
Vermessung der Umwelt in Lebenszyklusanalysen am Beispiel der Elektrofahrzeuge weltweit

Gerfried Jungmeier
J. Dunn
S. Ehrenberger
R. Widmer
Challenges for the Successful Market Introduction of Electric-Vehicles

Charging infrastructure

Monitoring: Electricity, emissions

Additional renewable electricity

Electric-vehicles
1) On the market available
2) Substituting gasoline & diesel

The consumer
Statement on Environmental Assessment of Electric Vehicles

“There is international consensus that the environmental effects of electric vehicles can only be analyzed on the basis of Life Cycle Assessment (LCA) including the production, operation and the end of life treatment of the vehicles”

…and in comparison to conventional vehicles
Assessment of LCA-Aspects over Full Value Chain

Primary Energy

- Electricity production
- Electricity grid
- Charging infrastructure

Production of vehicle
Production of battery

Electric vehicle

„End of life management“
Dismantling of vehicle

Transportation service
The 7 Key Issues in LCA of EVs

1) General issues: state of technology, heating & cooling of vehicle

2) Life cycle modeling: end of life, data quality, allocation, lifetime

3) Vehicle cycle: production – use – end of life e.g. energy demand of vehicle

4) Fuel cycle (electricity production): PV with storage

5) Inventory analysis: CO₂, MJ, kg <-> CSB, waste water, heavy metals

6) Impact assessment: GHG, primary energy <-> biodiversity, toxicity

7) Reference system: vehicle size, driving range, ≤ 100% substitution?

Example: 66,000 BEV in Norway (Norsk elbil forening 2015)
- 85% substitute „fossil driven“ ICE kilometres
- 15% substitute walking, bicycling, public transport and additional mobility

→ 9,000 additional vehicles?

addresses the key issues related to climate change:
- How can society cope better with the risks of global warming and how can we minimise the associated economic damage?
- Will climate change also bring economic opportunities?
- How can these opportunities be realised?
- What steps are necessary to guide our society towards a more sustainable development path in order to slow down climate change?

creating opportunities from climate change

establish a centre of European dimensions by pooling the scientific excellence of three research groups

Our mission is:
- strengthen resilience to climate and weather risks
- promote the transition to a low-carbon economy and society by 2050
Research Groups

- **CRM**
  - Weather & Climate Risk Management
  - Risk Identification
  - Impact Quantification
  - Climate Solutions & Climate Services

- **SYS**
  - Future Energy Systems & Lifestyle
  - Energy Systems Assessment
  - Best Technology Choice
  - Lifestyle Transformation Tools

- **CPE**
  - International Climate Policy & Economics
  - Macroeconomic Analysis
  - Policy evaluation
  - Policy Design
The 2 Keys: Renewable Energy and Energy Efficiency

- Renewable Energy: Hydro power, Biodiesel rape*, Ren-H₂, FT-Biodiesel wood,
- Energy Efficiency: Electric PV incl. storage, Internal combustion engine and battery electric passenger cars

Greenhouse gas emissions [g CO₂-eq/km] vs. Fuel consumption [kWh/100km]

- Reduction -90%

Source: LCA of passenger vehicles, Joanneum Research, *) without iLUC
The 2 Keys: Renewable Energy and Energy Efficiency

Internal combustion engine and battery electric passenger cars

- Diesel
- Biodiesel rape*)
- Ren-H₂ hydro power
- FT-Biodiesel wood
- Electricity UCTE mix
- Electricity PV incl. storage
- Electricity natural gas
- Electricity hydro power

Increase +30%

Fuel consumption [kWh/100km]

Greenhouse gas emissions [g CO₂-eq/km]

Source: LCA of passenger vehicles, Joanneum Research, *) without iLUC
Vehicle Fleet Worldwide 2014

About 700,000 electric vehicles

Assumption:
- BEV 65%, PHEV 35%
- BEV: 14,000 km/a
- PHEV 8,000 km/a (electric)
- EVs substitute 95% of km driven by conventional vehicles

Source: EVI 2015, IEA-HEV, own assumptions
Estimated GHG (CO$_2$, CH$_4$, N$_2$O) Emissions of National Electricity Productions

From primary resource extraction to charging point

National electricity production

Source: own calculations using data of ecoinvent
Estimated PM-Emissions of National Electricity Productions

From primary resource extraction to charging point

- Canada (Québec)
- Norway
- Sweden
- Switzerland
- France
- USA (Northeast)
- China
- Greece
- USA (Midwest)
- Turkey

Source: own calculations using data of ecoinvent

Ranges due to:
- Emissions of national electricity production
- Electricity consumption of EVs at charging point
- Fuel consumption of substituted conventional ICEs
- Emissions&energy consumption of real world driving cycles
- Data availability, uncertainty and consistency, e.g. PM

-70%  -15%  -15%  -35%  +35%  -80%  -15%  -15%  -20%

Ranges due to:
- Emissions of national electricity production
- Electricity consumption of EVs at charging point
- Fuel consumption of substituted conventional ICEs
- Emissions&energy consumption of real world driving cycles
- Data availability, uncertainty and consistency, e.g. PM

Ranges:
- Substituting diesel and gasoline ICE vehicles

FR: -75%  DE: -70%  NL: -70%  GB: -60%  CN: +45%  NO: -85%  US: -75%  JP: -50%  Rest: -544  Total: -60%
Estimated NO\textsubscript{x} – and SO\textsubscript{2}-Emissions of Electric Vehicles Worldwide (2014)

Ranges due to:
- Emissions of national electricity production
- Electricity consumption of EVs at charging point
- Fuel consumption of substituted conventional ICEs
- Emissions\&energy consumption of real world driving cycles
- Data availability, uncertainty and consistency, e.g. PM

Substituting diesel and gasoline ICE vehicles

Acidification potential emissions [t SO\textsubscript{2}-eq/a]
Estimated CH$_4$-, NMVOC-, NO$_x$- and CO- Emissions of EVs Worldwide (2014)

Ranges due to:
- Emissions of national electricity production
- Electricity consumption of EVs at charging point
- Fuel consumption of substituted conventional ICEs
- Emissions&energy consumption of real world driving cycles
- Data availability, uncertainty and consistency, e.g. PM

Ranges in %:
-75%  -55% -50%  -40%  +60%  -80%  -30%  -25%  -30%

Regions:
- FR
- DE
- NL
- GB
- CN
- NO
- US
- JP
- Rest
- Total
Additional Renewable Electricity Production and Electric Vehicles

1. „Direct connection“
2. „Via storage“
3. „Stored in Grid“
4. „Real time charging“

How to connect?
Charging of EVs with Additional Renewable Electricity

“Direct connection”
- Direct connection from renewable sources

“Via storage”
- Charging via storage system

“Stored in grid”
- Stored in grid systems

“Real time charging”
- Real time charging from renewable sources

Substitution of natural gas CC power plant during the day, e.g. “lunch time”

Additional electricity from coal power plant during night

Loading of EV 1 kWh
- Indirect PV loading 0.7 kWh
- Production

Saving
Emissions for Different Loading Strategies with Additional Renewable Electricity

- **Electricity from PV**:
  - Li-Ion Battery: 100 g CO₂-eq/kWh
  - Hydro Pump Storage: 73 g CO₂-eq/kWh

- **Electricity from wind power**:
  - Li-Ion Battery: 28 g CO₂-eq/kWh
  - Hydro Pump Storage: 13 g CO₂-eq/kWh

GHG emissions [g CO₂-eq/kWh] vs. Simultaneousness of EV Loading and Renewable Power Generation.
GHG Emissions of Electric Vehicles - Renewable Electricity

Average significant GHG reduction ($\text{CO}_2$, $\text{CH}_4$, $\text{N}_2\text{O}$): 74 - 81%

Intermediate battery storage assumed
1) PV 20%
2) Wind 10%

Electricity consumption EV at charging point for real driving cycle (e.g. heating/cooling):
15 – 30 kWh/100 km

Source: own calculations using data of ecoinvent
PM (< 10 µm)-Emissions of Electric Vehicles – Renewable Electricity

Average significant reduction PM-emissions (< 10 µm): 75 - 87%

Intermediate battery storage assumed
1) PV 20%
2) Wind 10%

Electricity consumption EV at charging point for real driving cycle (e.g. heating/cooling):
15 – 30 kWh/100 km

Source: own calculations using data of ecoinvent
**Additional renewable electricity** with adequate charging strategies is essential for further significant reductions.

**Broad estimated ranges** mainly due to:
- Emissions of national electricity production
- Electricity consumption of EVs at charging point
- Fuel consumption of substituted conventional ICEs
- Data availability, uncertainty and consistency, e.g. PM

**Estimation of environmental effects** substituting diesel/gasoline:
- GHG-reduction: - 20%
- PM < 10 reduction: - 60%
- Acidification increase: + 40%
- Ozone reduction: - 30%

About **700,000 EVs worldwide** (end of 2014):
Main countries US, JP, CN, F, DE, NO

Environmental Assessment of EVs only possible on **Life Cycle Assessment** compared to conventional vehicles.
Gerfried Jungmeier

JOANNEUM RESEARCH Forschungsgesellschaft mbH.

LIFE – Centre for Climate, Energy and Society

Future Energy Systems and Lifestyles

Elisabethstraße 18
A-8010 Graz
AUSTRIA

+43 316 876-1313

www.joanneum.at/eng

gerfried.jungmeier@joanneum.at
