

# Integrating technical scaling laws into LCA

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## Scaling

- A transformation that enlarges or diminishes objects
- 1. Estimation of data
  - Population size
  - Metabolic rate
  - Earthquakes
  - Financial markets
  - Production costs
  - ...
- 2. Underlying mechanisms
  - Allometry
  - Euclidean relationships
  - ...

## Function of scaling laws

- Commonly expressed as a power law

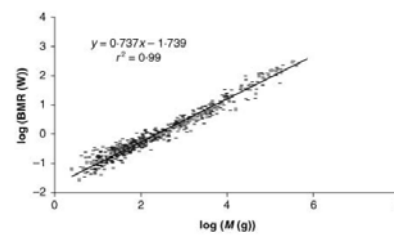
$$y = a x^b$$

$$\log(y) = b \log(x) + \log(a)$$

$b$ : scaling factor

$a$ : standardized constant

- Isometric  $b = 1$
- Geometric  $b = 1/3$
- Allometric  $b = 1/4$



(Savage, Gillooly et al 2004)

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## Scaling in LCA

- Many situations where no or incomplete data available
- Pilot plant process vs. full scale processes
- Small system vs. large system
- Many changes
  - Technological
  - Societal
  - Economical
  - Environmental
  - Legislation
  - ...

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## Objectives of this study

### 1. Goal

- Establish scaling laws for industrial equipment
- Identify underlying mechanisms
- Comparison scaling in living and non-living systems

### 2. Goal

- Establish scaling laws for the impacts of these equipments (production & operation)
- Determine „rule-of-thumb“ to scale LCA results
- Implement scaling laws in LCA

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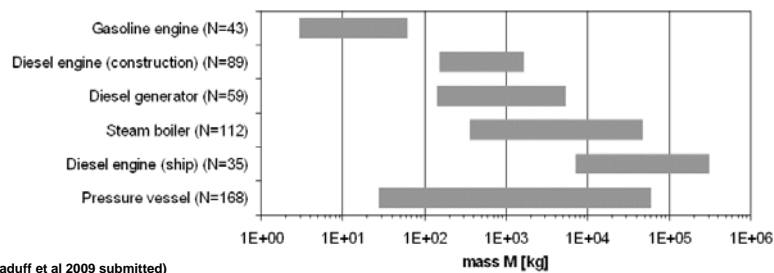
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## Part 1: Establishing scaling laws

- Industrial equipment, total of 504 cases

### ■ Variables

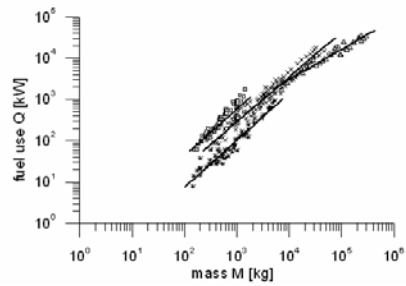
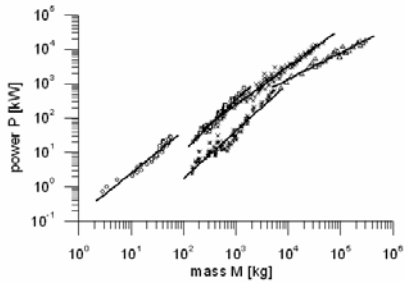
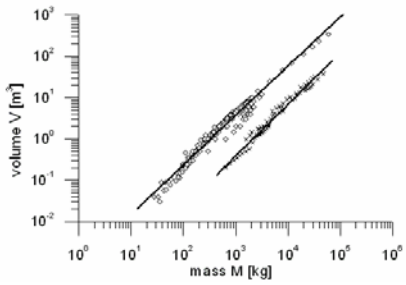
- Volume:  $V \propto a_v M^{b_v}$
- Fuel use:  $F_{in} \propto a_F M^{b_F}$
- Power output:  $P_{out} \propto a_p M^{b_p}$



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# Results



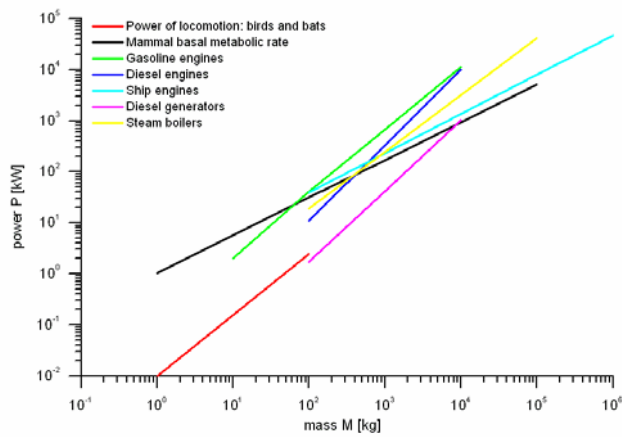
| Equipment        | r <sup>2</sup> | b (95% CI)         |
|------------------|----------------|--------------------|
| Gasoline engine  | 0.94           | 1.27 (1.17 – 1.37) |
| Diesel engine    | 0.95           | 1.51 (1.44 – 1.59) |
| Ship engine      | 0.95           | 0.79 (0.73 – 0.86) |
| Diesel generator | 0.94           | 1.43 (1.35 – 1.53) |
| Steam boiler     | 0.97           | 1.13 (1.09 – 1.17) |

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(Caduff et al 2009 submitted)

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# Comparison Biology



(Caduff et al 2009 submitted)

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## Scaling in LCA: Conclusion part 1

- Scaling of industrial equipment is not isometrically
- Material input vs. power & fuel use is not isometric, effects on LCA expected not to be isometric
- Results are comparable with active biological systems

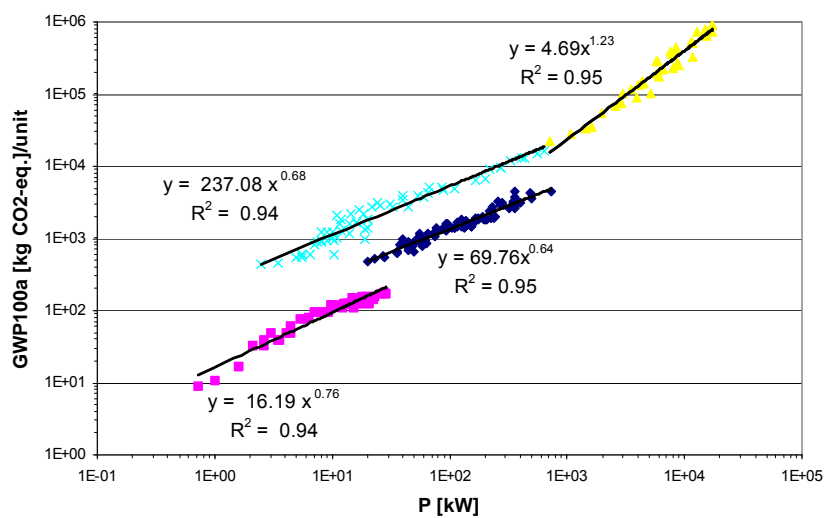
### Study part 2:

- Establish inventory for each dataset
- Calculate impact of production and operation
- Plot & regression
- Determining scaling factor

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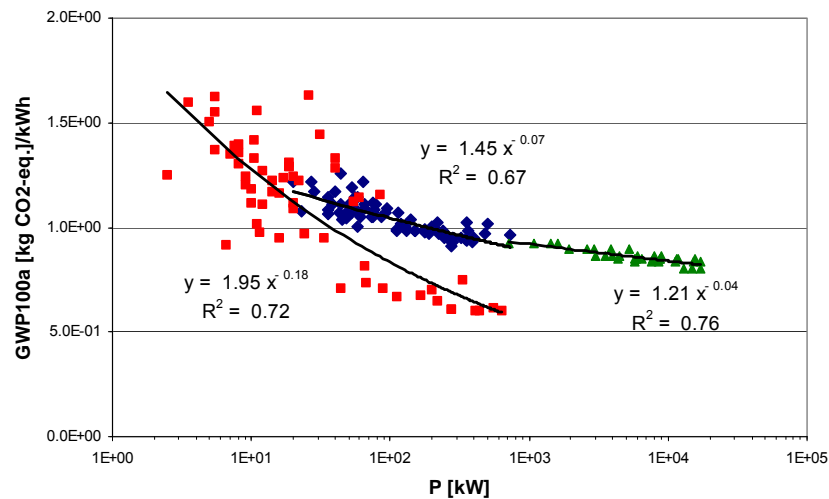
## Engines production – GWP / unit



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## Engines operation – EI99 (HA) / kWh



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## Scaling in LCA: Conclusion part 2

- Environmental impacts per FU do not remain constant
- First indication: „rule-of-thumb“ for infrastructure of  $b = 0.65$
- Additional tool for prospective technology assessments
- Data intensive
- Material changes not included, still data missing
- Labour- and time intensive development work
- „pure“ size effects

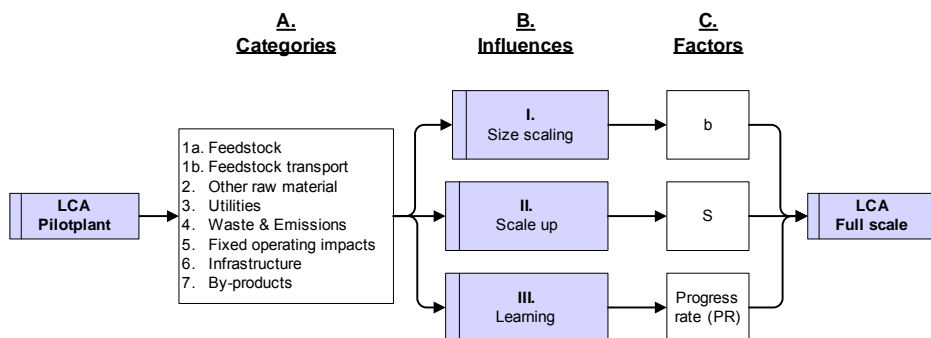
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## Integration in LCA

- Parameterise inventory/impact using power law
  - Every single input with a factor, or
  - one scaling factor for process of material, or
  - rule-of-thumb for whole groups, e.g. plastics, infrastructure, energy, chemicals, etc.
- If no factors available → method / guideline on how to establish such factors
- Integration in e.g. ecoinvent possible, if parameterisation is possible.
- Applicable mainly for short term changes, within same technological settings
- Method can be used to also implement other influences such as learning

## Outlook: Framework



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Thank you for your attention

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