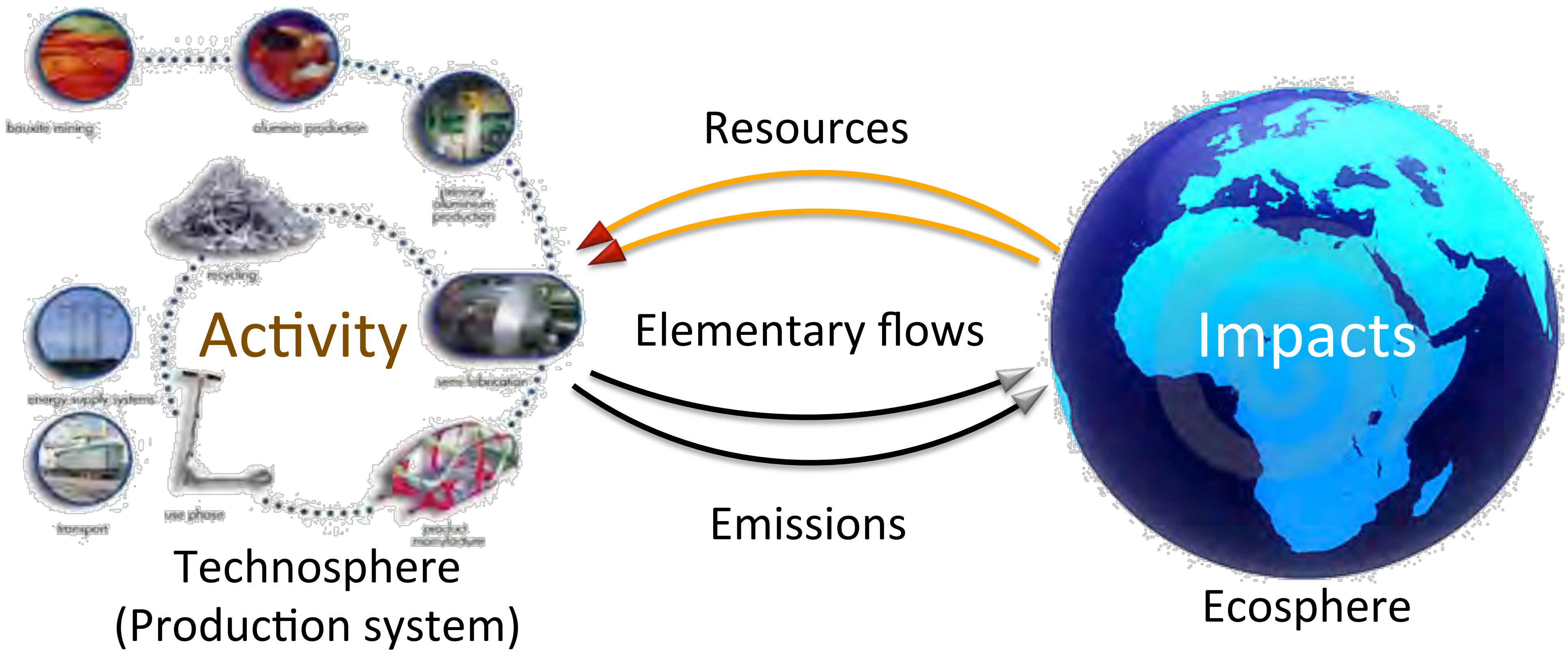
Environmental sustainability assessment of urban systems applying coupled urban metabolism and life cycle assessment

Illustration of quantification of the (absolute) sustainability of urban systems

Morten Birkved
Associate professor
DTU Management Engineering

Benjamin Goldstein
DTU Management Engineering

Life Cycle Assessment (LCA)



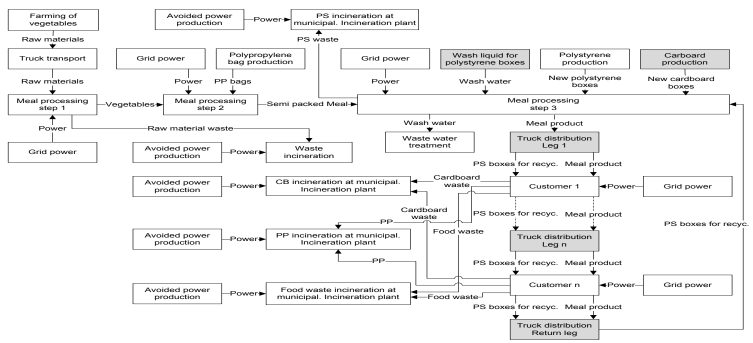
Life Cycle Assessment (LCA)

Inventory of environmental exchanges

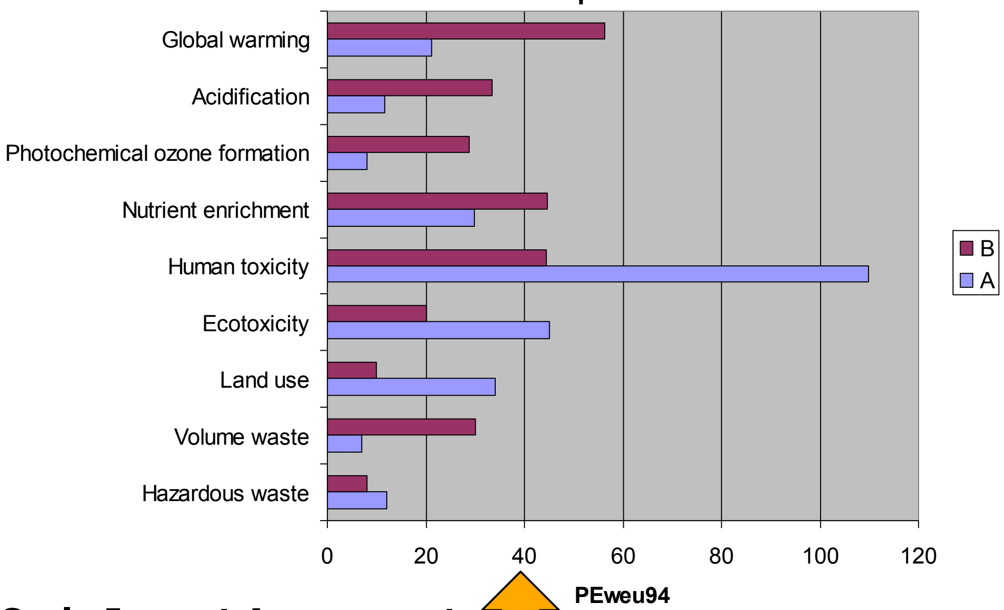
		Emission	Emission
	CAS.no.	to air	to w ater
Substance		g	g
2-hydroxy-ethanacrylate	816-61-0	0,0348	
4,4-methylenebis cyclohexylamine	1761-71-2	5,9E-02	
Ammonia	7664-81-7	3,7E-05	4,2E-05
Arsenic (As)	7440-38-2	2,0E-06	
Benzene	71-43-2 (cur	5,0E-02	
Lead (Pb)	7439-92-1	8,5E-06	
Butoxyethanol	111-76-2	6,6E-01	
Carbondioxide	124-38-9	2,6E+02	
Carbonmonoxide (CO)	630-08-0	1,9E-01	
Cadmium (Cd)	7440-46-9	2,2E-07	
Chlorine (Cl2)	7782-50-5	4,6E-04	
Chromium (Cr VI)	7440-47-3	5,3E-06	
Dicyclohexane methane	86-73-6	5,1E-02	
Nitrous oxide(N2O)	10024-97-2	1,7E-02	
2,4-Dinitrotoluene	121-14-2	9,5E-02	
HMDI	5124-30-1	7,5E-02	
Hydro carbons (electricity, stationary combustic	-	1,7E+00	
Hydrogen ions (H+)	-		1,0E-03
i-butanol	78-83-1	3,5E-02	
i-propanol	67-63-0	9,2E-01	
copper (Cu)	7740-50-8	1,8E-05	
Mercury(Hg)	7439-97-6	2,7E-06	
Methane	74-82-8	5,0E-03	
Methyl i-butyl ketone	108-10-1	5,7E-02	
Monoethyl amine	75-04-7		7,9E-06
Nickel (Ni)	7440-02-0	1,1E-05	
Nitrogen oxide (NOx)	10102-44-0	1,1E+00	
NMVOC, diesel engine (exhaust)	-	3,9E-02	
NMVOC, pow er plants (stationary combustion)	-	3,9E-03	
Ozone (O3)	10028-15-6	1,8E-03	
PAH	ikke specifik	2,4E-08	
Phenol	108-95-2		1,3E-05
Phosgene	75-44-5	1,4E-01	
Polyeter polyol	ikke specifik	1,6E-01	
1,2-propylenoxide	75-56-9	8,2E-02	
Nitric acid	7782-77-6 (c	8,5E-02	
Hydrochloric acid	7647-01-0 (c	1,9E-02	
Selenium (Se)	7782-49-2	2,6E-05	
Sulphur dioxide(SO2)	7446-09-5	1,3E+00	
Toluene	108-88-3	4,8E-02	
Toluene-2,4-diamine	95-80-7	7,9E-02	
Toluene diisocyanat (TDI)	26471-62-5	1,6E-01	
Total-N	-		2,6E-05
Triethylamine	121-44-8	1,6E-01	
Unspecified aldehydes	-	7,5E-04	
Uspecified organic compounds	-	1,5E-03	
Vanadium	7440-62-2	1,8E-04	
VOC, diesel engine (exhaust)	-	6,4E-05	
VOC, stationary combustion (coal fired)	-	4,0E-05	
VOC, stationary combustion (natural gas fired)	-	2,2E-03	
VOC, stationary combustion (oil fired)	-	1,4E-04	
Xylene	1330-20-7	1,4E-01	
Zinc (Zn)	7440-66-6	8,9E-05	

Life Cycle Inventory (LCI)

Analysed product system

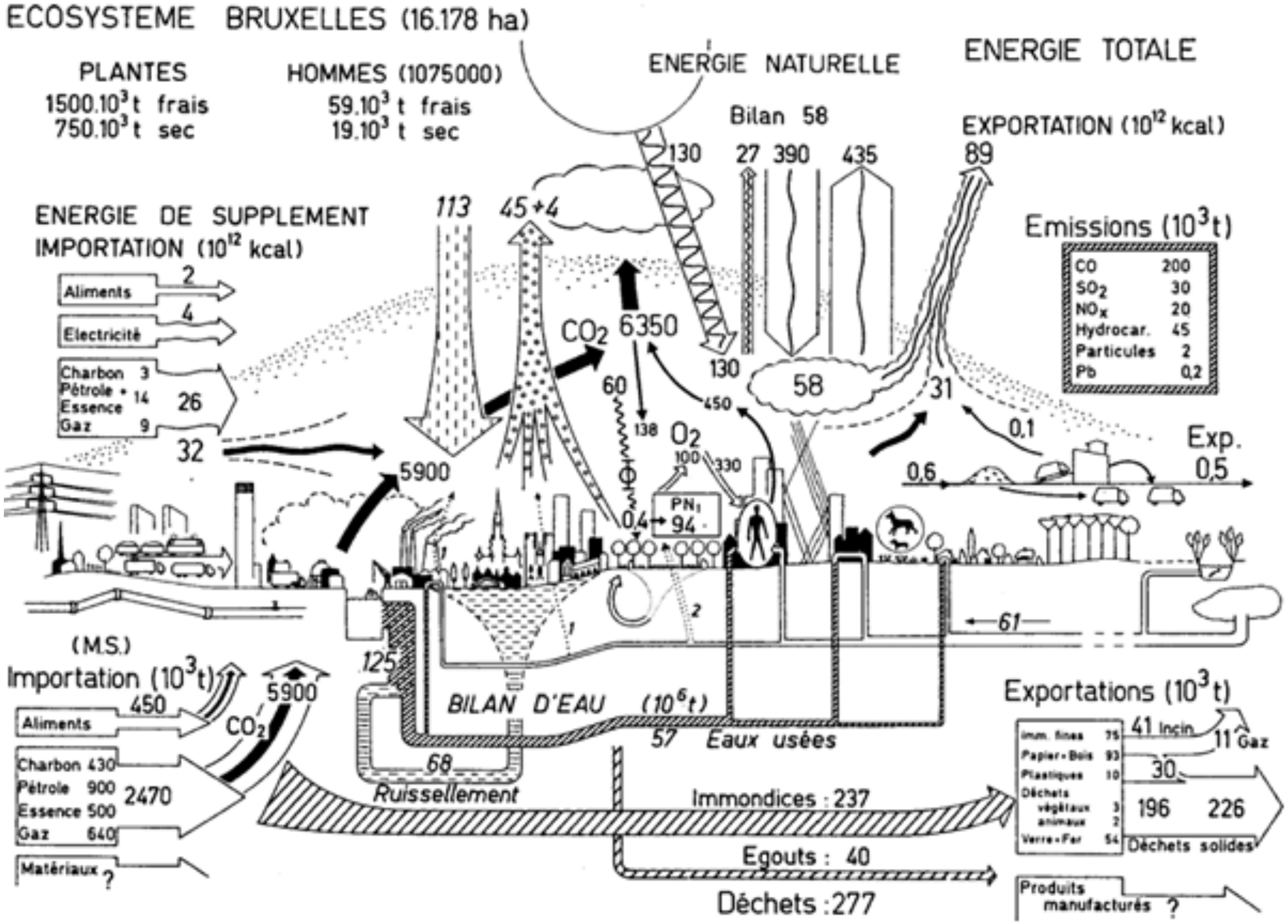


Environmental profile of solutions



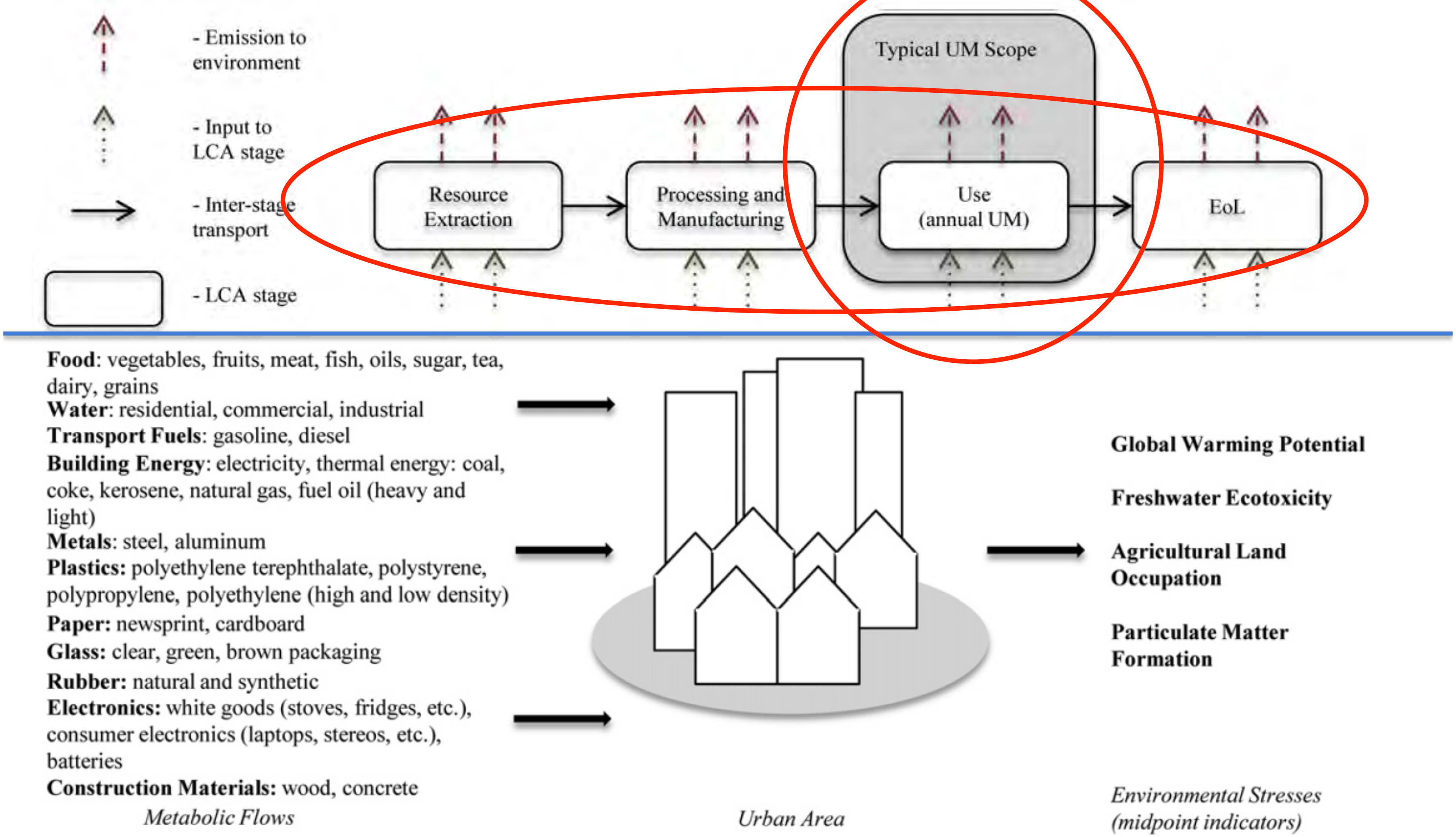
Life Cycle Impact Assessment (LCIA)

Classic Urban Metabolism (UM)



Duvigneaud and Denaeyer-De Smet (1977)

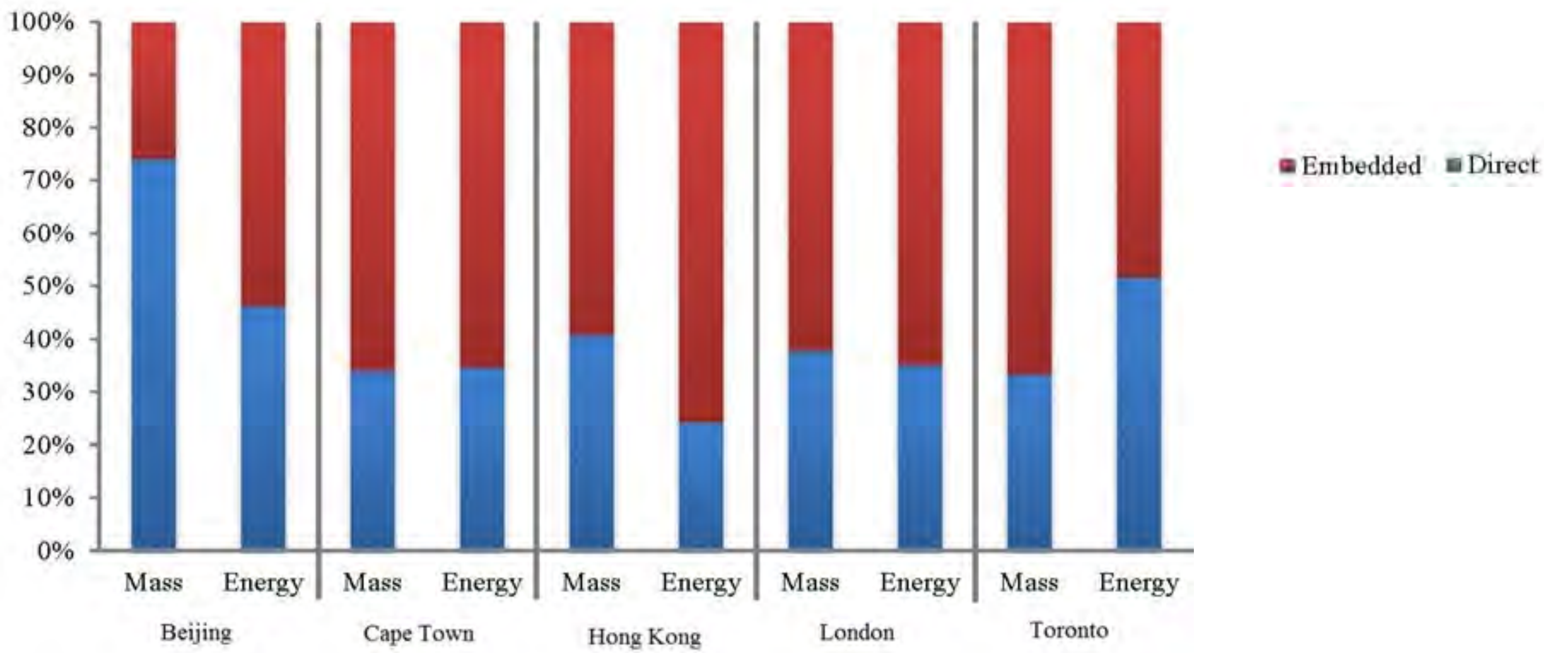
Coupling of Urban Metabolism and LCA (UM-LCA)



From: Goldstein et al. (2013)

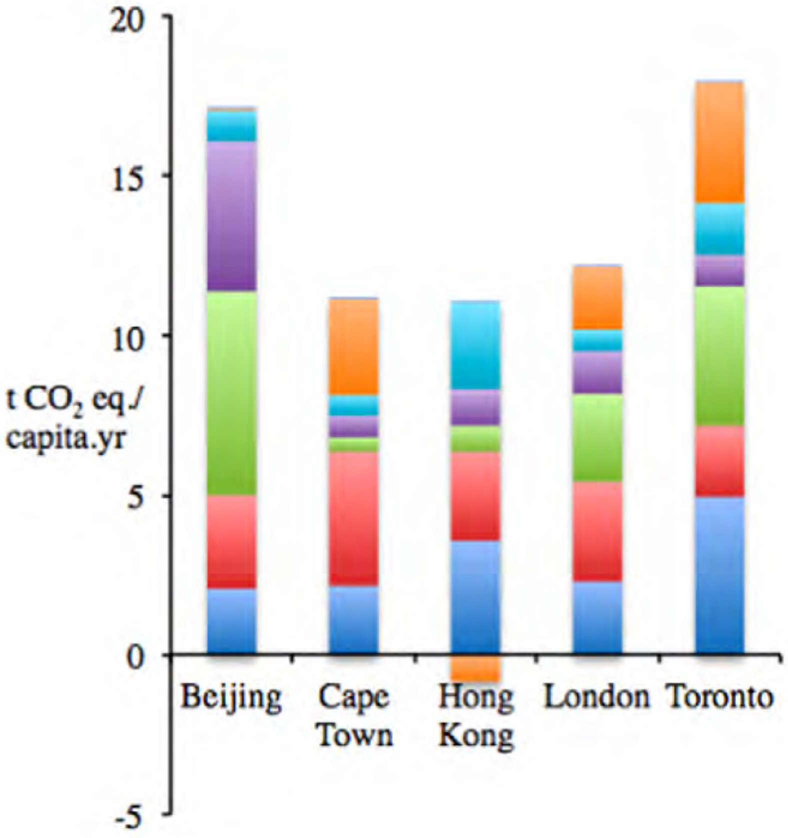
UM-LCA – Case cities and mass flows

City (year modeled)	Beijing (2006)	Cape Town (1997)	Hong Kong (1997)	London (2000)	Toronto (1999)
Population (10^6)	17.07	3.04	6.62	7.40	5.07
Population density (residents/km^2)	1016	1239	6480	4978	858
Gross domestic product (10^9 Year 2000 United States Dollars)	85.2	18.9	169	211	165
Human development index	0.633	0.616	0.824	0.833	0.879
Average daily temperature (ºC)	12	17	23	11	9



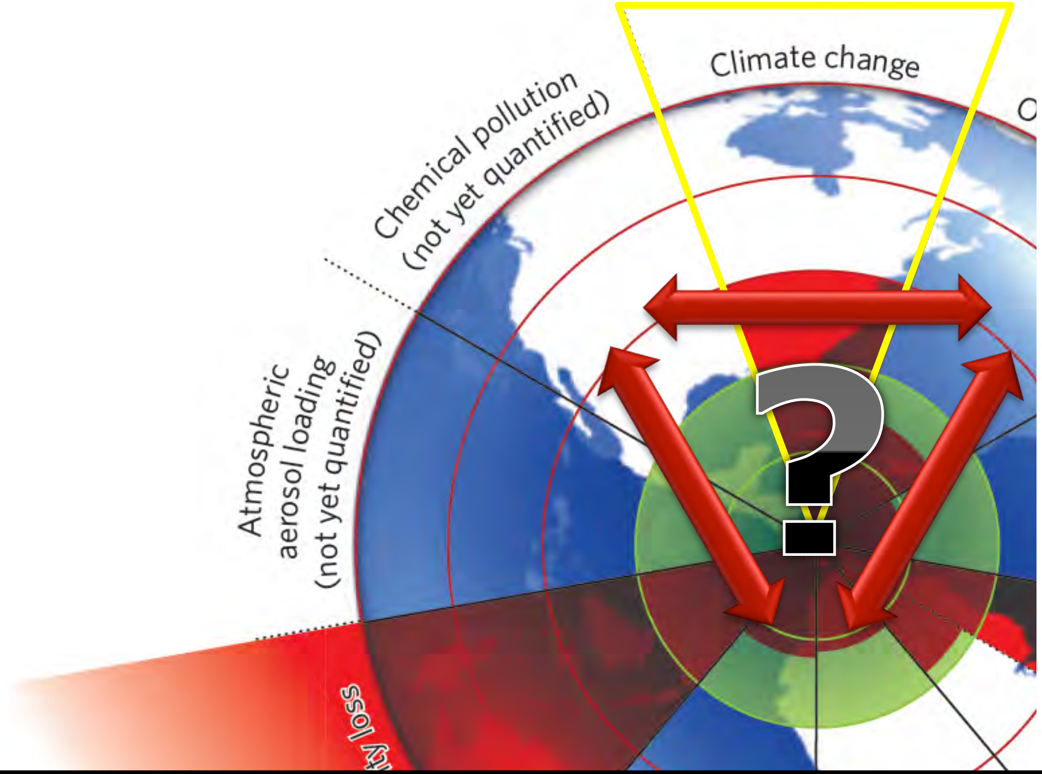
From: Goldstein et al. (2013)

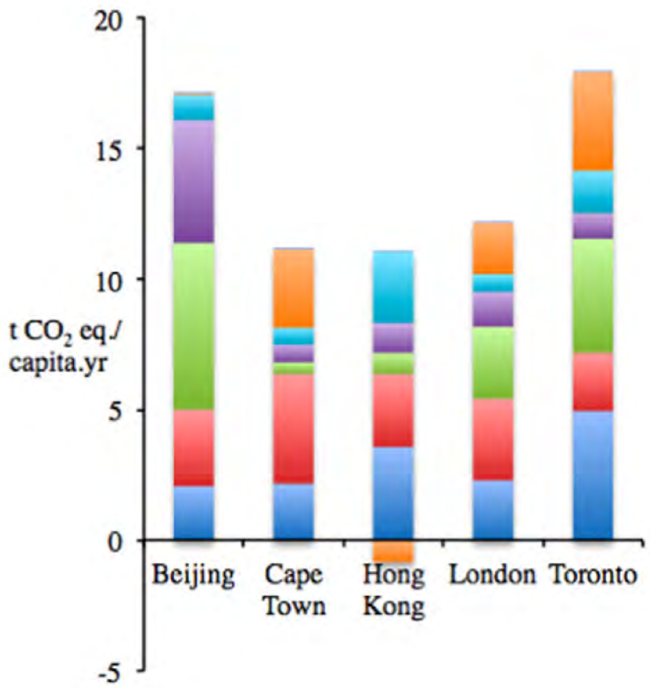
UM-LCA – Impact indicators



From: Goldstein et al. (2013)

Absolute sustainability

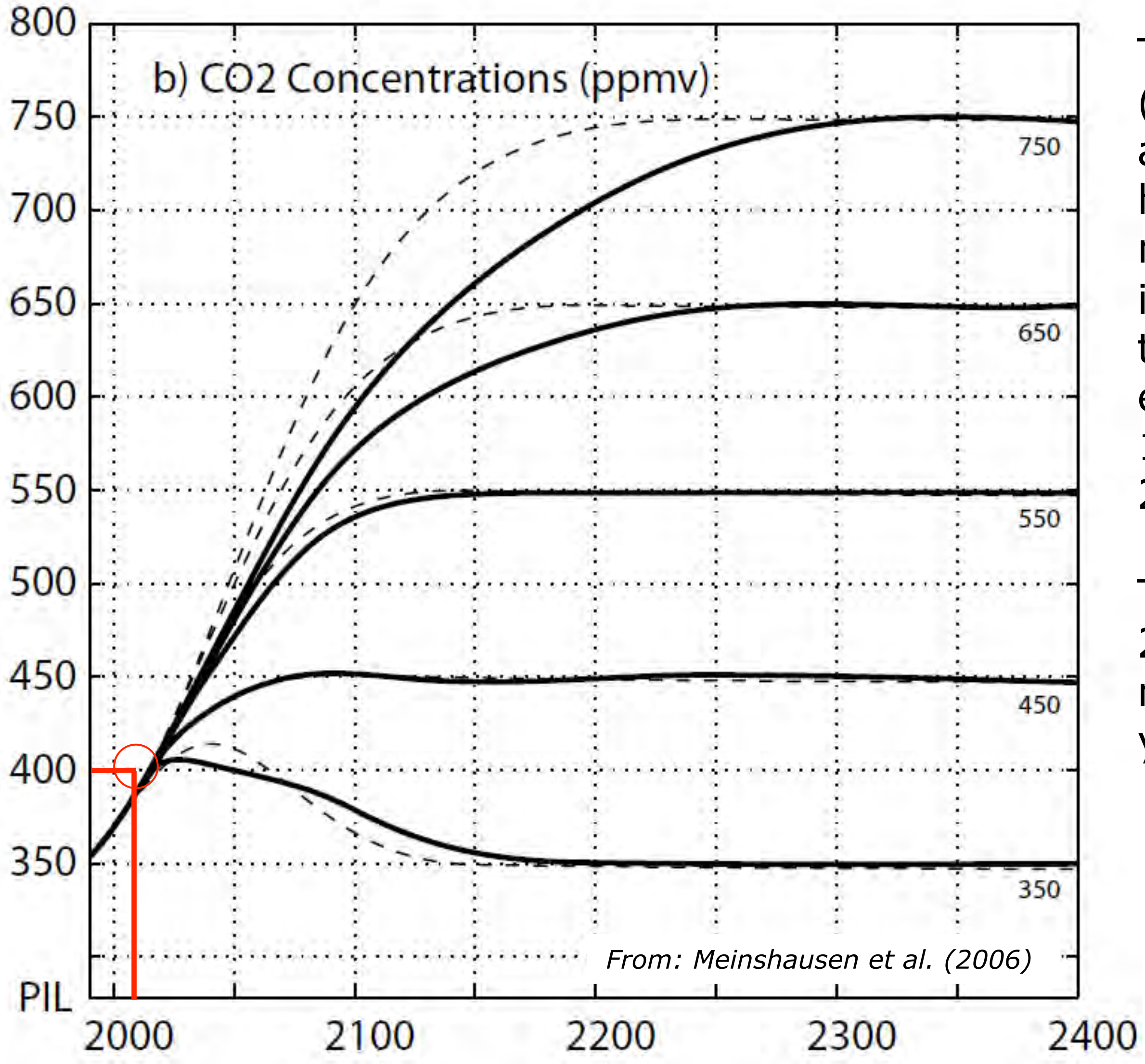




Earth-system process	Comment	Proposed boundary	2009 status
Climate change	(i) Atmospheric carbon dioxide concentration (parts per million by volume)	350	387
	(ii) Change in radiative forcing (watts per metre squared)	1	1.5

From: Rockström et al. (2009)

Relating CO2 emissions to atmospheric CO2 concentrations



To reach below 350 ppm (again) around 2100 with app. 75 % propability and hence keeping the global mean-temperature increase below 2Cº realtive to PIL means cutting emissions to 60 % of the 1990 emissios levels by 2050

The global emissions in 2050 should amount to maximum 14.4 GtCO_2-eq/ year

Urban sustainability performance relative to planetary boundaries

City	Population (millions)	GDP (billions Year 2000 USD)
Beijing (2006)	17.1	85.2
Cape Town (1997)	3.0	18.9
Hong Kong (1997)	6.6	169
London (2000)	7.4	211
Toronto (1999)	5.07	160

Allocation of CO2 emissions 14.4 $GtCO_2$-eq/year assuming unaltered population and GDP development trends:

Egalitarian: Equal allocation per person (world population 6.188 billion people in 2000)
Individualist: Equal allocation per dollar GDP (world GDP in 2000 of 32,334 billion US $)

	Beijing	Cape Town	Hong Kong	London	Toronto
Contribution to GWP [Mt CO2-eq/year]	291.9	34.1	67.5	90.3	91.3
Emission reduction needed by 2050 - egalitarian allocation of CO2 boudary quotas (%)	86.2	79.0	76.9	80.7	86.9
Emission reduction needed by 2050 - individualist allocation of CO2 boudary quotas (%)	87.0	75.3	-11.5	-4.1	21.9

Conclusions

- Fusing urban metabolism and life cycle assessment enables and facilitates inclusion of up- and downstream processes in the assessment of urban systems
- Fusing urban metabolism and life cycle assessment enables comparison of sustainability performance of urban systems by relying on a ISO standardized assessment methodology and a wide pallet of impact/performance indicators
- Relying on a broad/holistic set of impact indicators lowers the chance of shuffling impacts among impact categories
- Recent published absolute measures for sustainable development can be applied in combination with the fused UM-LCA approach
- The absolute sustainability performace of urban cities are not solely controlled by the actual environmental performance of the cities but also the way the absolute sustainability measures are distributed