A protocol for approaching process data uncertainties in Life Cycle Inventory Analysis

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Patrik Henriksson & Jeroen Guinée
Institute of Environmental Sciences (CML), Dept. Industrial Ecology

Universiteit Leiden
The Netherlands

Contents:

LCI data sourcing

- Most LCAs today present point values as results

42

- LCA practitioners (we all!!) do a lot of data picking without knowing its accuracy

- For our studies we continuously use “averages” without really knowing that we do … and/or how they have been developed

LCA uncertainty analysis developing fast

- Most attention up till now to propagation methods:
  - Monte-Carlo analysis
  - analytical error propagation
  - fuzzy logic
  - …
- Producing uncertainty estimates requires:
  - input parameters
  - propagation method
  - definitions

LCI uncertainty analysis largely disregarded

- Particularly input parameters for each Unit Process Data (UPD) point
  - basically ecoinvent pedigree approach (“post-normal” uncertainties)

Numeral Unit Spread Assessment Pedigree (NUSAP)

- **Indicator score:** 1 to 5 → σ_g 1.0-2.0
- **Characteristic**
  - Reliability
  - Completeness
  - Temporal correlation
  - Geographical correlation
  - Further technological correlation
  - Sample size

E.g. Geographical correlation indicator score: 3

Data from smaller area than area under study, or from similar area

What about the "normal" uncertainties?

Data on related processes or materials but on laboratory scale of different technology	- emission factor B(a)P for diesel train based on lorry motor data Examples for related processes or materials: - data for tyles instead of bricks production - data of refinery infrastructure for chemical plants infrastructure
unknown	sample size behind a figure reported in the information source

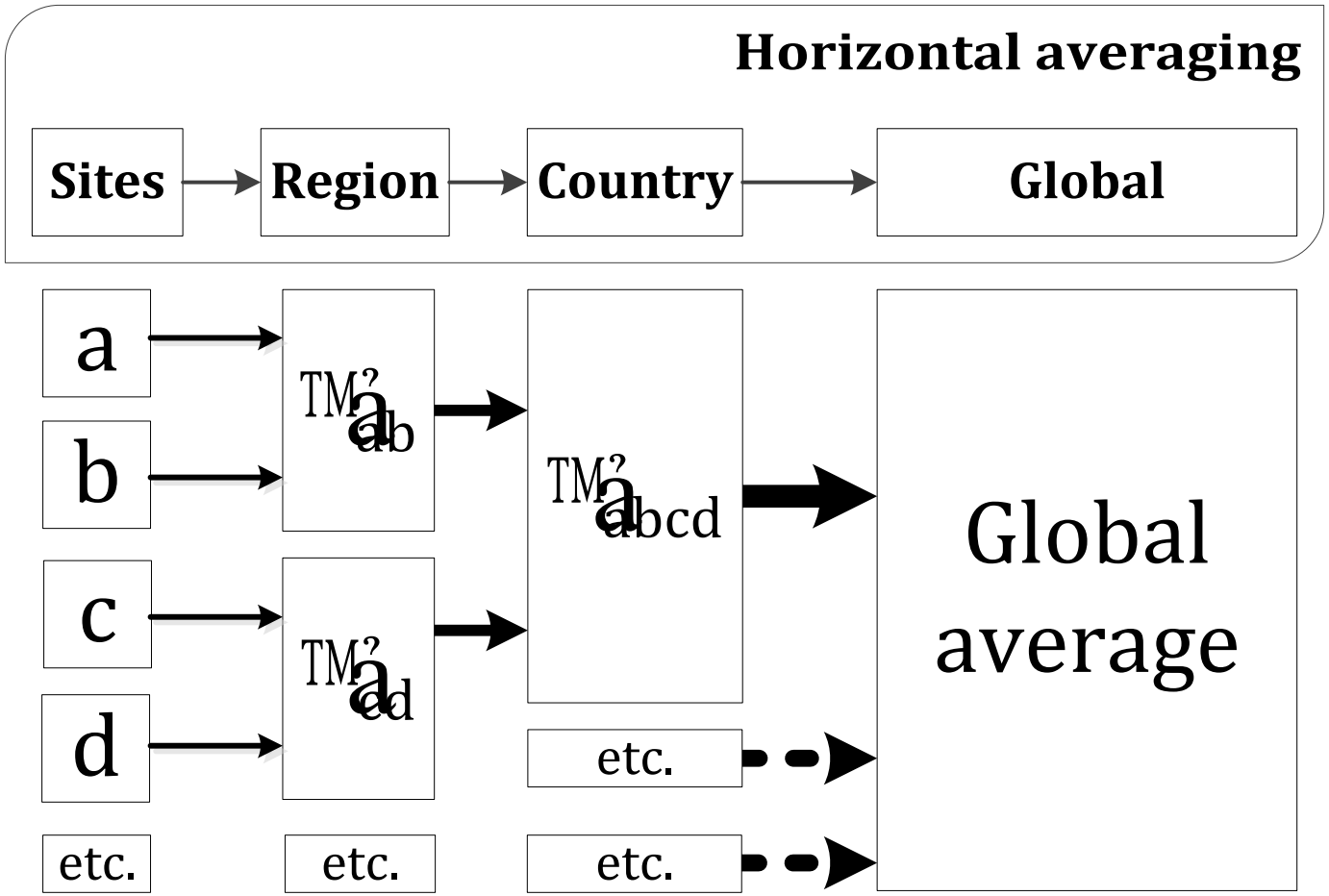
Weidema&Wesnæs 1996

Frischknecht et al. 2007

Purpose of this work

- To propose a method for horizontal averaging of data where dispersion from both inherent uncertainty, spread and unrepresentativeness are incorporated in the input parameters
  - not LCIA data
  - not methodological choices

Definitions



cf. UNEP-SETAC 'Shonan Guidance Principles'

Definitions

Dispersion	Any form of range around a variable, resulting from inherent uncertainty, spread or unrepresentativeness
Inherent uncertainty	Uncertainties related to the inaccuracies of measurements or model at no level of horizontal averaging
Spread	Variability around an average resulting from horizontal averaging
Unrepresentativeness	Uncertainty resulting from the level of representativeness

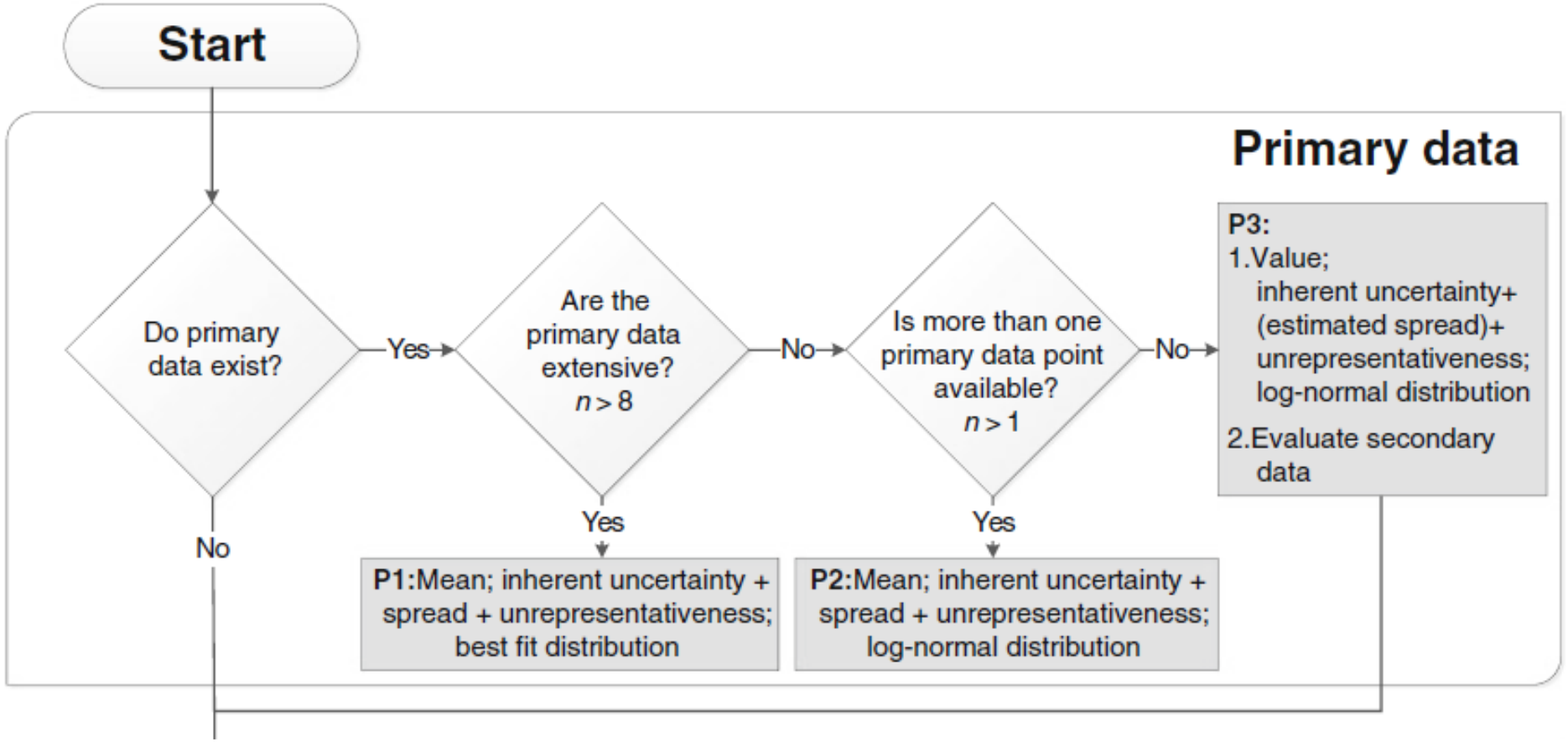
Proposed method

- Dispersion is the sum of:
  - Inherent uncertainty
  - Spread due to **horizontal averaging** } Normal (NUS)
  - Unrepresentativeness } Post-normal (AP)

- Combining the three into one quantitative measure of dispersion for each UPD point

- Propagation into LCI results

Decision tree



EXAMPLE SOYBEANS: PRACTICAL APPLICATION OF PROPOSED METHOD

Inherent uncertainty:

e.g. *secondary data* on Brazilian soybeans

TABLE 11.1
DEFAULT EMISSION FACTORS TO ESTIMATE DIRECT N_2O EMISSIONS FROM MANAGED SOILS

Emission factor	Default value	Uncertainty range
EF_1 for N additions from mineral fertilisers, organic amendments and crop residues, and N mineralised from mineral soil as a result of loss of soil carbon [kg N_2O–N (kg N)$^{-1}$]	0.01	0.003 - 0.03
EF_{1FR} for flooded rice fields [kg N_2O–N (kg N)$^{-1}$]	0.003	0.000 - 0.006
$EF_{2\ CG,\ Temp}$ for temperate organic crop and grassland soils (kg N_2O–N ha^{-1})	8	2 - 24
$EF_{2\ CG,\ Trop}$ for tropical organic crop and grassland soils (kg N_2O–N ha^{-1})	16	5 - 48
$EF_{2F,\ Temp,\ Org,\ R}$ for temperate and boreal organic nutrient rich forest soils (kg N_2O–N ha^{-1})	0.6	0.16 - 2.4
$EF_{2F,\ Temp,\ Org,\ P}$ for temperate and boreal organic nutrient poor forest soils (kg N_2O–N ha^{-1})	0.1	0.02 - 0.3
$EF_{2F,\ Trop}$ for tropical organic forest soils (kg N_2O–N ha^{-1})	8	0 - 24

From: IPCC 2006 - N_2O Emissions from managed soils

Spread due to horizontal averaging:
e.g. *secondary data* on Brazilian soybeans

Average: **Cederberg 1998** and **FNP 2000** quotated in Ostermayer 2002

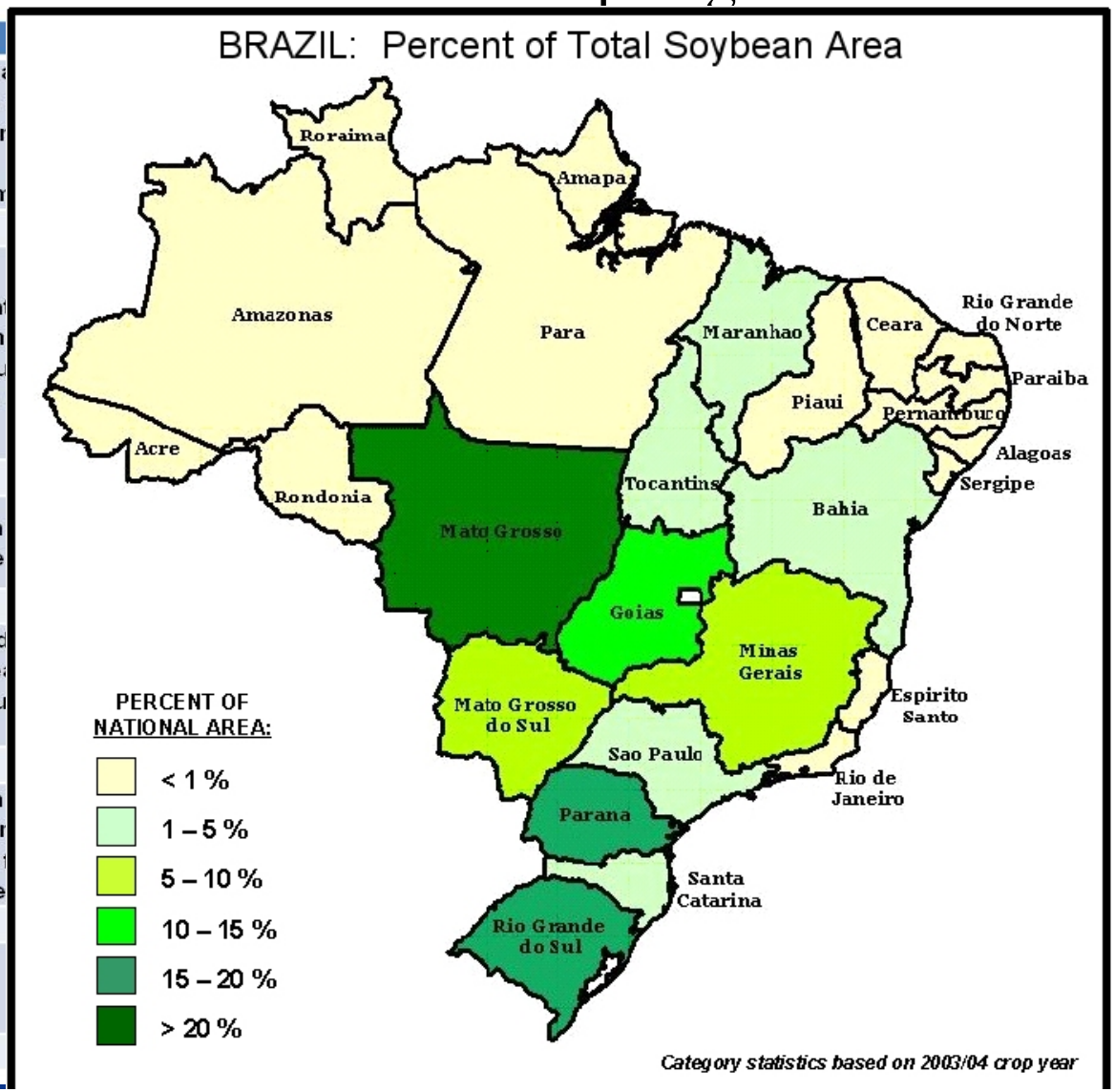
		ecoinvent 2.2 (2007!)	Cederberg 1998	FAO 2002 & 2012	Cederberg& Flysjö 2004	Cavalett & Ortega 2010	Castanheira et al. 2013
		Database	Report	FAO	Report	Article	Article
Economical inputs							
Diesel	kg	55.25	51.00	-	55.25	55.25	42.8
Nitrogen (kg N)	kg	3.1	0.00	3.7	8.0	0.00	0,00
Phosphorus (kg P)	kg	26.2	17.5	28.8	31.0	33.8	26.2
Potassium (kg K)	kg	24.9	33.2	51.5	57.0	65.4	49.8
Economic outputs							
Soybeans, kg	kg	2544	2200	2867	2500	2830	2940

Unrepresentativeness

e.g. *secondary data* on Brazilian soybeans

- Each data point is scored to the ecoinvent v2.2 pedigree

Indicator score	1	2
Reliability	Verified data based on measurements	Verified da based on or non-ver based on measuren
	1.00	1.05
Completeness	Representative data from a sufficient sample of sites over an adequate period to even out normal fluctuations	Represent from a sm of sites bu adequate
	1.00	1.02
Temporal correlation	Less than 3 years of difference to year of study	Less than difference
	1.00	1.03
Geographical correlation	Data from area under study	Average d larger are the area u included
	1.00	1.01
Further technological correlation	Data from enterprises, processes and materials under study	Data from and mater study but enterprise
	1.00	-
Sample size	>100, continuous measurement, balance of purchased products	> 20
	1.00	1.02



Combining the three

	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	*Online resource: Henriksson et al. (2013) Int J LCA*			Reference:	*Halberg et al. 2012*		*Perez 2009*		*IPCC modelled*		*Basset-Mens et al. (GAP scenario) 2007*		*Imbeah 1998*	
2					Value 1		Value 2		Value 3		Value 4		Value 5	
3	White cells need input		Unit process flow		Value	Uncertainty	Value	Uncertainty	Value	Uncertainty	Value	Uncertainty	Value	Uncertainty
4			Uncertainty factors	Unit	Indicator score	factor	Indicator score	factor	Indicator score	factor	Indicator score	factor	Indicator score	factor
5			**Economic inputs**											
6	**Weighted mean, $x_{a(wt)}$:**	**2,82E+03**	***Feed***	**kg**	**3,10E+03**	0,0051476	**2,87E+03**	2,855E-05			**2,70E+03**	0,0044094		
7	$x_{a=}$	2,89E+03	**Inherent uncertainty as σ_g^i:**		**1,05**		**1,05**		**1,05**		**1,05**		**1,05**	
8	$x_{g=}$	2,89E+03	Reliability:		*2. Verified data partly*	1,05	*2. Verified data partly*	1,05	*1. Verified data based*	1,00	*3. Non-verified data p*	1,10	*1. Verified data based*	1,00
9	Inherent uncertainty σ_g^i:	1,050	Completeness:		*4. Representative dat*	1,10	*3. Representative dat*	1,05	*1. Representative dat*	1,00	*4. Representative dat*	1,10	*1. Representative dat*	1,00
10	Inherent uncertainty CV^i:	0,052	Temporal correlation:		*1. Less than 3 years o*	1,00	*3. Less than 10 years*	1,10	*1. Less than 3 years o*	1,00	*2. Less than 6 years o*	1,03	*1. Less than 3 years o*	1,00
11	Representativeness CV^i:	0,078	Geographic correlation:		*3. Data from smaller*	1,02	*3. Data from smaller*	1,02	*1. Data from area un*	1,00	*3. Data from smaller*	1,02	*1. Data from area un*	1,00
12	Spread σ_g^s	1,072	Further techonological correlation:		*3. Data on related pr*	1,20	*1. Data from enterpri*	1,00	*1. Data from enterpri*	1,00	*1. Data from enterpri*	1,00	*1. Data from enterpri*	1,00
13	Spread, CV^i	0,06946318	(Sample size):		*5. Unknown*	1,20	*5. Unknown*	1,20	*1. n = >100, continous*	1,00	*3. n = > 10, aggregate*	1,05	*1. n = >100, continous*	1,00
14	**Overall uncertainty Phi**	**0,116**	**Representativeness factor as σ_g^r:**		**1,150**		**1,115**		**1,000**		**1,077**		**1,000**	
15	**Overall uncertainty SD95**	**1,119**		$w_{i=}$	182,11	564528,86	280,70	805611,13			510,59	1378591,64		
194			**Economic outputs**											
195	**Weighted mean, $x_{a(wt)}$:**	**1,00E+03**	***Pigs, 85-100 kg each***	**kg**	**1,00E+03**	0	**1,00E+03**	0			**1,00E+03**	0	**1,00E+03**	0
196	$x_{a=}$	1,00E+03	**Inherent uncertainty as σ_g^i:**		**1,05**		**1,05**		**1,05**		**1,05**		**1,05**	
197	$x_{g=}$	1,00E+03	Reliability:		*2. Verified data partly*	1,05	*2. Verified data partly*	1,05	*1. Verified data based*	1,00	*3. Non-verified data p*	1,10	*1. Verified data based*	1,00
198	Inherent uncertainty σ_g^i:	1,050	Completeness:		*4. Representative dat*	1,10	*3. Representative dat*	1,05	*1. Representative dat*	1,00	*4. Representative dat*	1,10	*1. Representative dat*	1,00
199	Inherent uncertainty CV^i:	0,041	Temporal correlation:		*1. Less than 3 years o*	1,00	*3. Less than 10 years*	1,10	*1. Less than 3 years o*	1,00	*2. Less than 6 years o*	1,03	*1. Less than 3 years o*	1,00
200	Representativeness CV^i:	0,078	Geographic correlation:		*3. Data from smaller*	1,02	*3. Data from smaller*	1,02	*1. Data from area un*	1,00	*3. Data from smaller*	1,02	*1. Data from area un*	1,00
201	Spread σ_g^s	1,000	Further techonological correlation:		*3. Data on related pr*	1,20	*1. Data from enterpri*	1,00	*1. Data from enterpri*	1,00	*1. Data from enterpri*	1,00	*1. Data from enterpri*	1,00
202	Spread, CV^i	0,000	(Sample size):		*5. Unknown*	1,20	*5. Unknown*	1,20	*1. n = >100, continous*	1,00	*3. n = > 10, aggregate*	1,05	*1. n = >100, continous*	1,00
203	**Overall uncertainty sigma**	**8,80E+01**	**Representativeness factor as σ_g^r:**		**1,150**		**1,115**		**1,000**		**1,077**		**1,000**	
204	**Overall uncertainty SD95**	**1,093**		$w_{i=}$	182,11	182106,08	280,70	280700,74			510,59	510589,50	1680,33	1680333,29
206	**Weighted mean, $x_{a(wt)}$:**	**3,89E+03**	***Solid manure***	**kg**							**4,00E+03**	0,0027752	**3,60E+03**	0,0027752
207	$x_{a=}$	3,80E+03	**Inherent uncertainty as σ_g^i:**		**1,05**		**1,05**		**1,05**		**1,05**		**1,05**	
208	$x_{g=}$	3,79E+03	Reliability:		*1. Verified data based*	1,00	*1. Verified data based*	1,00	*1. Verified data based*	1,00	*3. Non-verified data p*	1,10	*1. Verified data based*	1,00
209	Inherent uncertainty σ_g^i:	1,050	Completeness:		*1. Representative dat*	1,00	*1. Representative dat*	1,00	*1. Representative dat*	1,00	*4. Representative dat*	1,10	*4. Representative dat*	1,10
210	Inherent uncertainty CV^i:	0,052	Temporal correlation:		*1. Less than 3 years o*	1,00	*1. Less than 3 years o*	1,00	*1. Less than 3 years o*	1,00	*2. Less than 6 years o*	1,03	*4. Less than 15 years*	1,20
211	Representativeness CV^i:	0,078	Geographic correlation:		*1. Data from area un*	1,00	*1. Data from area un*	1,00	*1. Data from area un*	1,00	*3. Data from smaller*	1,02	*3. Data from smaller*	1,02
212	Spread σ_g^s	1,077	Further techonological correlation:		*1. Data from enterpri*	1,00	*1. Data from enterpri*	1,00	*1. Data from enterpri*	1,00	*1. Data from enterpri*	1,00	*1. Data from enterpri*	1,00
213	Spread, CV^i	0,074	(Sample size):		*1. n = >100, continous*	1,00	*1. n = >100, continous*	1,00	*1. n = >100, continous*	1,00	*3. n = > 10, aggregate*	1,05	*5. Unknown*	1,20
214	**Overall uncertainty Phi**	**0,119**	**Representativeness factor as σ_g^r:**		**1,000**		**1,000**		**1,000**		**1,077**		**1,148**	
215	**Overall uncertainty SD95**	**1,123**		$w_{i=}$							510,59	2042357,98	187,18	673838,72

Henriksson et al. 2013. A protocol for horizontal averaging of unit process data – including estimates for uncertainty. *Int J Life Cycle Assess (FirstOnLine). DOI 10.1007/s11367-013-0647-4*

Weighted factor – weighted means

- $x_{wt} = \sum_{i=1}^{n} w_i x_i / \sum_{i=1}^{n} w_i$

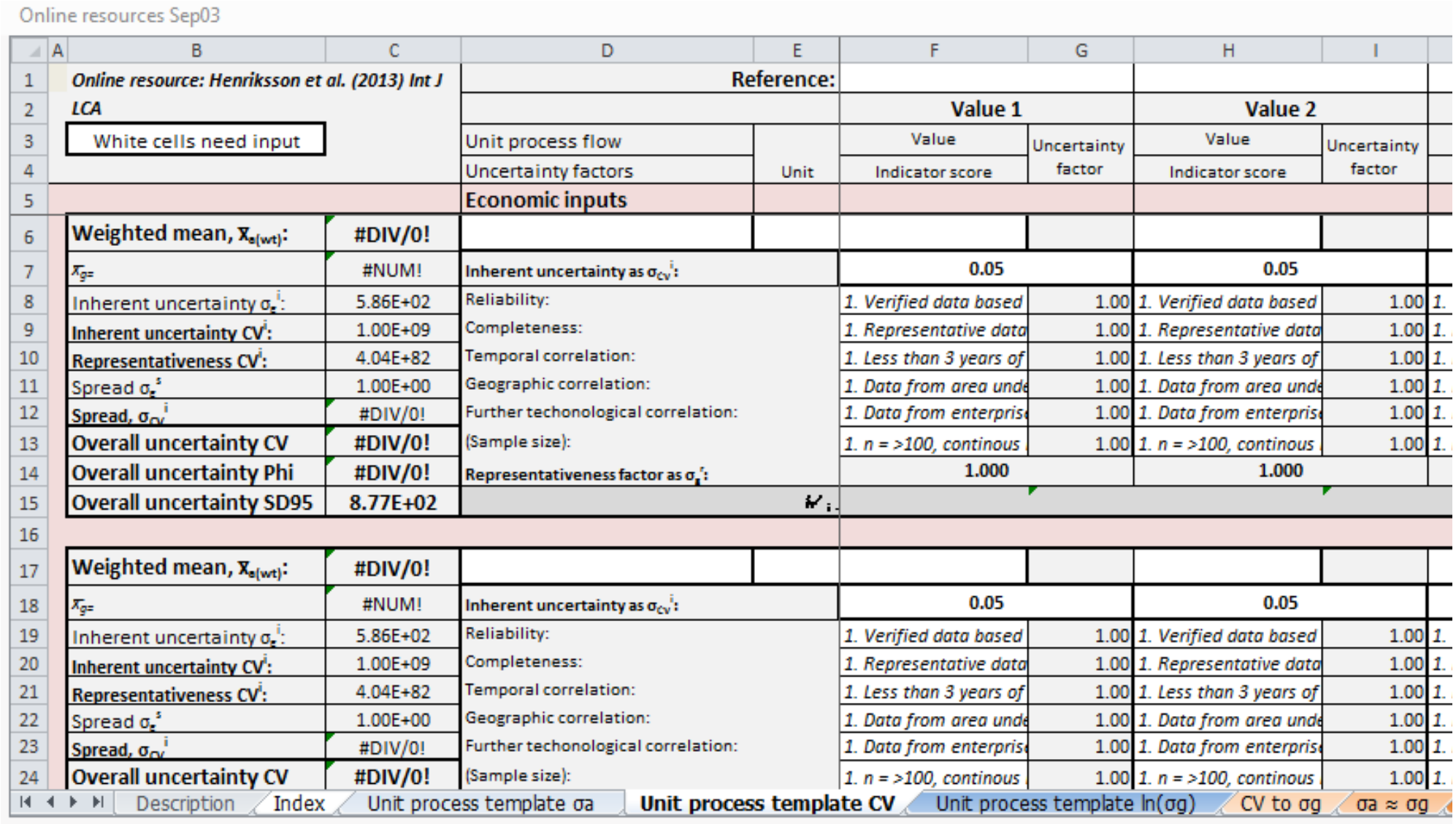
- $w_i = 1/\sigma_i^2$ **arithmetic standard deviation**

- $w_i = 1/CV_i^2$ coefficient of variation

- $w_i = 1/(\ln \sigma_i)^2$ geometric standard deviation

Spreadsheet – Online resources

http://cml.leiden.edu/software/software-quanlci.html



Online resources Sep03

	A	B	C	D	E	F	G	H	I
1		*Online resource: Henriksson et al. (2013) Int J*		Reference:					
2		*LCA*				Value 1		Value 2	
3		White cells need input		Unit process flow		Value	Uncertainty factor	Value	Uncertainty factor
4				Uncertainty factors	Unit	Indicator score		Indicator score	
5				Economic inputs					
6		Weighted mean, $\bar{x}_{s(wt)}$:	#DIV/0!						
7		$\bar{x}_{g=}$	#NUM!	Inherent uncertainty as σ_{CV}^{i}:		0.05		0.05	
8		Inherent uncertainty σ_s^i:	5.86E+02	Reliability:		*1. Verified data based*	1.00	*1. Verified data based*	1.00
9		Inherent uncertainty CV^i:	1.00E+09	Completeness:		*1. Representative data*	1.00	*1. Representative data*	1.00
10		Representativeness CV^i:	4.04E+82	Temporal correlation:		*1. Less than 3 years of*	1.00	*1. Less than 3 years of*	1.00
11		Spread σ_s^s	1.00E+00	Geographic correlation:		*1. Data from area unde*	1.00	*1. Data from area unde*	1.00
12		Spread, σ_{CV}^{i}	#DIV/0!	Further techonological correlation:		*1. Data from enterprise*	1.00	*1. Data from enterprise*	1.00
13		Overall uncertainty CV	#DIV/0!	(Sample size):		*1. n = >100, continous*	1.00	*1. n = >100, continous*	1.00
14		Overall uncertainty Phi	#DIV/0!	Representativeness factor as σ_s^r:		1.000		1.000	
15		Overall uncertainty SD95	8.77E+02						
16									
17		Weighted mean, $\bar{x}_{s(wt)}$:	#DIV/0!						
18		$\bar{x}_{g=}$	#NUM!	Inherent uncertainty as σ_{CV}^{i}:		0.05		0.05	
19		Inherent uncertainty σ_s^i:	5.86E+02	Reliability:		*1. Verified data based*	1.00	*1. Verified data based*	1.00
20		Inherent uncertainty CV^i:	1.00E+09	Completeness:		*1. Representative data*	1.00	*1. Representative data*	1.00
21		Representativeness CV^i:	4.04E+82	Temporal correlation:		*1. Less than 3 years of*	1.00	*1. Less than 3 years of*	1.00
22		Spread σ_s^s	1.00E+00	Geographic correlation:		*1. Data from area unde*	1.00	*1. Data from area unde*	1.00
23		Spread, σ_{CV}^{i}	#DIV/0!	Further techonological correlation:		*1. Data from enterprise*	1.00	*1. Data from enterprise*	1.00
24		Overall uncertainty CV	#DIV/0!	(Sample size):		*1. n = >100, continous*	1.00	*1. n = >100, continous*	1.00

Description | Index | Unit process template σa | **Unit process template CV** | Unit process template ln(σg) | CV to σg | σa ≈ σg

Spreadsheet – Online resources

http://cml.leiden.edu/software/software-quanlci.html

Online resource: Henriksson et al. (2013) Int J LCA		Reference:		*Ostermayer 2002*		*Cederberg 1998*		*Castanheira et al. 2013*	
White cells need input				Value 1		Value 2		Value 3	
		Unit process flow	Unit	Value	Uncertainty factor	Value	Uncertainty factor	Value	Uncertainty factor
		Uncertainty factors		Indicator score		Indicator score		Indicator score	
		Economic inputs							
Weighted mean, $\bar{x}_{s(wt)}$:	#DIV/0!	*Diesel*	kg						
$x_{g=}$	#NUM!	Inherent uncertainty as σ_{CV}^{i}:		0.05		0.05		0.05	
Inherent uncertainty σ_s^i:	5.86E+02	Reliability:		*1. Verified data based*	1.00	*1. Verified data based*	1.00	*1. Verified data based*	1.00
Inherent uncertainty CV^i:	1.00E+09	Completeness:		*1. Representative data*	1.00	*1. Representative data*	1.00	*1. Representative data*	1.00
Representativeness CV^i:	4.04E+82	Temporal correlation:		*1. Less than 3 years of*	1.00	*1. Less than 3 years of*	1.00	*1. Less than 3 years of*	1.00
Spread σ_s^s	1.00E+00	Geographic correlation:		*1. Data from area unde*	1.00	*1. Data from area unde*	1.00	*1. Data from area unde*	1.00
Spread, σ_{CV}^i	#DIV/0!	Further techonological correlation:		*1. Data from enterprise*	1.00	*1. Data from enterprise*	1.00	*1. Data from enterprise*	1.00
Overall uncertainty CV	#DIV/0!	(Sample size):		*1. n = >100, continous*	1.00	*1. n = >100, continous*	1.00	*1. n = >100, continous*	1.00
Overall uncertainty Phi	#DIV/0!	Representativeness factor as $\sigma_{g'}$		1.000		1.000		1.000	
Overall uncertainty SD95	8.77E+02		w_i						

- Inventory flow
- Unit
- Reference

Spreadsheet – Online resources

http://cml.leiden.edu/software/software-quanlci.html

Online resource: Henriksson et al. (2013) Int J LCA		Reference:		*Ostermayer 2002*		*Cederberg 1998*		*Castanheira et al. 2013*	
White cells need input				Value 1		Value 2		Value 3	
		Unit process flow	Unit	Value	Uncertainty factor	Value	Uncertainty factor	Value	Uncertainty factor
		Uncertainty factors		Indicator score		Indicator score		Indicator score	
		Economic inputs							
Weighted mean, $\bar{x}_{s(wt)}$:	**4.97E+01**	*Diesel*	kg	5.53E+01	0.0126324	5.10E+01	0.0009889	4.28E+01	0.0206902
$\bar{x}_{g=}$	4.94E+01	**Inherent uncertainty as σ_{CV}^{i}:**		0.05		0.05		0.05	
Inherent uncertainty σ_{s}^{i}:	1.05E+00	Reliability:		*1. Verified data ba*	1.00	*1. Verified data based*	1.00	*1. Verified data based*	1.00
Inherent uncertainty CV^{i}:	5.00E-02	Completeness:		*1. Representative da*	1.00	*1. Representative data*	1.00	*1. Representative data*	1.00
Representativeness CV^{i}:	4.04E+82	Temporal correlation:		*1. Less than 3 years of*	1.00	*1. Less than 3 years of*	1.00	*1. Less than 3 years of*	1.00
Spread σ_{s}^{s}	1.14E+00	Geographic correlation:		*1. Data from area unde*	1.00	*1. Data from area unde*	1.00	*1. Data from area unde*	1.00
Spread, σ_{CV}^{i}	1.28E-01	Further techonological correlatio		*1. Data from enterpris*	1.00	*1. Data from enterpris*	1.00	*1. Data from enterpris*	1.00
Overall uncertainty CV	**4.04E+82**	(Sample size):		*1. n = >100, continous*	1.00	*1. n = >100, continous*	1.00	*1. n = >100, continous*	1.00
Overall uncertainty Phi	**1.95E+01**	**Representativeness factor α_{i}^{i}:**		1.000		1.000		1.000	
Overall uncertainty SD95	**1.00E+01**		w_i	400.00	22120.0	400.00	20400.00	400.00	17120.00

- Central value (arithmetic mean)
- Inherent uncertainty (coefficient of variation)

Spreadsheet – Online resources

http://cml.leiden.edu/software/software-quanlci.html

Online resource: Henriksson et al. (2013) Int J LCA		Reference:		*Ostermayer 2002*		*Cederberg 1998*		*Castanheira et al. 2013*	
White cells need input				Value 1		Value 2		Value 3	
		Unit process flow	Unit	Value	Uncertainty factor	Value	Uncertainty factor	Value	Uncertainty factor
		Uncertainty factors		Indicator score		Indicator score		Indicator score	
		Economic inputs							
Weighted mean, $\bar{x}_{s(wt)}$:	**4.57E+01**	*Diesel*	kg	**5.53E+01**	0.0126324	**5.10E+01**	0.0009889	**4.28E+01**	0.0206902
$\bar{x}_{g=}$	4.94E+01	**Inherent uncertainty as σ_{CV}^{i}:**		**0.05**		**0.05**		**0.05**	
Inherent uncertainty σ_s^i:	1.05E+00	Reliability:		*2. Verified data partly*	1.05	*3. Non-verified data pa*	1.10	*2. Verified data partly*	1.05
Inherent uncertainty CV^i:	5.00E-02	Completeness:		*3. Representative data*	1.05	*3. Representative data*	1.05	*3. Representative data*	1.05
Representativeness CV^i:	3.98E-02	Temporal correlation:		*3. Less than 10 years o*	1.10	*4. Less than 15 years o*	1.20	*1. Less than 3 years of*	1.00
Spread σ_s^s	1.14E+00	Geographic correlation:		*5. Data from unknown*	1.10	*5. Data from unknown*	1.10	*3. Data from smaller a*	1.02
Spread, σ_{CV}^i	1.28E-01	Further techonological correlation:		*3. Data on related proc*	1.20	*3. Data on related proc*	1.20	*1. Data from enterpris*	1.00
Overall uncertainty CV	1.43E-01	(Sample size):		*3. n = > 10, aggregated*	1.05	*3. n = > 10, aggregated*	1.05	*2. n = >20*	1.02
Overall uncertainty Phi	**1.42E-01**	**Representativeness factor as σ_s^r:**		**1.129**		**1.161**			
Overall uncertainty SD95	**1.16E+00**			53.89	2980.24	37.16			10483.55

1. n = >100, continous measurer
2. n = >20
3. n = > 10, aggregated figure in
4. n = >3
5. Unknown

- Representativeness (dropdown menu)
- Weighted mean, (based upon inherent uncertainty + representativeness)
- Spread (calculated amongst values)

Spreadsheet – Online resources

http://cml.leiden.edu/software/software-quanlci.html

- Weighted mean
- Inherent uncertainty
- Representativeness
- Spread
- Overall dispersion
  - Phi = CMLCA
  - SD95 = Simapro

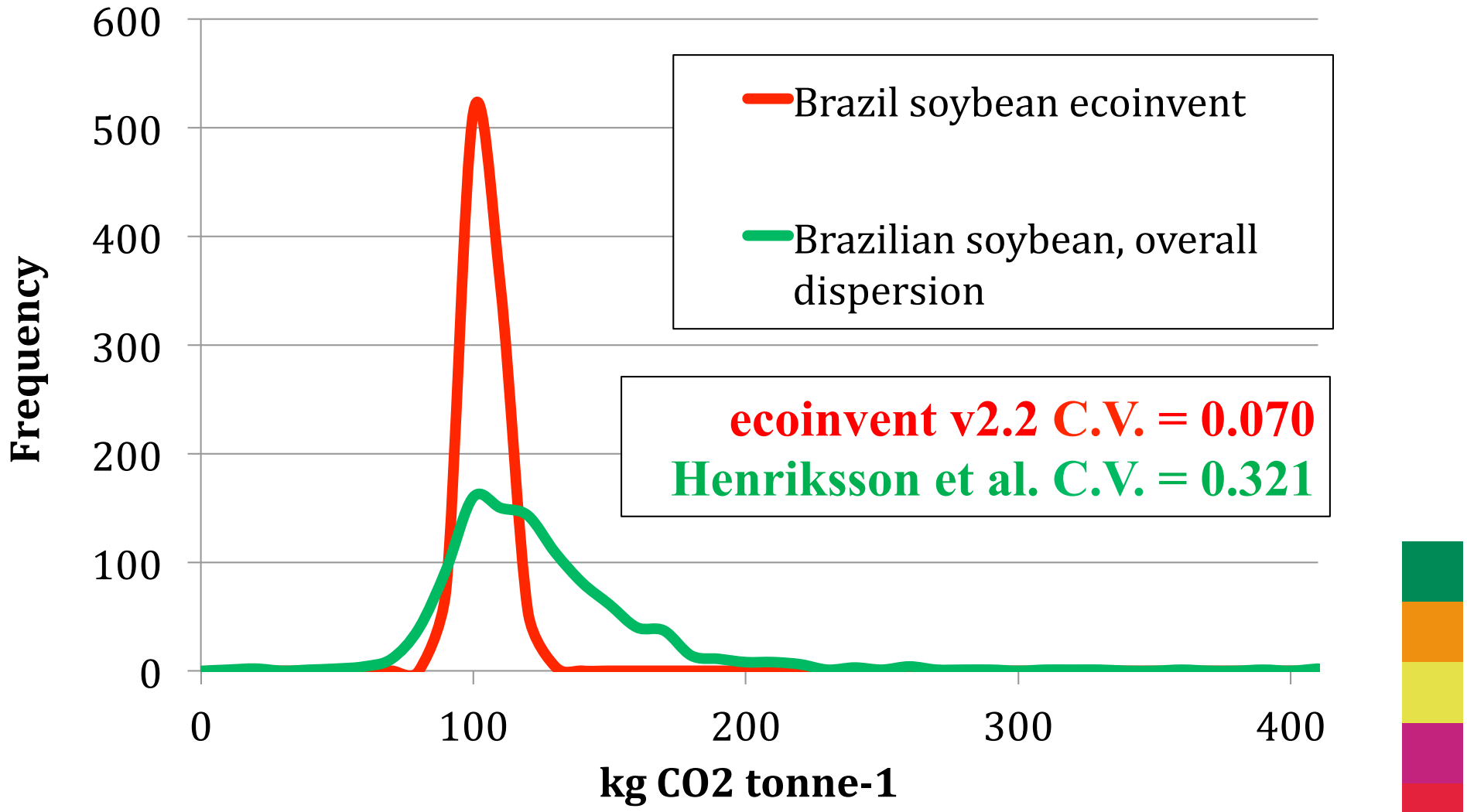
Online resource: Henriksson et al. (2013) Int J LCA

White cells need input

Weighted mean, $\bar{x}_{a(wt)}$:	**4.57E+01**
$\bar{x}_{g=}$	4.94E+01
Inherent uncertainty σ_g^i:	1.05E+00
Inherent uncertainty CV^i:	5.00E-02
Representativeness CV^i:	3.98E-02
Spread σ_g^s	1.14E+00
Spread, σ_{CV}^i	1.28E-01
Overall dispersion CV	**1.43E-01**
Overall dispersion Phi	**1.42E-01**
Overall dispersion SD95	**1.16E+00**

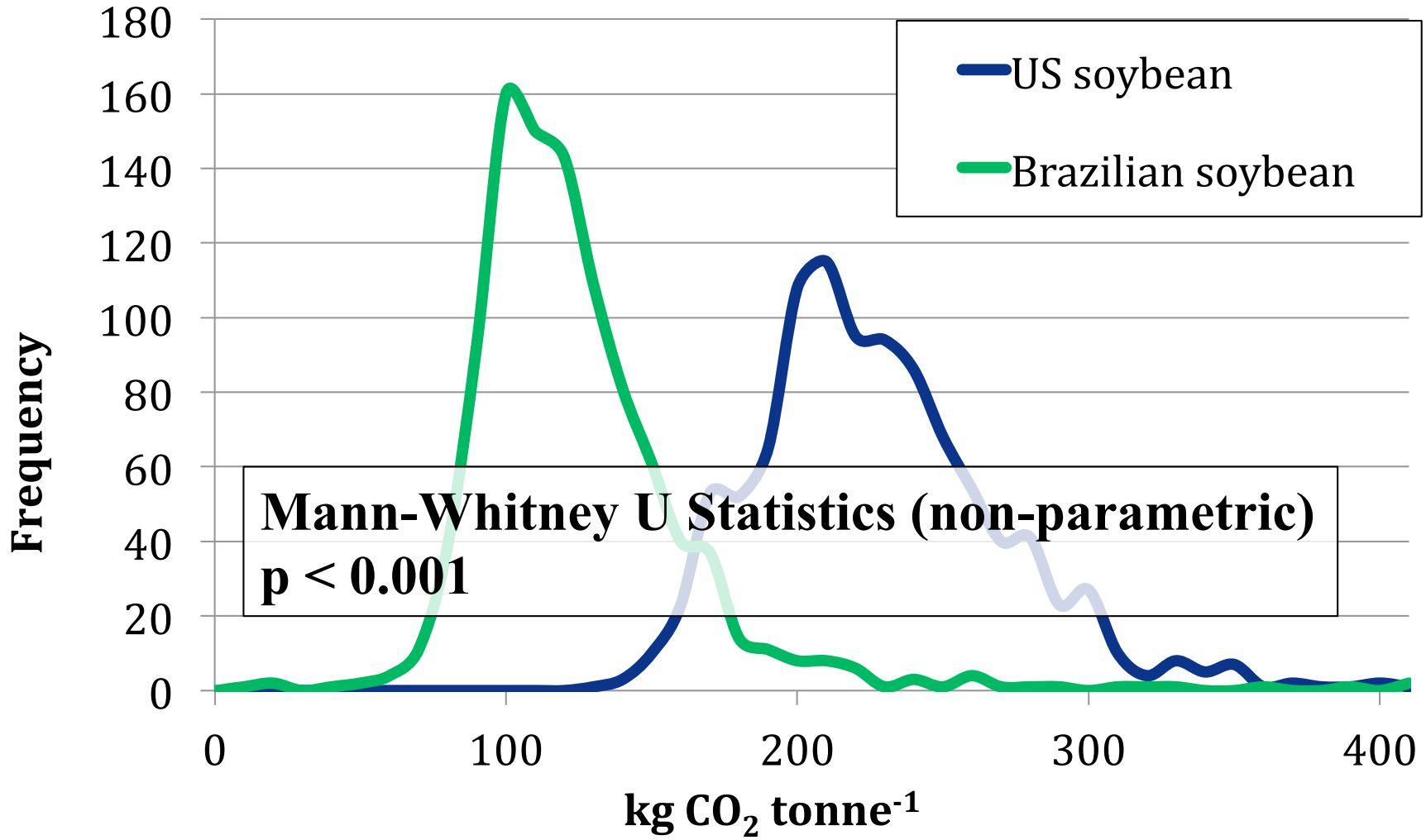
Propagation into LCI results - Histograms

(= further work under construction)



Propagation into LCI results - Histograms

(= further work under construction)



Discussion

- Quantitative use of NUSAP is beyond original intent
- Averages or values behind the averages?
- Spread and inherent uncertainty often out-weight representativeness
- Absolute or comparative uncertainty

Conclusions

- Method is practical but intensive
- Better reporting of raw data
  - including inherent uncertainties, spread in background data & distributions instead of averaged point values
- Propagation and analysis – work in progress…

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http://www.seatglobal.eu

Henriksson, Guinée, Heijungs, de Koning & Green (2013) A protocol for horizontal averaging of unit process data — including estimates for uncertainty. Int J of LCA. DOI 10.1007/s11367-013-0647-4

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