	Pt	ALL	0.98	%	[87]
2002	c/P		cost_per_performance		SoA	600	€/kW	[97]
2002	c/P		cost_per_performance		PoT	60	€/kW	[97]
30	eta	E-transmission	efficiency		SoA	0.955	%	[2][85]
30	eta		efficiency		PoT	0.98	%	[2][85]
50	P/m		performance_density		ALL	12.954545454545	kW/kg	[109]
30	eta	differential	efficiency		SoA	0.95	%	[2][85]
30	eta		efficiency		PoT	0.98	%	[2][85]
50	P/m		performance_density		ALL	3.607594936708861	kW/kg	[109]
21	P	charging_interface	nominal_power		ALL	30	kW	[79]
50	P/m		performance_density		ALL	0.324675325	kW/kg	[79]
1002	R/P		resource_per_performance	Al	ALL	1	kg/kW	[79][110]
1002	R/P		resource_per_performance	Cu	ALL	0.195	kg/kW	[79][110]
1002	R/P		resource_per_performance	Ste	ALL	0.08	kg/kW	[79][110]
1002	R/P		resource_per_performance	Fe	ALL	0.67	kg/kW	[79][110]
1002	R/P		resource_per_performance	Pla	ALL	0.705	kg/kW	[79][110]
1300	x_res		resource_recycling_rate	Cu	ALL	0.95	%	[87]
1300	x_res		resource_recycling_rate	Al	ALL	0.9	%	[87]
2002	c/P		cost_per_performance		SoA	66.66666667	€/kW	[12][79]
2002	c/P		cost_per_performance		PoT	33.33333333	€/kW	[12][79]

Table S4. Resource materials

short name	Name
Al	aluminium
Sb	antimony
Cd	cadmium
Ce	cerium
Cr	chrome
Co	cobalt
Cu	copper
Dy	dysprosium
Ga	gallium
Ge	germanium
Au	gold

In	indium
Fe	iron
La	lanthanum
Pb	lead
Li	lithium
Mn	manganese
Nd	neodymium
Ni	nickel
Pd	palladium
Sn	pewter
Pt	platinum
Pr	praseodymium
Si	silicon
Ag	silver
Ste	steel
Ta	tantalum
Te	tellurium
Tb	terbium
Ti	titanium
Zn	zinc
Cem	cement
Con	concrete
Cot	cotton
Gla	glass
P	phosphorus
Pla	plastic
San	sand
Gra	graphite
BCo	(soft) brown coal
HCo	hard coal
Gas	natural gas
Oil	petroleum
U	uranium
Wo	wood
HP	hydro power
WP	wind power
PV	Photovoltaic
BE	Bioenergy
OR	Other resources

References

1. *Energieeffiziente Antriebstechnologien*. *Hybridisierung - Downsizing - Software und IT;* Siebenpfeiffer, W., Ed.; Springer: Dordrecht, 2013, ISBN 978-3-658-00789-8.
2. Füßel, A. *Technische Potenzialanalyse der Elektromobilität*. *Stand der Technik, Forschungsausblick und Projektion auf das Jahr 2025;* Springer Vieweg: Wiesbaden, 2017, ISBN 9783658166960.
3. BMW AG. Technische Daten des BMW i3 und BMW i3s. https://www.bmw.de/de/neufahrzeuge/bmw-i/i3/2017/technische-daten.html?bmw=sea:59052874707_kwd-27082900038&ds_rl=1278189&ds_rl=1278189&gclid=EAIaIQobChMI28a1vsX45AIVGM53Ch2uvgN1EAAYASABEgI7cfD_BwE&gclsrc=aw.ds#tab-0 (accessed on 2 October 2019).
4. European Biomass Association (AEBIOM). *Report on conversion efficiency of biomass*. *BASIS – Biomass Availability and Sustainability Information System*, 2015. http://www.basisbioenergy.eu/fileadmin/BASIS/D3.5_Report_on_conversion_efficiency_of_biomass.pdf (accessed on 22 October 2019).
5. Economic Commission for Europe. Baseline Efficiency Analysis of Fossil Fuel Power Plants. https://www.unece.org/fileadmin/DAM/energy/se/pdfs/CES/ge11/CEP.11.2015.INF.4.e.pdf (accessed on 4 November 2019).
6. Schlesinger, M.; Hofer, P.; Kemmler, Andreas, Kirchner, Almut; Koziel, S.; Ley, A.; Piégsa, A.; Seefeldt, F.; Straßburg, S.; Weinert, K.; Knaut, A.; et al. *Entwicklung der Energiemärkte – Energiereferenzprognose*. *Studie im Auftrag des Bundesministeriums für Wirtschaft und Technologie*; Projekt Nr. 57/12 des Bundesministeriums, 2014. https://www.bmwi.de/Redaktion/DE/Publikationen/Studien/entwicklung-der-energiemaerkte-energiereferenzprognose-endbericht.html (accessed on 13 November 2018).
7. Wittke, F. *Auswertungstabellen zur Energiebilanz für die Bundesrepublik Deutschland 1990 bis 2017*, 2018. https://ag-energiebilanzen.de/10-0-Auswertungstabellen.html.
8. U.S. Department of the Interior Bureau of Reclamation. *Hydroelectric Power*, 2005. https://www.usbr.gov/power/edu/pamphlet.pdf (accessed on 22 October 2019).
9. Frans van Aart. *ENERGY EFFICIENCY IN POWER PLANTS*.
10. Brauner, G. *Systemeffizienz bei regenerativer Stromerzeugung*. *Strategien für effiziente Energieversorgung bis 2050;* Springer Fachmedien Wiesbaden: Wiesbaden, 2019, ISBN 978-3-658-24853-6.
11. ISE, Fraunhofer. *Konzentrator-Photovoltaik mit höchster Effizienz – 41,4% Modulwirkungsgrad*, 2018.
12. Risch, F.; Franke, J. *Abschlussbericht zum Forschungsprojekt – Machbarkeitsstudie zum kontaktlosen Laden von Elektromobilen (E|ROAD)*, 2011.
13. Haken, K.-L. *Grundlagen der Kraftfahrzeugtechnik*, 5., aktualisierte Auflage; Hanser: München, 2018, ISBN 978-3-446-45412-5.
14. Huss, A.; Maas, H.; Hass, H. *Well-to-wheels analysis of future automotive fuels and powertrains in the European context*. *Tank-to-wheels (TTW) report, version 4, July 2013*. JEC well-to-wheels analysis; Publications Office: Luxembourg, 2013, ISBN 978-92-79-31195-6.
15. Böcker, J. *Antriebe für umweltfreundliche Fahrzeuge*. *Skript zur Vorlesung*. Stand 20.03.2018. https://ei.uni-paderborn.de/fileadmin/elektrotechnik/fg/lea/Lehre/AUF/Dokumente/Skript_Fahrzeugantriebe.pdf (accessed on 17.10.18).
16. LUMITOS AG. Luftdichte. https://www.chemie.de/lexikon/Luftdichte.html (accessed on 11 October 2019).
17. Georg-August-Universität Göttingen. Erdbeschleunigung. https://lp.uni-goettingen.de/get/text/7500 (accessed on 11 October 2019).

18. Internationales Institut für Nachhaltigkeitsanalysen und -strategien. *GEMIS - Globales Emissionsprogramm integrierter Systeme*, 2017.
19. t. Wang. Projected electricity generation worldwide from 2015 to 2050, by energy source (in trillion kilowatt hours). https://www.statista.com/statistics/238610/projected-world-electricity-generation-by-energy-source/ (accessed on 5 August 2019).
20. IEA. World energy Outlook 2017 **2017**.
21. International Energy Agency (iea). *Key World Energy Statistics 2018*, 2018. https://webstore.iea.org/download/direct/2291?fileName=Key_World_2018.pdf (accessed on 9 May 2019).
22. Forschungsstelle für Energiewirtschaft e.V. *Basisdaten zur Bereitstellung elektrischer Energie. Stromerzeugung in Deutschland*.
23. Linde Gas GmbH. *Rechnen Sie mit Wasserstoff. Die Datentabelle*.
24. energie-lexikon.info. Uran. https://www.energie-lexikon.info/uran.html (accessed on 13 February 2019).
25. Sören Steger, Michael Ritthoff, Winfried Bulach, Doris Schüler, Izabela Kosinska, Stefanie Degreif, Günter Dehoust, Thomas Bergmann, Peter Krause, Rüdiger Oetjen-Dehne. *Stoffstromorientierte Ermittlung des Beitrags der Sekundärrohstoffwirtschaft zur Schonung von Primärrohstoffen und Steigerung der Ressourcenproduktivität*, 2019. https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2019-03-27_texte_34-2019_sekundaerrohstoffwirtschaft.pdf (accessed on 5 August 2019).
26. T. E. Graedel; T.E. Graedel; Julian Allwood; Jean-Pierre Birat; Matthias Buchert; Christian Hagelüken; Barbara K. Reck; Scott F. Sibley. *Recycling Rates of Metal. A Status Report*, 2011 (accessed on 27 June 2019).
27. Felix Schnegg. Nimm mal lieber die Gurken - Lebenszyklus einer Weinflasche. https://trenntmagazin.de/glasrecycling-nimm-mal-lieber-die-gurken-lebenszyklus-einer-weinflasche/ (accessed on 6 August 2019).
28. EU-Recycling. Textile Ökonomie statt Textil-Recycling. https://eu-recycling.com/Archive/18411 (accessed on 6 August 2019).
29. Sandra Enkhardt. PV Cycle erreicht 96 Prozent Recyclingquote bei Silizium-Solarm. https://www.pv-magazine.de/2016/02/18/pv-cycle-erreicht-96-prozent-recyclingquote-bei-silizium-solarmodulen/ (accessed on 6 August 2019).
30. Gerd Meyring; Dörte Neitzel. Rohstoff Graphit - Das sechste Element. https://www.technik-einkauf.de/ratgeber/rohstoffe/rohstoff-graphit-das-sechste-element/ (accessed on 5 July 2019).
31. Umweltbundesamt. Altfahrzeugverwertung und Fahrzeugverbleib. https://www.umweltbundesamt.de/daten/ressourcen-abfall/verwertung-entsorgung-ausgewaehlter-abfallarten/altfahrzeugverwertung-fahrzeugverbleib#textpart-3 (accessed on 22 June 2019).
32. Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (BMU), Umweltbundesamt. *Jahresbericht über die Altfahrzeug-Verwertungsquoten in Deutschland im Jahr 2016*, 2018. https://www.bmu.de/fileadmin/Daten_BMU/Download_PDF/Abfallwirtschaft/jahresbericht_altfahrzeug_2016_bf.pdf (accessed on 22 June 2019).
33. Umweltbundesamt. Glas und Altglas. https://www.umweltbundesamt.de/daten/ressourcen-abfall/verwertung-entsorgung-ausgewaehlter-abfallarten/glas-altglas#textpart-6 (accessed on 27 June 2019).
34. Michael Memmler, Dr. Thomas Lauf, Sven Schneider. *Emissionsbilanz erneuerbarer Energieträger - Bestimmung der vermiedenen Emissionen im Jahr 2017*, 2018.

35. Petra Icha. *Entwicklung der spezifischen Kohlendioxid-Emissionen des deutschen Strommix in den Jahren 1990 - 2018*, 2019 (accessed on 9 May 2019).
36. T. Marheineke, W. Krewitt, J. Neubarth, R. Friedrich, A. Voß. *Ganzheitliche Bilanzierung der Energie- und Stroffströme von Energieversorungstechniken*, 2000 (accessed on 9 May 2019).
37. Fachagentur Nachwachsende Rohstoffe e.V. (FNR). *Basisdaten Bioenergie Deutschland 2018*, 2018. http://www.fnr.de/fileadmin/allgemein/pdf/broschueren/Basisdaten_Bioenergie_2018.pdf (accessed on 9 May 2019).
38. Berkhout, V.; Buchmann, E.; Callies, D.; Cernusko, R.; Dobschinski, J.; Durstewitz, M.; Faulstich, S.; Grashof, K.; Hahn, B.; Jäger, F.; et al. *Windenergie Report Deutschland 2017*, 2018. http://windmonitor.iee.fraunhofer.de/opencms/export/sites/windmonitor/img/Windmonitor-2017/WERD_2017_180523_Web_96ppi.pdf.
39. Harald Andruleit (Koordination), Martin Blumenberg, Jolanta Kus, Jürgen Meßner, Martin Pein, Dorothee Rebscher, Mareike Schamel, Michael Schauer, Michael Schmidt, Sandro Schmidt, Gabriela von Goerne. *BGR Energiestudie 2017 - Daten und Entwicklungen der deutschen und globalen Energieversorgung (21)*, 2017. https://www.bgr.bund.de/DE/Themen/Energie/Downloads/energiestudie_2017.pdf;jsessionid=1A02D92254138B2E47F12F6FC8EACFD7.1_cid292?__blob=publicationFile&v=5 (accessed on 18 August 2018).
40. Bundesanstalt für Geowissenschaften und Rohstoffe. *Seltene Erden*. Rohstoffwirtschaftliche Steckbriefe, 2014. http://www.bgr.bund.de/DE/Themen/Min_rohstoffe/Downloads/rohstoffsteckbrief_se.pdf%3F__blob%3DpublicationFile%26v%3D6 (accessed on 14 August 2014).
41. Zhou, B.; Li, Z.; Chen, C. Global Potential of Rare Earth Resources and Rare Earth Demand from Clean Technologies. *Minerals* **2017**, *7*, *doi:*10.3390/min7110203.
42. Agora Verkehrswende. *Strategien für die nachhaltige Rohstoffversorgung der Elektromobilität*. Synthesepapier zum Rohstoffbedarf für Batterien und Brennstoffzellen, 2017. https://www.agora-verkehrswende.de/veroeffentlichungen/strategien-fuer-die-nachhaltige-rohstoffversorgung-der-elektromobilitaet/ (accessed on 14 February 2019).
43. U.S. Geological Survey. *Mineral Commodity Summaries 2018*, 2018. https://minerals.usgs.gov/minerals/pubs/mcs/ (accessed on 14 February 2019).
44. Hagelüken, C. *Autoabgaskatalysatoren. Grundlagen - Herstellung - Entwicklung - Recycling - Ökologie ; mit 65 Tabellen*, 2., aktualisierte und erw. Aufl.; expert-Verl.: Renningen, 2005, ISBN 3816924883.
45. Nickel Institute. *Das Leben von Ni*, 2016. https://www.nickelinstitute.org/media/1197/lifeofni_de.pdf (accessed on 13 October 2019).
46. U.S. Geological Survey; U.S. Department of the Interior. *MINERAL COMMODITY SUMMARIES 2019*, 2019. http://prd-wret.s3-us-west-2.amazonaws.com/assets/palladium/production/atoms/files/mcs2019_all.pdf (accessed on 9 July 2019).
47. Neitzel, D. Rohstoff Mangan - Reichtum vom Grund der Weltmeere. https://www.technik-einkauf.de/ratgeber/rohstoffe/rohstoff-mangan-reichtum-vom-grund-der-weltmeere/ (accessed on 13 February 2019).
48. Russer, J.A.; Haider, M.; Weigelt, M.; Becherer, M.; Kahlert, S.; Merz, c.; Hoja, M.; Franke, J.; Russer, P. A System for Wireless Inductive Power Supply of Electric Vehicles while Driving Along the Route. *2017 7th International Electric Drives Production Conference (E/DPC)*; IEEE: Würzburg, 2017, ISBN 978-1-5386-1069-5.
49. ADAC. Wann sich vom Gebrauchten trennen? (accessed on 12 November 2018).

50. International Organization of Motor Vehicle Manufacturers (OICA). 2018 PRODUCTION STATISTICS. http://www.oica.net/category/production-statistics/2018-statistics/ (accessed on 8 October 2019).
51. Pemberton Associates. Far Horizons - Managing the Future: The automotive world to 2100. http://www.sutherlandcampbell.com/news/WhitePaper.pdf (accessed on 8 October 2019).
52. Bantle, C. *Kraftwerkspark in Deutschland*. *Aktueller Kraftwerkspark, Stromerzeugungsanlagen im Bau und in Planung, absehbare Stilllegungen konventioneller Kraftwerke*, 2018 (accessed on 16 May 2019).
53. Fraunhofer ISE. Nettostromerzeugung in Deutschland in 2018. https://www.energy-charts.de/energy_pie_de.htm?year=2018 (accessed on 5 August 2019).
54. Deutsche Energie-Agentur GmbH (dena). *dena-Leitstudie Integrierte Energiewende*. *Impulse für die Gestaltung des Energiesystems bis 2050*, 2018. https://www.dena.de/fileadmin/dena/Dokumente/Pdf/9261_dena-Leitstudie_Integrierte_Energiewende_lang.pdf (accessed on 5 August 2019).
55. Bundesnetzagentur. *Monitoringbericht 2017*, 2017. https://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen_Institutionen/DatenaustauschundMonitoring/Monitoring/Monitoringberichte/Monitoring_Berichte_node.html;jsessionid=FD11C8AE92C0328B7656CC0F883D673E (accessed on 12 November 2018).
56. Shell Wasserstoff-Studie. Energie der Zukunft?: Nachhaltige Mobilität durch Brennstoffzelle und H2 **2017**.
57. Nationale Organisation Wasserstoff-und Brennstoffzellentechnologie. *Ein Portfolio von Antriebssystemen für Europa: Eine faktenbasierte Analyse*. *Die Rolle von batteriebetriebenen Elektrofahrzeugen, Plug-in Hybridfahrzeugen und Brennstoffzellenfahrzeugen,* 2013. http://www.solarer-wasserstoff.de/download/portfolio.pdf (accessed on 11.08.18).
58. Mineralölwirtschaftsverband e.V. Ver-braucher-preise. https://www.mwv.de/statistiken/verbraucherpreise/ (accessed on 13 November 2018).
59. BDEW Bundesverband der Energie- und Wasserwirtschaft e.V. *BDEW-Strompreisanalyse Mai 2017*. *Haushalte und Industrie*, 2017.
60. Bundesministerium für Verkehr und digitale Infrastruktur. Bestandsaufnahme der Straßen des überörtlichen Verkehrs. https://www.bmvi.de/SharedDocs/DE/Artikel/StB/bestandsaufnahme-strassen-ueberoertlich.html (accessed on 12 November 2018).
61. Bundesanstalt für Straßenwesen (bast). SVZ 2015 Datensatz. https://www.bast.de/BASt_2017/DE/Statistik/Verkehrsdaten/2015/SVZ-2015-Daten.html.
62. KBA. Bestand am 1. Januar 2019 nach Fahrzeugklassen. https://www.kba.de/DE/Statistik/Fahrzeuge/Bestand/FahrzeugklassenAufbauarten/2019_b_fzkl_eckdaten_pkw_dusl.html?nn=652402 (accessed on 29 June 2019).
63. Statistisches Bundesamt (Destatis). Erzeugung: Monatsbericht über die Elektrizitätsversorgung. https://www.destatis.de/DE/ZahlenFakten/Wirtschaftsbereiche/Energie/Erzeugung/Tabellen/BilanzElektrizitaetsversorgung.html (accessed on 8 June 2018).
64. *Energietechnologien der Zukunft*. *Erzeugung, Speicherung, Effizienz und Netze;* Wietschel, M.; Ullrich, S.J.; Markewitz, P.; Schulte, F.; Genoese, F., Eds.; Springer Vieweg: Wiesbaden, 2015, ISBN 978-3-658-07129-5.
65. Soeren Steger, Miriam Fekkak, Stefan Bringezu. *Materialbestand und Materialfluesse in Infrastrukturen*. Meilensteinbericht des Arbeitspakets 2.3 des Projekts „Materialeffizienz und Ressourcenschonung" (MaRess), 2011. https://core.ac.uk/download/pdf/35139093.pdf (accessed on 20 June 2019).
66. Bundesverband Energiespeicher. *Fact Sheet Speichertechnologien: Wasserstoff-Speicherung*, 2016. https://www.bves.de/wp-content/uploads/2016/03/FactSheet_chemisch_P2G.pdf (accessed on 10.09.18).

67. Brinner, A.; Schmidt, M.; Schwarz, S.; Wagener, L.; Zuberbühler, U. *Technologiebericht 4.1 Power-to-gas (Wasserstoff) innerhalb des Forschungsprojekts TF_Energiewende*, 2018. https://epub.wupperinst.org/frontdoor/deliver/index/docId/7058/file/7058_Power-to-gas.pdf (accessed on 13 November 2018).
68. Frieske, B.; Klötzke, Matthias, Kreyenberg, Danny; Bienge, K.; Hillebrand, P.; Hüging, H.; Koska, T.; Monscheidt, J.; Ritthoff, M.; Soukup, O.; Tenbergen, J. *Begleitforschung zu Technologien, Perspektiven und Ökobilanzen der Elektromobilität. STROMbegleitung*. Abschlussbericht des Verbundvorhabens, 2015.
69. Krieg, D. *Konzept und Kosten eines Pipelinesystems zur Versorgung des deutschen Straßenverkehrs mit Wasserstoff*. Zugl.: Aachen, Techn. Hochsch., Diss., 2012; Forschungszentrum Jülich: Jülich, 2012, ISBN 9783893368006.
70. Edwards, R.; Larivé, J.-F.; Rickeard, D.; Weindorf, W. *Well-to-tank report version 4.a. JEC well-to-wheels analysis : well-to-wheels analysis of future automotive fuels and powertrains in the European context;* Publications Office: Luxembourg, 2014, ISBN 978-92-79-33888-5.
71. M. Robinius et al. Comparative Analysis of Infrastructures: Hydrogen Fueling and Electric Charging of Vehicles **2018**.
72. Tjarks, G. *Wasserstoff- und Brennstoffzellentechnologie in Deutschland;* Karlsruhe, 2018.
73. Kurt Mühlgrabner. *Sorglos Laden in der Zukunft. Expert Roundtable der Standortagentur Tirol;* Tirol, 2018.
74. Felgenhauer, Markus, F.; Pellow, M.A.; Benson, S.M.; Hamacher, T. *Evaluating co-benefits of battery and fuel cell vehicles in a community in California*; Volume 114, 2016. https://www.sciencedirect.com/science/article/pii/S0360544216311173?via%3Dihub#appsec1 (accessed on 12 November 2018).
75. Dr. Matthias Buchert; Dr. Wolfgang Jenseit; Stefanie Dittrich; Florian Hacker; Dr. Eckhard Schüler-Hainsch; Dr. Klaus Ruhland; Sven Knöfel; Prof Dr. Daniel Goldmann; Kai Rasenack; Frank Treffer. *Ressourceneffizienz und ressourcenpolitische Aspekte des Systems Elektromobilität. Arbeitspaket 7 des Forschungsvorhabens OPTUM: Optimierung der Umweltentlastungspotenziale von Elektrofahrzeugen*. Anhang zum Schlussbericht, 2011.
76. Nationale Plattform Elektromobilität (NPE). *Ladeinfrastruktur für Elektrofahrzeuge in Deutschland. Statusbericht und Handlungsempfehlungen 2015*. AG 3 - Ladeinfrastruktur und Netzintegration, 2015. http://nationale-plattform-elektromobilitaet.de/die-npe/publikationen/ (accessed on 13 November 2018).
77. Auer, J. Ladeinfrastruktur für Elektromobilität im Jahr 2050 in Deutschland; Karlsruher Institut für Technologie, Karlsruhe, 2019.
78. Würz, T. *Wireless electric vehicle charging - today and tomorrow;* Würzburg, 2017.
79. Gould, R.; INTIS GmbH. *Optimierung von Komponenten der induktiven Energieübertragung und Systemerprobung. Verbundvorhaben gefördert vom Bundesministerium für Verkehr und digitale Infrastruktur (BMVI).*
80. Olsson, O. Slide-in Electric Road System: Inductive project report **2013**.
81. Nordelöf, A.; Alatalo, M.; Söderman, M.L. A scalable life cycle inventory of an automotive power electronic inverter unit—part I: design and composition. *Int J Life Cycle Assess* **2018**, *52*, 1305, doi:10.1007/s11367-018-1503-3.
82. Dr. Doris Schüler; Dr. Winfried Bulach; Stefanie Degreif; Dr. Matthias Buchert; Guido Sellin; Prof. Dr.-Ing. Tobias Elwert; Prof. Dr.-Ing. Goldmann; Dr. Dieter Schmid; Dr. Ulrich Kammer. *Elektrofahrzeugrecycling 2020 – Schlüsselkomponente Leistungselektronik ElmoReL 2020*, 2017. http://www.resourcefever.org/publications/reports/ElmoRel_Endbericht.pdf (accessed on 4 June 2019).
83. Marmiroli, B.; Dotelli, G.; Spessa, E. Life Cycle Assessment of an On-Road Dynamic Charging Infrastructure. *Applied Sciences* **2019**, *9*, *doi:*10.3390/app9153117.

84. Limb, B.J.; Asher, Z.D.; Bradley, T.H.; Sproul, E.; Trinko, D.A.; Crabb, B.; Zane, R.; Quinn, J.C. Economic Viability and Environmental Impact of In-Motion Wireless Power Transfer. *IEEE Trans. Transp. Electrific.* **2018**, 1, doi:10.1109/TTE.2018.2876067.
85. *Die Elektrifizierung des Antriebsstrangs*. *Basiswissen;* Tschöke, H., Ed.; Springer Vieweg: Wiesbaden, 2015, ISBN 978-3-658-04644-6.
86. Thielmann, A.; Neef, C.; Hettesheimer, T.; Dörscher, H.; Wietschel, M.; Tübke, J. *Energiespeicher-Roadmap (Update 2017)*. *Hochenergie-Batterien 2030+ und Perspektiven zukünftiger Batterietechnologien*, 2017.
87. Umweltbundesamt. *Ableitung von Recycling- und Umweltanforderungen und Strategien zur Vermeidung von Versorgungsrisiken bei innovativen Energiespeichern*, 2016.
88. Pistoia, G.; Liaw, B. *Behaviour of Lithium-Ion Batteries in Electric Vehicles;* Springer International Publishing: Cham, 2018, ISBN 978-3-319-69949-3.
89. Ellingsen, L.A.-W.; Majeau-Bettez, G.; Singh, B.; Srivastava, A.K.; Valøen, L.O.; Strømman, A.H. Life Cycle Assessment of a Lithium-Ion Battery Vehicle Pack. *Journal of Industrial Ecology* **2014**, *18*, 113–124, doi:10.1111/jiec.12072.
90. Romare, M.; Dahllöf, L. *The Life Cycle Energy Consumption and Greenhouse Gas Emissions from Lithium-Ion Batteries*. *A Study with Focus on Current Technology and Batteries for light-duty vehicles*, 2017.
91. Buchert, M.; Jenseit, W.; Merz, C.; Schüler, D. *Ökobilanz zum „Recycling von Lithium-Ionen-Batterien" (LithoRec)*, 2011. https://www.oeko.de/oekodoc/1500/2011-068-de.pdf (accessed on 30 August 2018).
92. Chen, X.; Chen, Y.; Zhou, T.; Liu, D.; Hu, H.; Fan, S. Hydrometallurgical recovery of metal values from sulfuric acid leaching liquor of spent lithium-ion batteries. *Waste Management* **2015**, *2015*, 349–356.
93. Chen, X.; Xu, B.; Zhou, T.; Liu, D.; Hu, H.; Fan, S. Separation and recovery of metal values from leaching liquor of mixed-type of spent lithium-ion batteries. *Separation and Purification Technology* **2015**, *2015*, 197–205.
94. Chen, X.; Fan, B.; Xu, L.; Zhou, T.; Kong, J. An atom-economic process for the recovery of high value-added metals from spent lithium-ion batteries. *Journal of Cleaner Production* **2015**, *2016*, 3562–3570.
95. Hu, J.; Zhang, J.; Li, H.; Chen, Y.; Wang, C. A promising approach for the recovery of high value-added metals from spent lithium-ion batteries. *Journal of Power Sources* **2017**, *2017*, 192–199.
96. Zheng, X.; Zhu, Z.; Lin, X.; Zhang, Y.; He, Y.; Cao, H.; Sun, Z. A Mini-Review on Metal Recycling from Spent Lithium Ion Batteries. *Engineering* **2018**, *2018*, 361–370.
97. Fries, M.; Kerler, M.; Rohr, S.; Schickram, S.; Sinning, M.; Lienkamp, M. *An Overview of Costs for Vehicle Components, Fuels, Greenhouse Gas Emissions and Total Cost of Ownership*. *Update 2017*, 2017.
98. U.S. Department of Energy. *Fuel Cell Technologies Office*. *Multi-Year Research, Development, and Demonstration Plan*. Planned program activities for 2011-2020, 2012. https://www.energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22 (accessed on 19.09.18).
99. Matz, S.; Burda, P.; Fuchs, J.; Horlbeck, L.; Eckl, R.; Lienkamp, M.; Ficht, A. *Description of the modelling style and parameters for electric vehicles in the concept phase*.
100. Hofman, H.; Kaufmann, R.; Tschopp, O. *E-Scooter – Sozial- und naturwissenschaftliche Beiträge zur Förderung leichter Elektrofahrzeuge in der Schweiz*. *Anhang zum Schlussbericht 2013*, 2014. https://www.newride.ch/documents/Forschungsprojekt_E-Scooters_2013/Anhang_zu_Schlussbericht_E-Scooter_2013.pdf (accessed on 2 August 2018).
101. Glöser-Chahoud, S.; Tercero Espinoza, L.A. *Dynamische Materialfluss-Analyse von Neodym und Dysprosium als Magnetwerkstoffe;* Fraunhofer-Institut für System- und Innovationsforschung ISI: Karlsruhe, 2015.

102. Reuter, B. *Bewertung von Nachhaltigkeitsaspekten zur Rohstoff- und Technologieauswahl für Elektrofahrzeuge;* Verlag Dr. Hut: München, 2016, ISBN 9783843927581.
103. Sahni, S.; Boustani, A.; Gutowski, T.; Graves, S. *Electric Motor Remanufacturing and Energy Savings*, 2010.
104. Bast, U.; Blank, R.; Buchert, M.; Elwert, T.; Finsterwalder, F.; Hörnig, G.; Klier, T. *Recycling von Komponenten und strategischen Metallen aus elektrischen Fahrantrieben*. Abschlussbericht zum Verbundvorhaben, 2014. https://www.ifa.tu-clausthal.de/fileadmin/Aufbereitung/Dokumente_News_ETC/MORE_Abschlussbericht.pdf (accessed on 21 September 2018).
105. Kreyenberg, D. *Fahrzeugantriebe für die Elektromobilität;* Springer Fachmedien Wiesbaden: Wiesbaden, 2016, ISBN 978-3-658-14283-4.
106. Klell, M.; Eichlseder, H.; Trattner, A. *Wasserstoff in der Fahrzeugtechnik. Erzeugung, Speicherung, Anwendung*, 4., aktualisierte und erweiterte Auflage; Springer Vieweg: Wiesbaden, 2018, ISBN 978-3-658-20447-1.
107. Marcinkoski, J.; Vijayagopal, R.; Kast, J.; Duran, A. Driving an Industry: Medium and Heavy Duty Fuel Cell Electric Truck Component Sizing. *World Electric Vehicle Journal* **2013**, *8*, 78–89.
108. Dhanushkodi, S.; Srinivasan, A. Life Cycle Analysis of Fuel Cell Technology. *J ENV INFORM* **2008**, *11*, 36–44, doi:10.3808/jei.200800109.
109. Green-Motors.de. Tesla Model S: Das wiegen die einzelnen Bauteile des Stromers. https://www.green-motors.de/news/1406182416-tesla-model-s-das-wiegen-die-einzelnen-bauteile-des-stromers (accessed on 11 February 2019).
110. Cirimele, V. Design and integration of a dynamic IPT system for automotive applications. Dissertation; Politecnico di Torino, Turin, 2017.