A New Inventory Data Model and Method for Uncertainty Evaluation in Life Cycle Assessment

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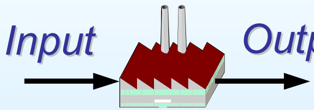
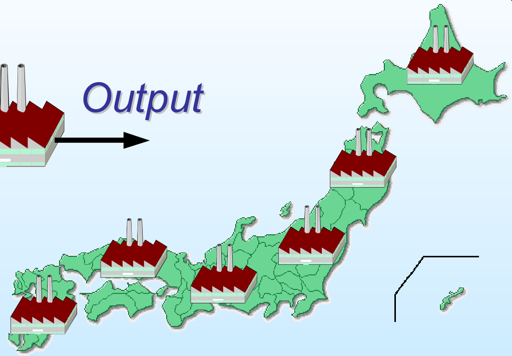
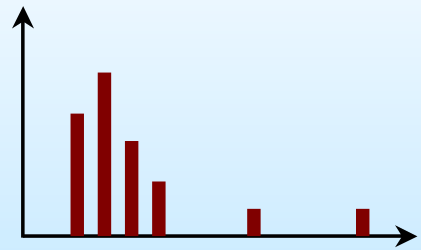
Introduction

Inventory analysis with industry 







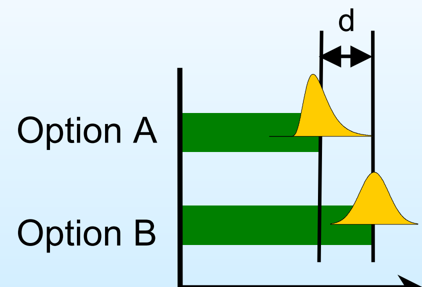
Source of uncertainty in LCI phase

...

Differences in emission between factories which produce same product

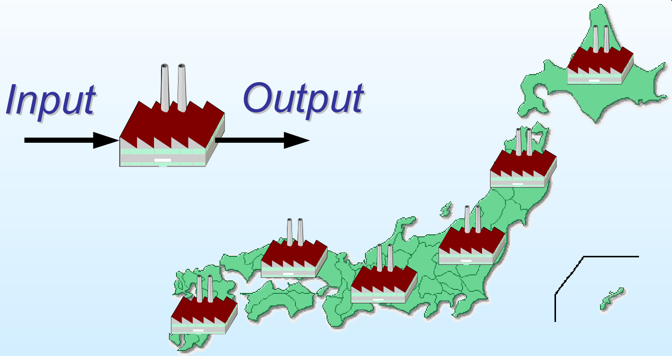
Huijbregts, Int. J. LCA (1998)

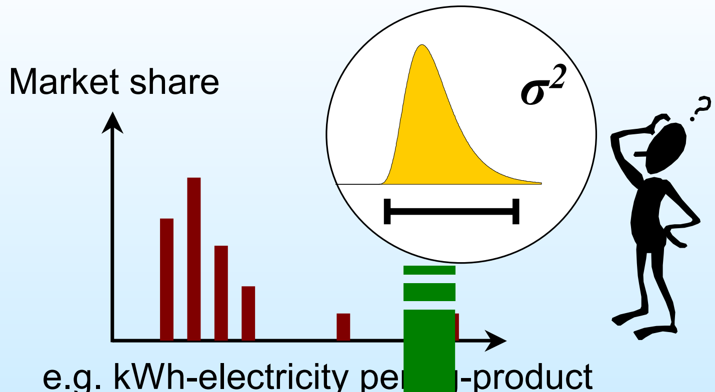
More informed decision making



Introduction

Inventory analysis with industry  „Please don‘t publish individual data“





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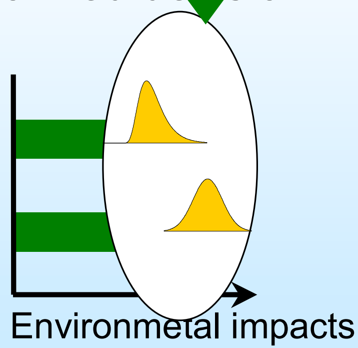
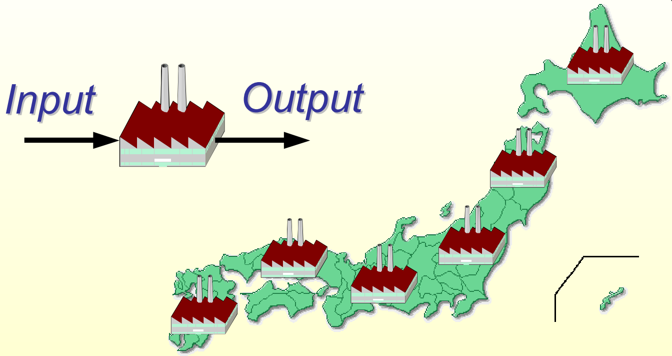
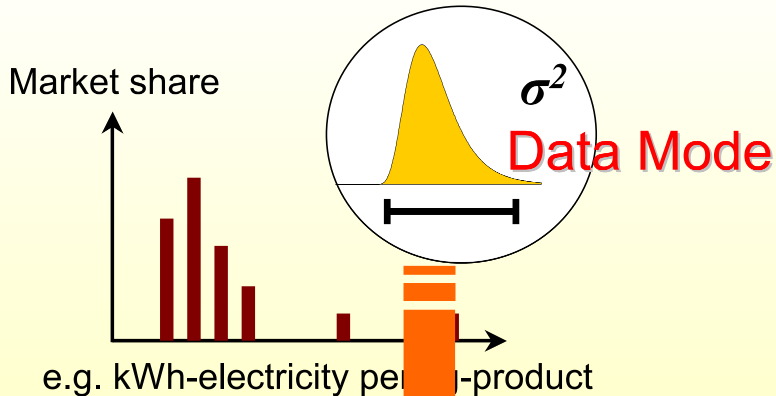


Objectives

Inventory analysis with industry  „Please don‘t publish individual data“





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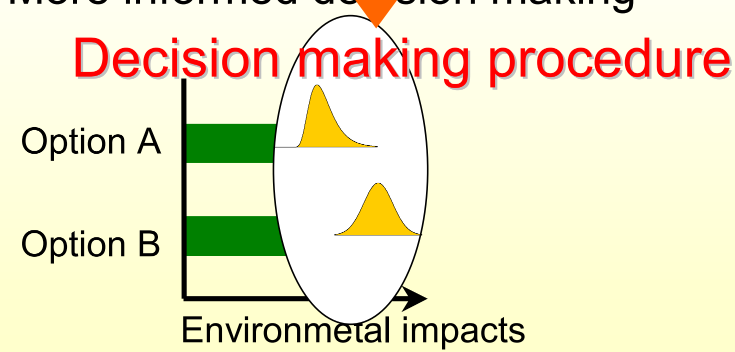
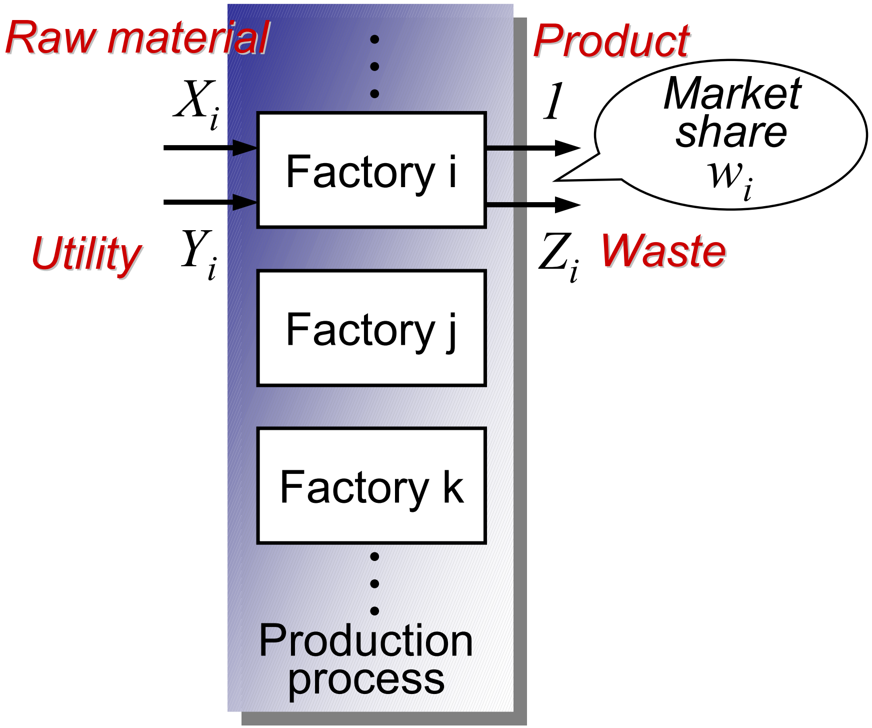
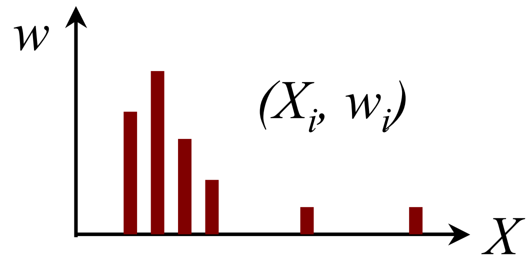


Inventory data model: conventional



Difference in Input/Output per unit amount of production



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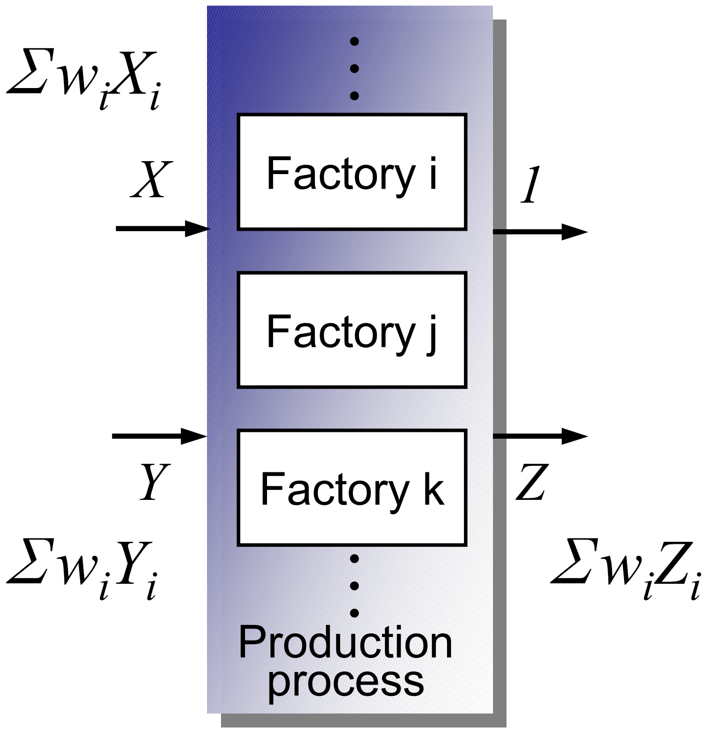

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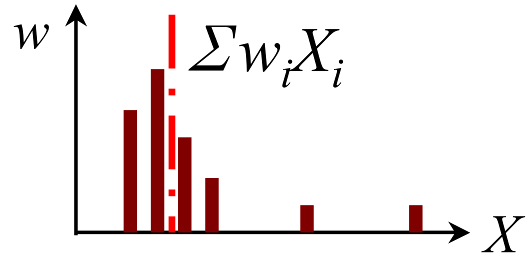
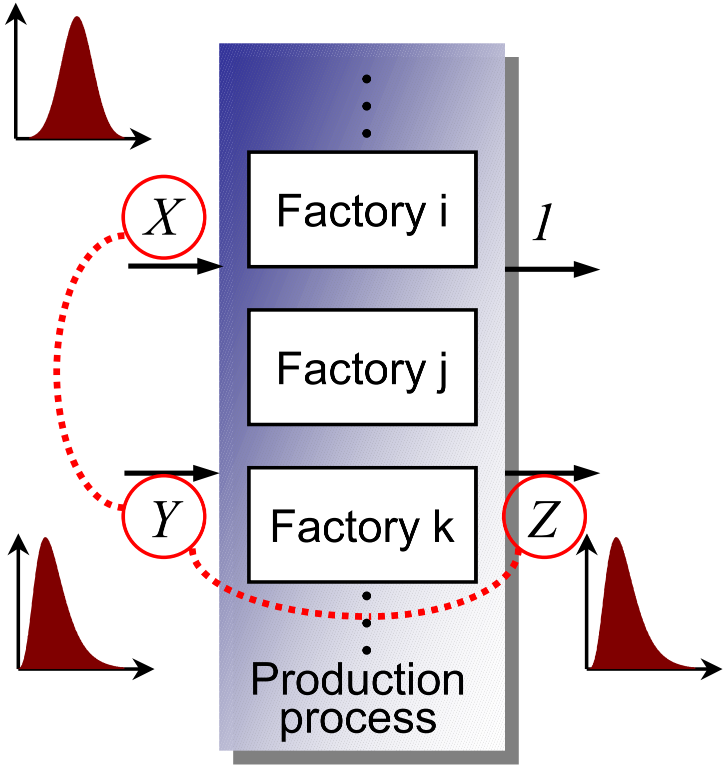


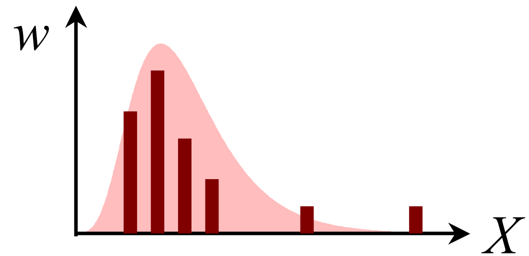
Weighted average

- Information of scattering are lost
- LCA result is obtained as deterministic value

Inventory data model: proposed



Difference in Input/Output per unit amount of production



Fitted probability distribution

- Scattering can be preserved
- Individual datapoints are masked

1) Probability distribution

2) Correlation coefficient

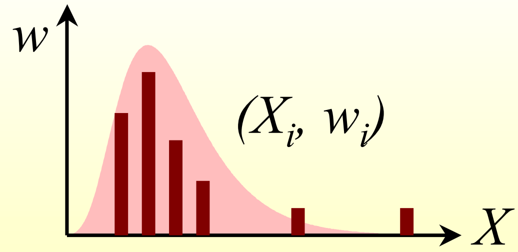
LCA result is obtained as ***probability distribution*** by ***Monte Carlo simulation***.

1) Distribution fitting

Original data from industry (X_i, w_i) ➡ Fit distribution for X

X_i raw material/product in factory i (*i=1~n*)

w_i marketing share of factory i (*i=1~n*)



Property of original data, Goodness-of-Fit statistics

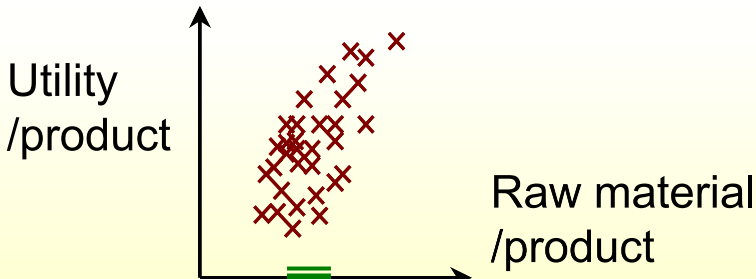
X = *Distribution (parameter)* ➡ *Lognormal (mean, standard dev.)*

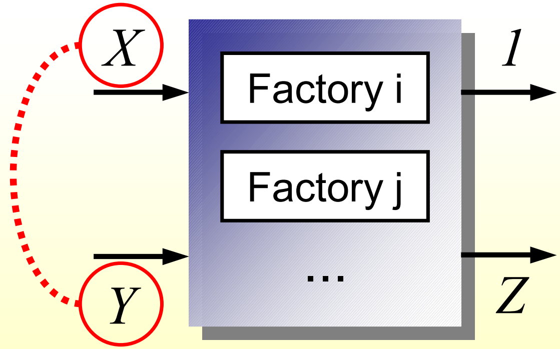
Maximum Likelihood Estimators α which maximize

Likelihood function $L(\alpha) = \prod_{i=1}^{n} \left(f(X_i, \alpha) \right)^{Nw_i}$

α is given by $\frac{\delta L(\alpha)}{\delta \alpha} = 0$

2) Correlation modeling

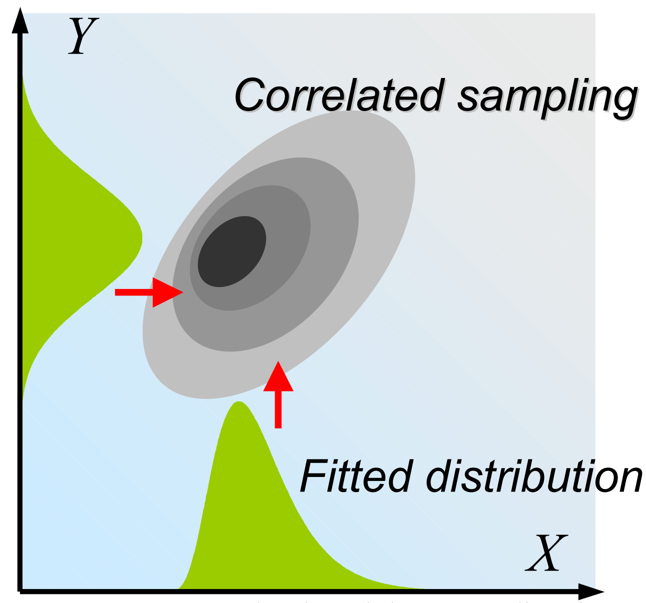




Rank order correlation coefficient

$$r_{X-Y} = \frac{\sum_{i=1}^{n}\left(rank(X_i) - \frac{n+1}{2}\right)\left(rank(Y_i) - \frac{n+1}{2}\right)}{\frac{n(n+1)(n-1)}{2}}$$

- Calculating correlation of rank order between parameters
- Suitable for correlated sampling in Monte Carlo simulation rather than regression coefficient



Decision making procedure

Collect data from industry

Input/Output data

Market share

Model inventory data

1) Probability distribution

2) Correlation coefficient

LCA by Monte Carlo simulation

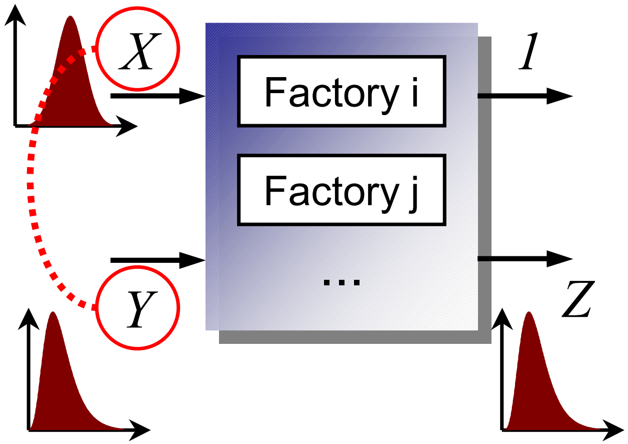
Result as probability distribution

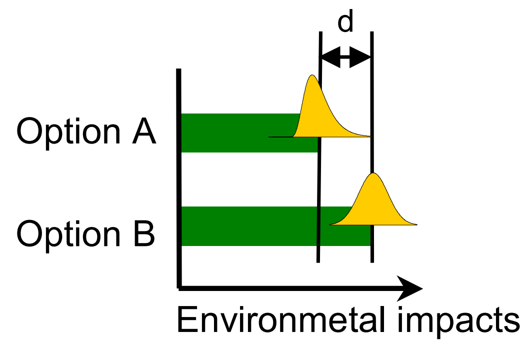
Compare distributions

Sensitivity analysis

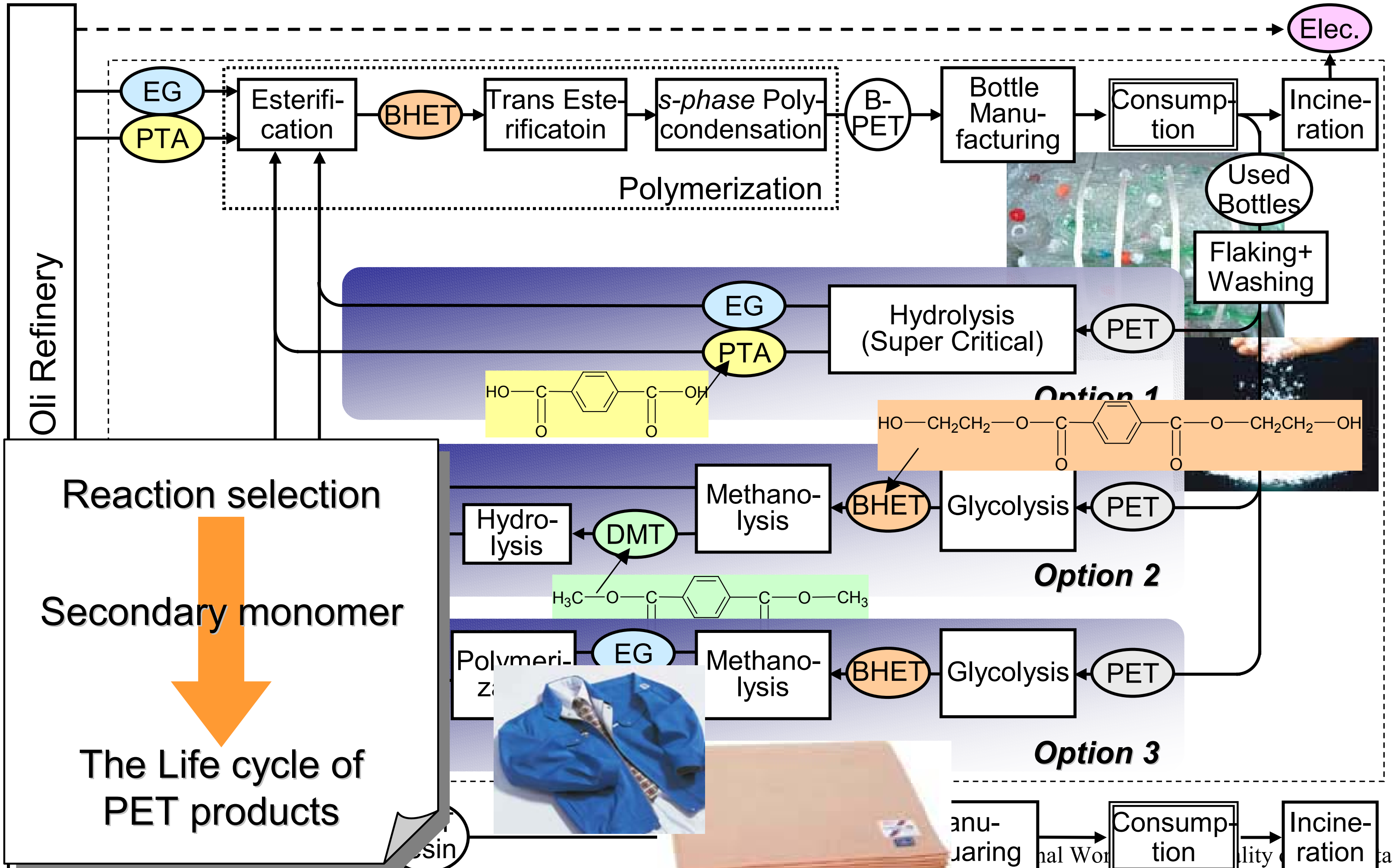
Prioritizing data to be refined

Decision considering uncertainty



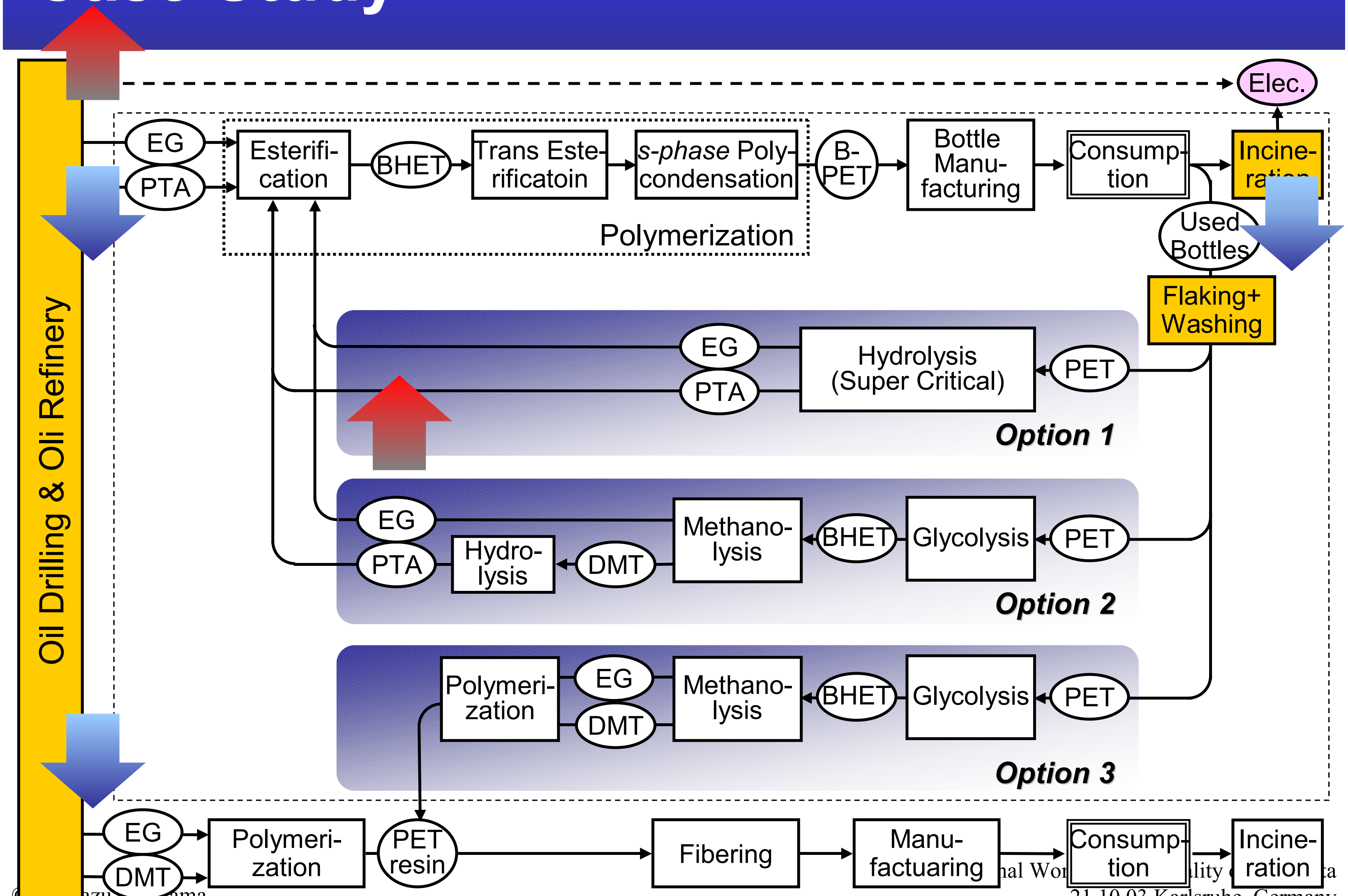


Case Study



Oli Refinery
Elec.
EG
PTA
Esterifi-cation
BHET
Trans Este-rificatoin
s-phase Poly-condensation
Polymerization
B-PET
Bottle Manu-facturing
Consump-tion
Incine-ration
Used Bottles
Flaking+ Washing
EG
PTA
Hydrolysis (Super Critical)
PET
Option 1
HO—C—C—OH
Methano-lysis
BHET
Glycolysis
PET
Hydro-lysis
DMT
Option 2
H3C—O—C—C—O—CH3
HO—CH2CH2—O—C—C—O—CH2CH2—OH
EG
Methano-lysis
BHET
Glycolysis
PET
Option 3
Consump-tion
Incine-ration
Reaction selection
Secondary monomer
The Life cycle of PET products

Case Study



Oil Drilling & Oli Refinery
Elec.
EG
PTA
Esterifi-cation
BHET
Trans Este-rificatoin
s-phase Poly-condensation
Polymerization
B-PET
Bottle Manu-facturing
Consump-tion
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Hydrolysis (Super Critical)
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Option 1
EG
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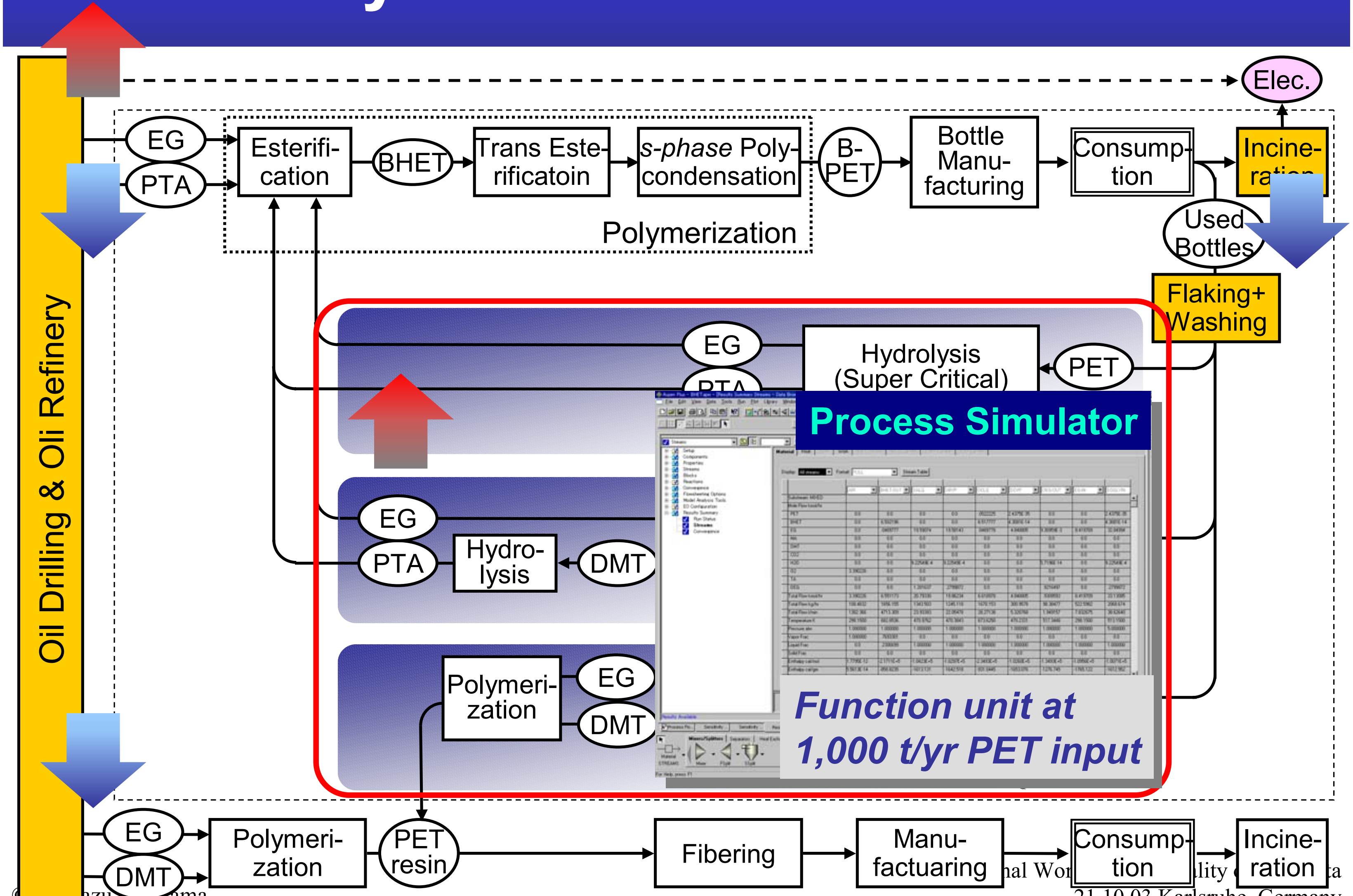
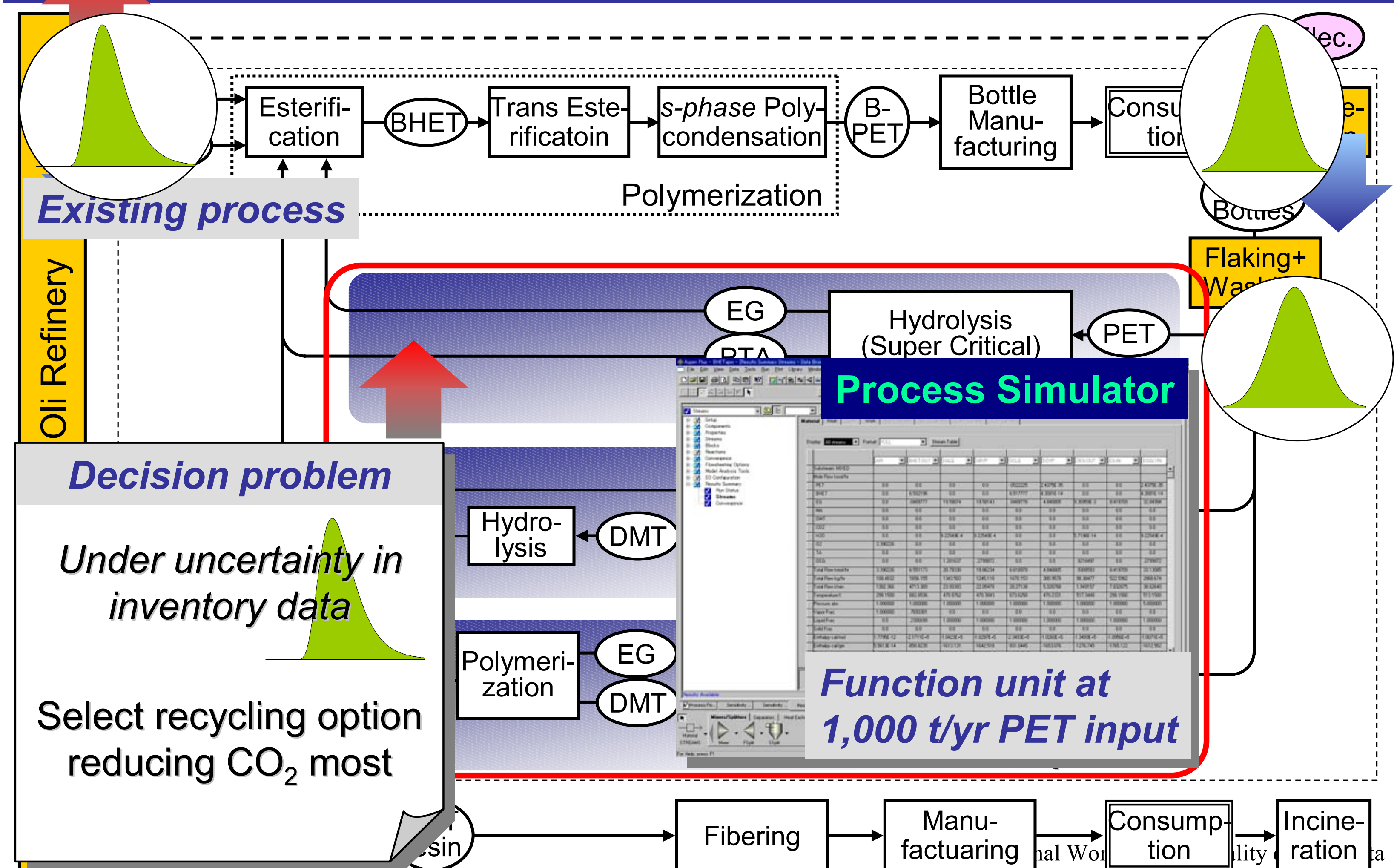
DMT
Methano-lysis
BHET
Glycolysis
PET
Option 2
Polymeri-zation
EG
DMT
Methano-lysis
BHET
Glycolysis
PET
Option 3
EG
DMT
Polymeri-zation
PET resin
Fibering
Manu-factuaring
Consump-tion
Incine-ration

Case Study



Oil Drilling & Oli Refinery
Elec.
EG
PTA
Esterifi-cation
BHET
Trans Este-rificatoin
s-phase Poly-condensation
Polymerization
B-PET
Bottle Manu-facturing
Consump-tion
Incine-ration
Used Bottles
Flaking+ Washing
EG
PTA
Hydrolysis (Super Critical)
PET
Process Simulator
EG
PTA
Hydro-lysis
DMT
Polymeri-zation
EG
DMT
Function unit at 1,000 t/yr PET input
EG
DMT
Polymeri-zation
PET resin
Fibering
Manu-factuaring
Consump-tion
Incine-ration

Case Study



Existing process
Esterifi-cation
BHET
Trans Este-rificatoin
s-phase Poly-condensation
B-PET
Bottle Manu-facturing
Polymerization
Bottles
Flaking+
Oli Refinery
EG
Hydrolysis (Super Critical)
PET
Process Simulator
Decision problem
Under uncertainty in inventory data
Select recycling option reducing CO_2 most
Hydro-lysis
DMT
Polymeri-zation
EG
DMT
Function unit at 1,000 t/yr PET input
Fibering
Manu-factuaring
Consump-tion
Incine-ration

Objectives in case study

Collect data from industry

Input/Output data

Market share

Assumed data

Model inventory data

1) Probability distribution

2) Correlation coefficient

Show the importance to collect & model uncertainty information

LCA by Monte Carlo simulation

Demonstrate the procedure

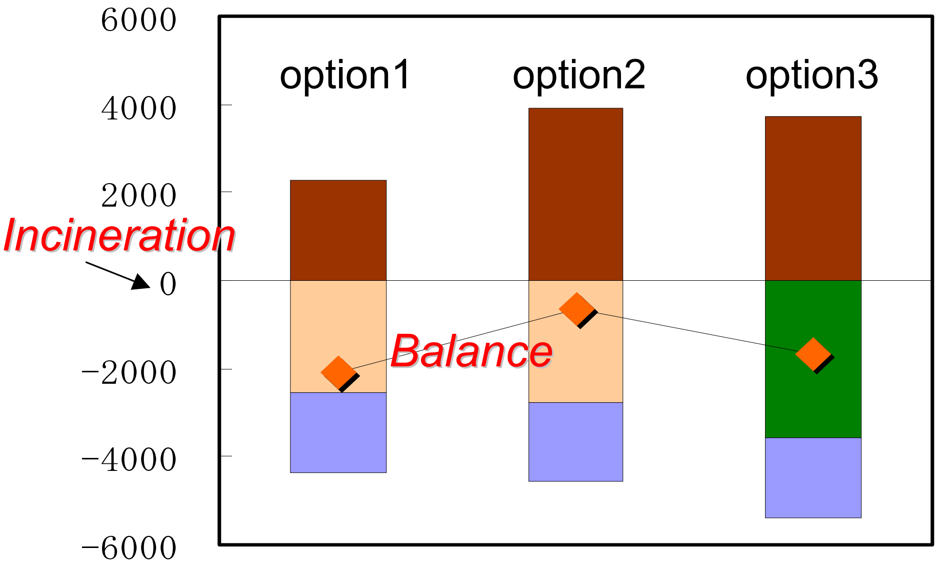
Compare distributions

Sensitivity analysis

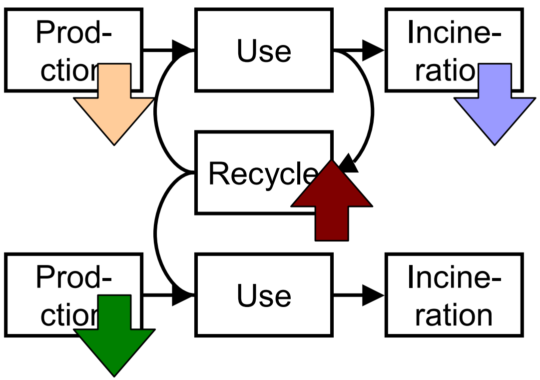
Decision considering uncertainty

LCA result: deterministic values

Changes of CO_2 emissions
after installation of plant [t-CO_2]



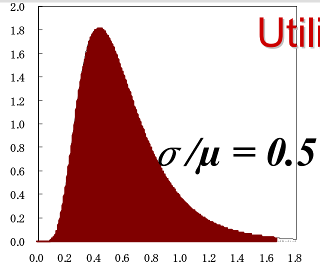
$\Delta CO_2 =$
Option 1~3 - Incineration



➡ Option1 (PET → PTA → PET bottle by super critical water) seems the best option

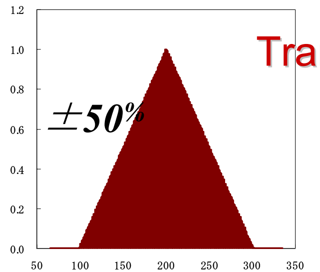
LCA result: considering uncertainty

Inventory as probability distribution ⇒ $\Delta CO_2 = Option1\sim3(\boldsymbol{p}_{Opt.i}) - Incineration(\boldsymbol{p}_{Inc.})$



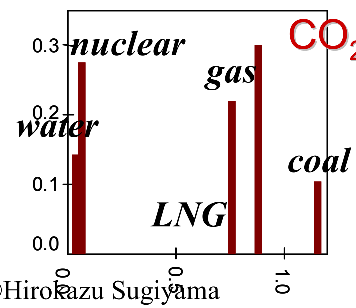
Utility

kg-steam/kg-PET resin



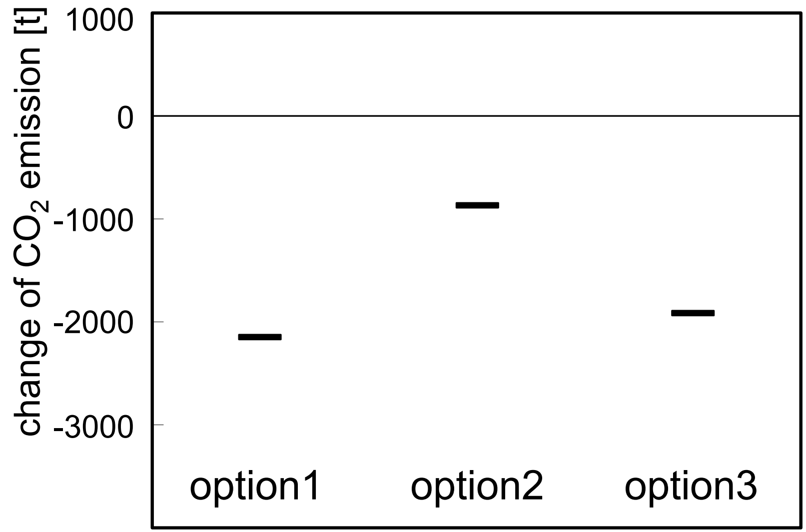
Transportation

km/kg-beverage



CO_2 emission factor

$kgCO_2/kWh$



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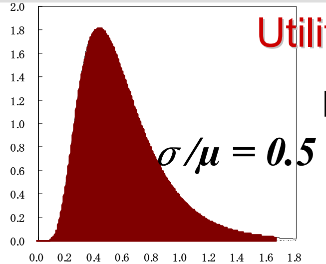
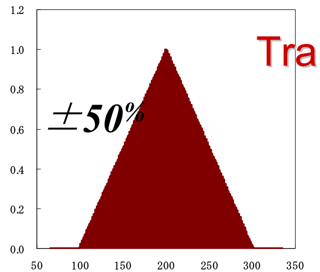


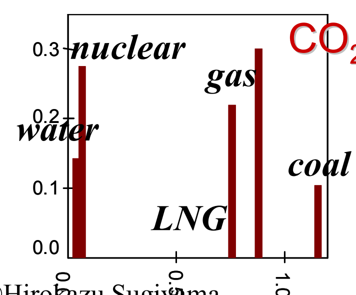
Utility

kg-steam/kg-PET resin



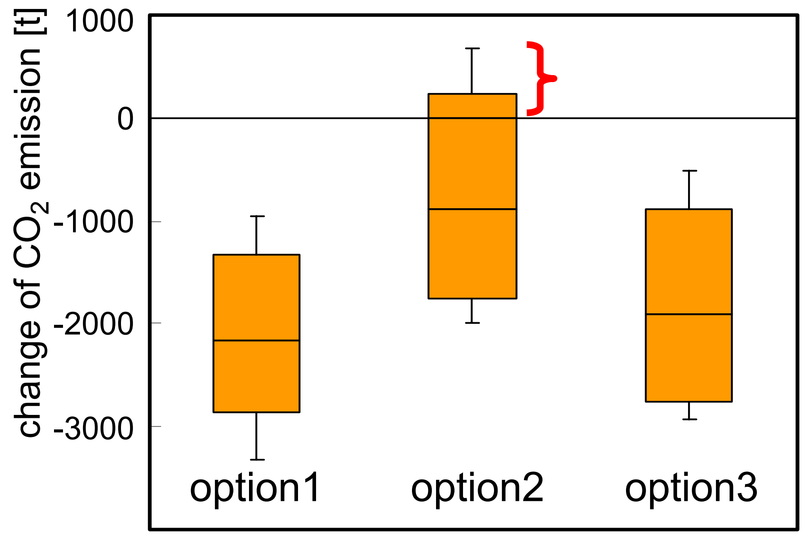
Transportation

km/kg-beverage



CO_2 emission factor

$kgCO_2/kWh$



- Option1,3 result in the reduction of CO_2 by 99% confidence
- Option 2 does not necessarily lead to overall reduction

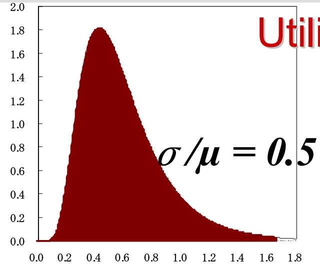
Comparison: relative measurements

Inventory as probability distribution

$\Delta CO_2 = Option2,3(\mathbf{p}_{Opt.2,3}) - Option\ 1(\mathbf{p}_{Opt.1})$

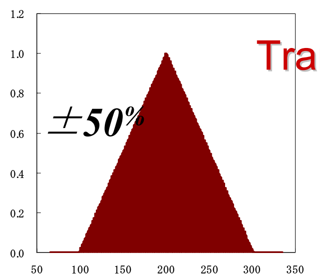
Utility

kg-steam/kg-PET resin



Transportation

km/kg-beverage



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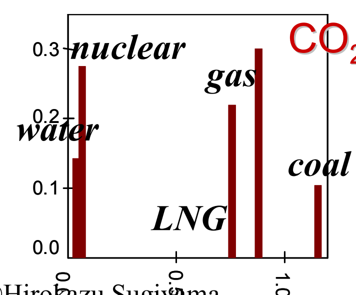
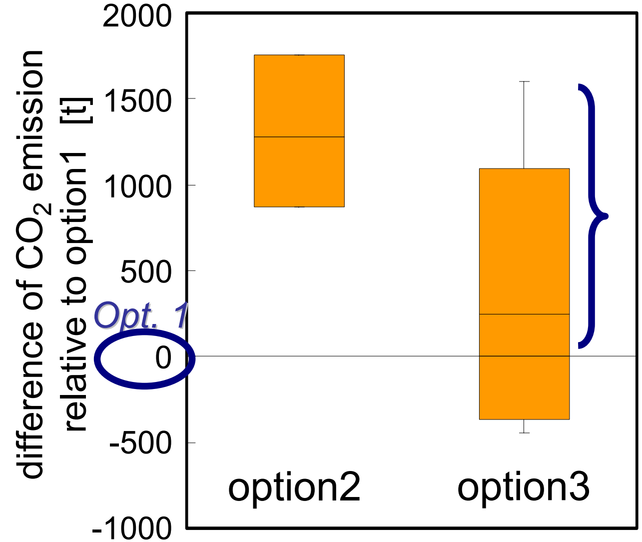




Integration over 0 = confidence that Option 1 superior to Option3 : 62%

Sensitivity analysis

Sensitivity analysis: regression model

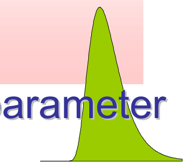
LCA Model

$\Delta CO_2 = Option2,3(\mathbf{p}_{Opt.2,3}) - Option\ 1(\mathbf{p}_{Opt.1})$ →

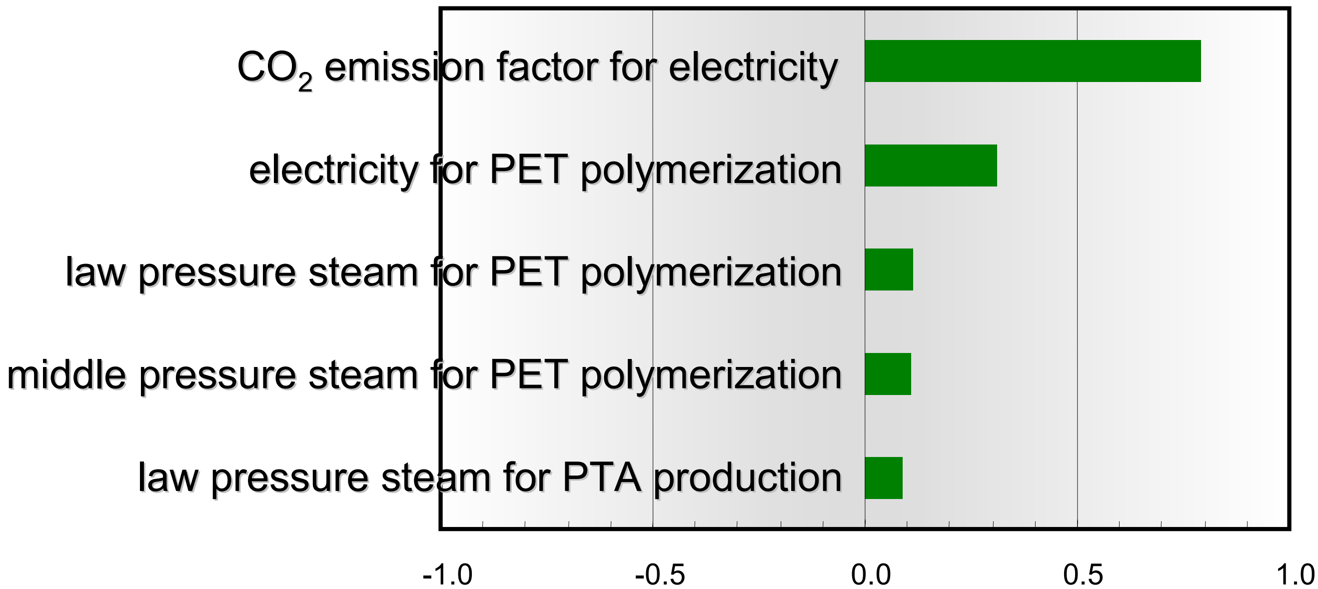
Regression model

$$\sum_k a_k x_k + b$$

Inventory parameter



Standardized partial regression coefficient



➡ Priority for the further data collection

Conclusions

- *Data Model*
  - Probability distribution for incorporation of uncertainty and for masking individual data
  - Rank order correlation coefficient for correlated sampling in Monte Carlo simulation

- *Decision Making Procedure*
  - LCA result in probablity distribution
  - Relative measurement + Sensitivity analyisis
  - Case study ⇐ *Assumption needed*

Even obtainig the mean value is still difficult.

Conclusions

- *To help industry open more data for LCA practitioner...*
  - Clarification of data development procedure as data model is effective.
  - Even if assumed data is used, case studies illustrating the effectivencess of uncertainty evaluation are important.

Acknowledgement

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