Sustainability: Measurements

You can’t manage what you don’t measure

Carbon Footprint

https://www.carbonfootprint.com /

Carbon Footprint

- Measuring the total Greenhouse Gas (GHG – CO_2, N_2O, methane . . .) emissions caused by individuals, organizations and activities
  - **Primary footprint** – direct emissions of carbon dioxide from travel choices and energy consumption "on site"
    - Scope 1 – direct emission from the site of the process or service
    - Scope 2 – emissions related to purchased electricity, heat, and/or steam used on site
  - **Secondary footprint** – indirect carbon dioxide emissions from the life cycle of the products used.
- So many calculators available. . .
  - www.carbonfootprint.com/calculator.aspx
- Young and Dhanda 2013, 183-4 – mini case carbon footprint

Carbon Footprint of a Beef Burger

```
300,000,000     citizens
* 150           burgers/year
* 4.35          kilograms of CO2-equivalent per burger
/ 1000          kilograms per metric ton
= 195,750,000   annual metric tons of CO2-equivalent for all US burgers
```

195,750,000 annual metric tons of CO2-equivalent for all US burgers
/10 metric tons of CO2-equivalent per SUV

=19.6 million SUVs

- http://openthefuture.com/cheeseburger_CF.html
- http://www.guardian.co.uk/environment/2007/jul/19/climatechange.climatechange
- http://www.foodcarbon.co.uk/index.html

Environmentally friendly food:

- Very little (or no) meat
- Eat primarily organic food
- Seasonal food is preferred
- Regionally produced food is preferred

(https://timeforchange.org/eat-less-meat-co2-emission-of-food)

Ecological Footprint

Ecological Footprint (EF)

- Measures a unit's influence on its habitat caused by the process of consumption and pollution.
  - can be applied to a population's unit: country, city, business, individual . . .
  - as well as activity such as the manufacturing of a product or driving a car.

- Consumption of all resources (energy, raw materials, water, etc.) is converted into a normalized measure of land area called "global hectares"(gha)

  * 1 ha = 10,000 m^2

- **Global hectares:** the amount of biologically productive land and sea area that
  - 1) supports human demand for food, fibre, timber, energy and space for infrastructure and
  - 2) absorbs the carbon dioxide emissions from the human economy.

EF

- Supply side: **biocapacity** – productive capacity of the biosphere and its ability to provide a flow of biological resources and services useful to humanity.
  - include cropland, forest and fishing grounds,
  - do not include deserts, glaciers and the open ocean.

- Demand side: the total area required to **produce** all the materials (food, water, etc.) that a country consumes, **absorb** the waste it generates, and **provide areas** for its infrastructure (built-up areas)

- Current Ecological Footprint Standards: www.footprintstandards.org

- See also
  - Albino 2013
  - Young and Dhanda 2013, 177-8
  - Global Footprint Network www.footprintnetwork.org

Table 2 List of countries ordered by EF (Data 2007, Source: www.footprintnetwork.org)

Country	EF (gha/pers)	Biocapacity (gha/pers)	Ecological remainder (if positive) (gha/pers)	Population (millions)
UAE	10.68	0.85	−9.83	6.25
Denmark	8.26	4.85	−3.41	5.45
United States	8.00	3.87	−4.13	308.67
Canada	7.01	14.92	7.91	32.95
Australia	6.84	14.71	7.87	20.85
Netherlands	6.19	1.03	−5.16	16.46
Sweden	5.88	9.75	3.87	9.16
Norway	5.56	5.48	−0.08	4.72
Spain	5.42	1.61	−3.81	44.05
Saudi Arabia	5.13	0.84	−4.29	24.68
Germany	5.08	1.92	−3.16	82.34
France	5.01	3.00	−2.01	61.71
Italy	4.99	1.14	−3.85	59.31
UK	4.89	1.34	−3.55	61.13
South Korea	4.87	0.33	−4.54	47.96
Japan	4.73	0.60	−4.13	127.40
Russia	4.41	5.75	1.34	141.94
Mexico	3.00	1.47	−1.53	107.49
Brazil	2.91	8.98	6.07	190.12
Ukraine	2.90	1.82	−1.08	46.29
Turkey	2.70	1.32	−1.38	73.00
Argentina	2.60	7.50	4.90	39.49
South Africa	2.32	1.14	−1.18	49.17
China	2.21	0.98	−1.23	1,336.55
Nigeria	1.44	1.12	−0.32	147.72
Bangladesh	0.62	0.38	−0.24	157.75
Puerto Rico	0.04	0.14	0.10	3.95

- (-) Ecological debtor countries
- (+) Ecological creditor countries

Table 1 EF and biocapacity for region (Data 2007, Source: www.footprintnetwork.org)

Region	EF of consumption (gha/pers)	Total biocapacity (gha/pers)	Ecological (deficit) reserve (gha/pers)	Population (millions)
Europe	4.7	2.9	(1.8)	730.9
Africa	1.4	1.5	0.1	963.9
Asia	1.8	0.8	(1.0)	4,031.2
US & Canada	7.9	4.9	(3.0)	341.6
Latin America & the Caribbean	2.6	5.5	2.9	569.5
Oceania	5.4	11.1	5.8	34.5
World	2.7	1.8	(0.9)	6,671.6

A simple question. . .

- How many earths would we need if everyone on earth were to live like the people in North America?

Table 1 EF and biocapacity for region (Data 2007, Source: www.footprintnetwork.org)

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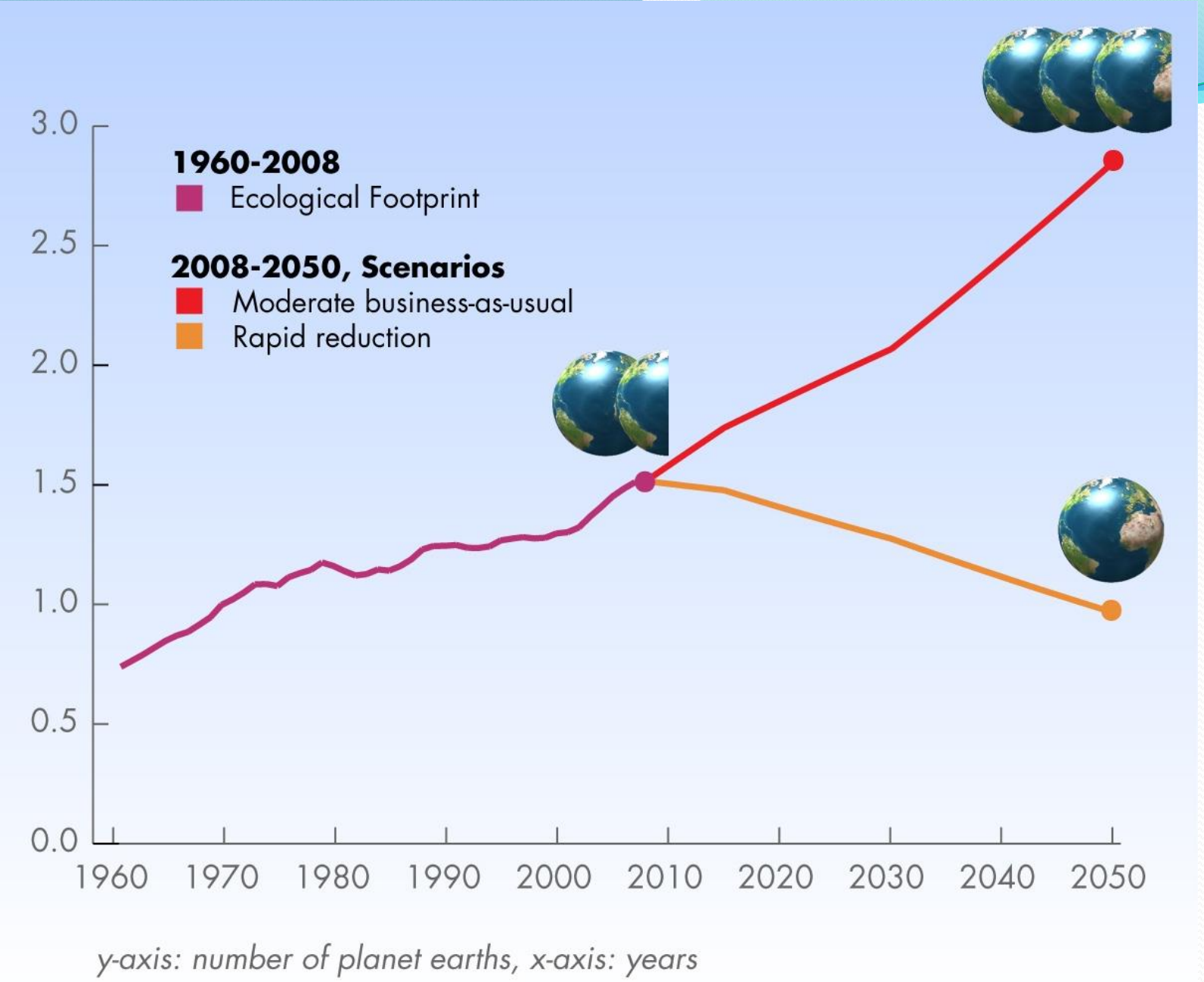


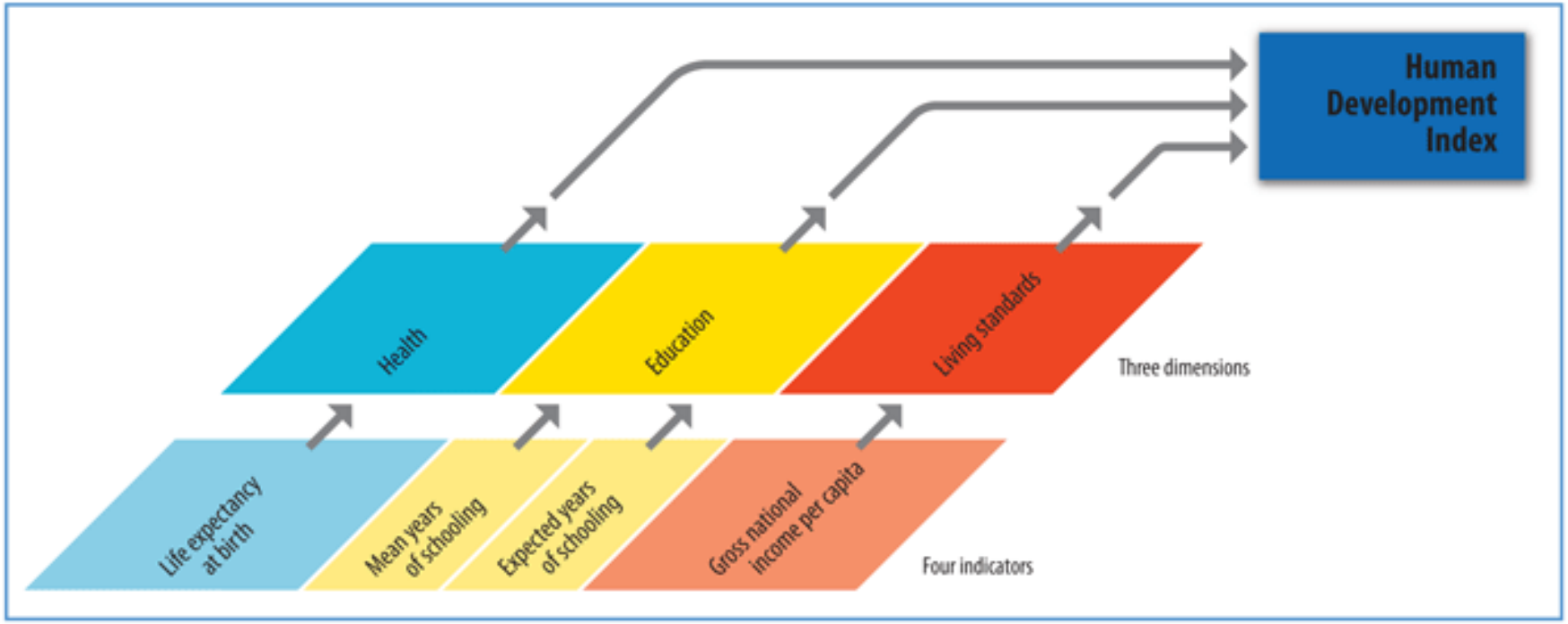
http://www.footprintnetwork.org/en/index.php/GFN/page/world_footprint/

Human Development Index

Human Development Index (HDI)

Components of the Human Development Index

The HDI—three dimensions and four indicators



Note: The indicators presented in this figure follow the new methodology, as defined in box 1.2.

Source: HDRO.

(Source UNDP: http://hdr.undp.org/en/statistics/hdi/)

- 182 countries measured In the scale of 0 (not developed) to 1 (highly developed), classified into four categories: Very High, High, Medium, Low Human Development
- For a complete report see UNDP: http://hdr.undp.org/en/statistics/
  as well as an interactive map: http://hdr.undp.org/en/statistics/data/hd_map/

HDI - examples

Very High Development	High Development	Medium Development	Low Development
1. Norway 2. Australia 3. Iceland 4. Canada 5. Ireland 6. Sweden 7. France 8. Switzerland 9. Japan 10. Luxemburg 11. Finland 12. United States . . . 21. United Kingdom 22. Germany 23. Singapore 24. Hong Kong 26. Korea . . . 38. Malta	39. Bahrain 40. Estonia 41. Poland 42. Slovakia 43. Hungary 44. Chile 45. Croatia . . . 51. Cuba . . . 59. Saudi Arabia . . . 66. Malaysia . . . 71. Russia 75. Brazil . . . 83. Lebanon	84. Armenia 85. Ukraine 86. Azerbaijan 87. Thailand 88. Iran 89. Georgia 90. Dominican Rep. . . . 92. China . . . 105. Philippines 106. El Salvador 107. Syria 108. Fiji . . . 111. Indonesia . . . 116. Vietnam . . . 137. Cambodia . . . 157. Uganda 158. Nigeria	159 Togo 160 Malawi 161 Benin 162 Timor-Leste . . . 178 Mali 179 Central Africa Rep. 180 Sierra Leon 181 Afghanistan 182 Niger

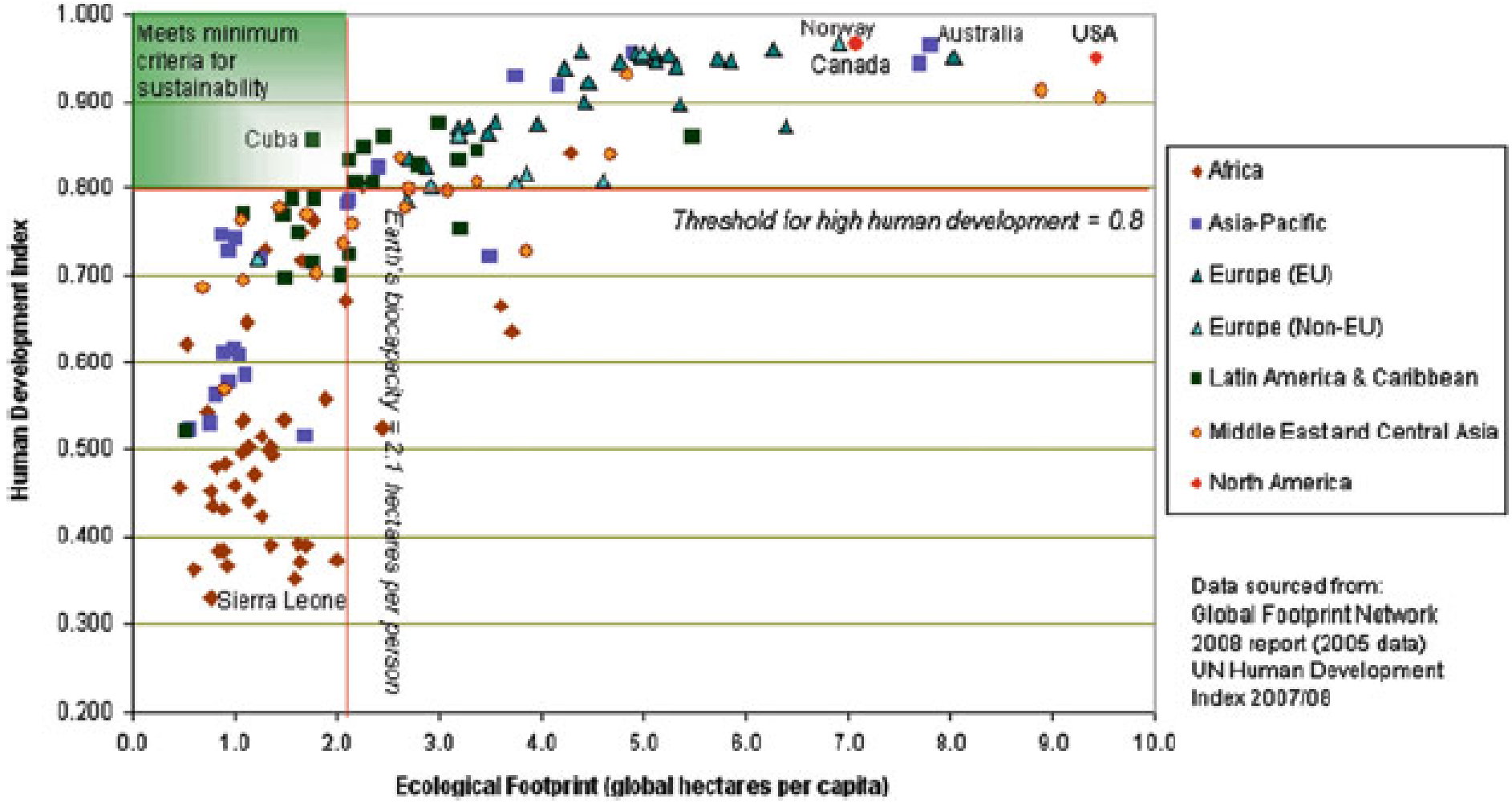
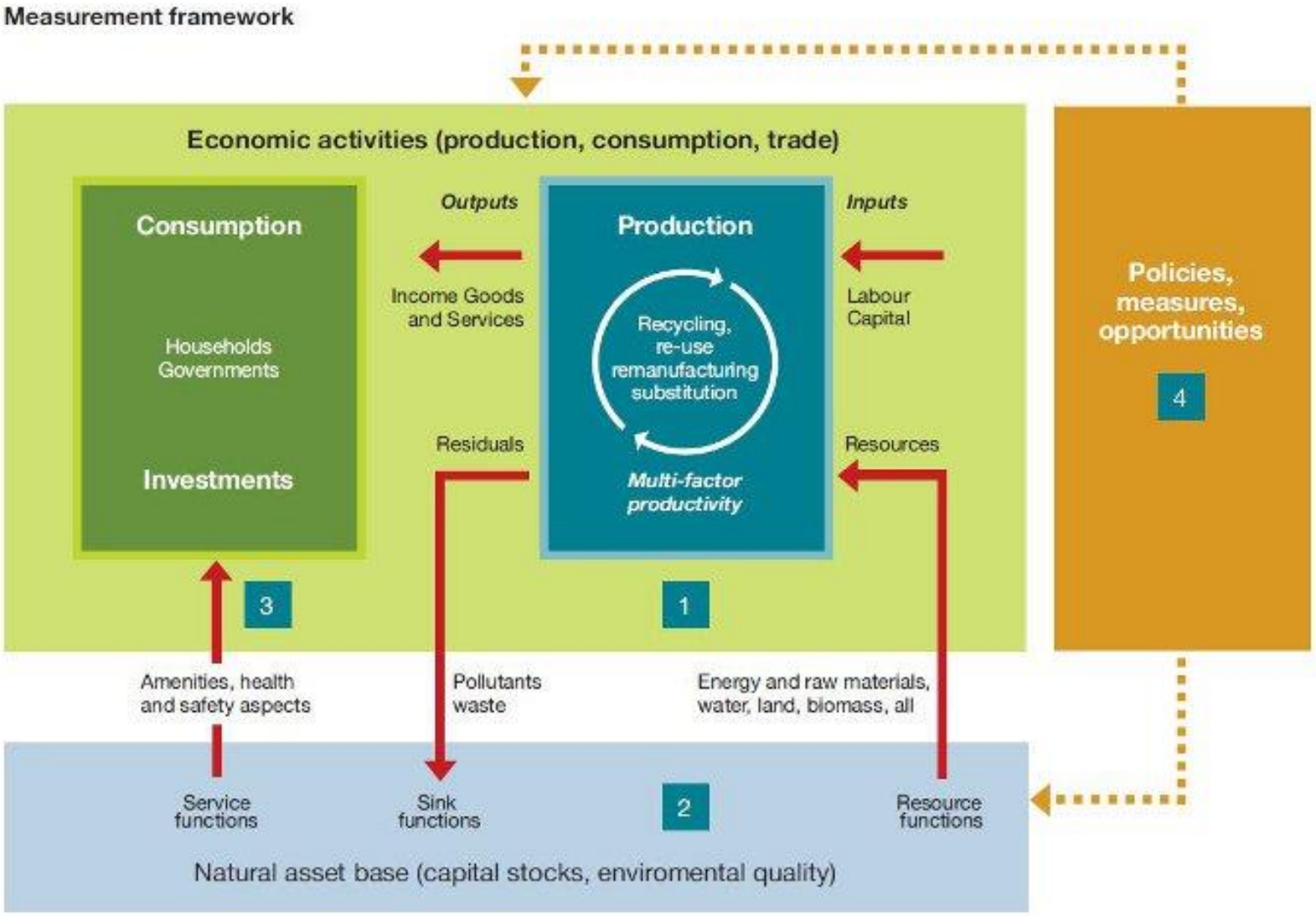


Fig. 2 HDI versus EF for different countries (Source: UNEP 2011)

Green Growth Indicators

OECD Green Growth Indicators

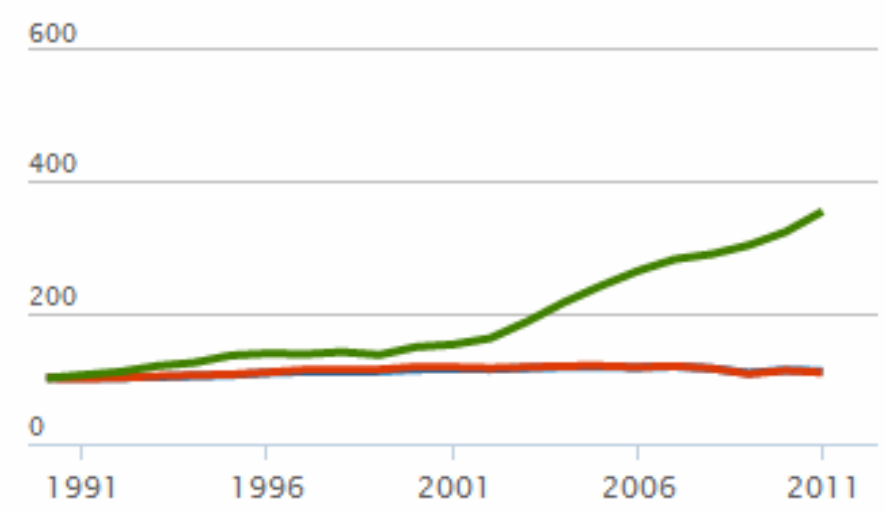


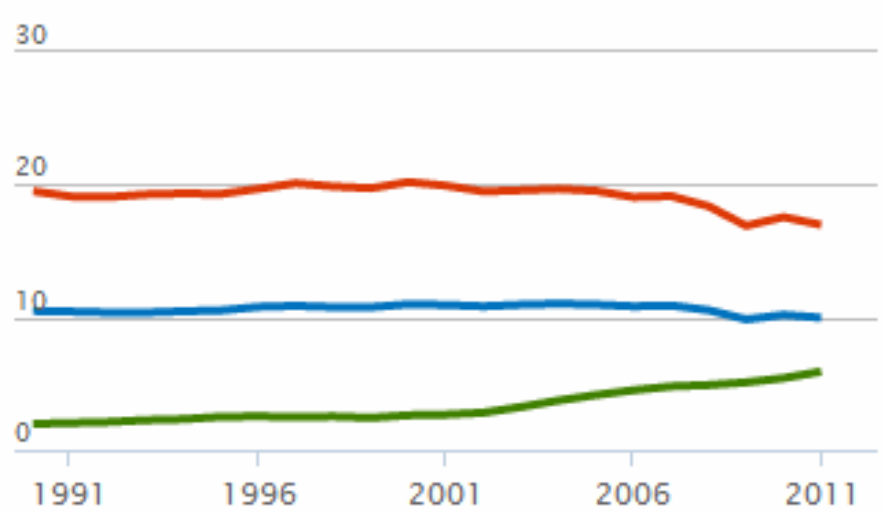
http://www.oecd.org/greengrowth/greengrowthindicators.htm

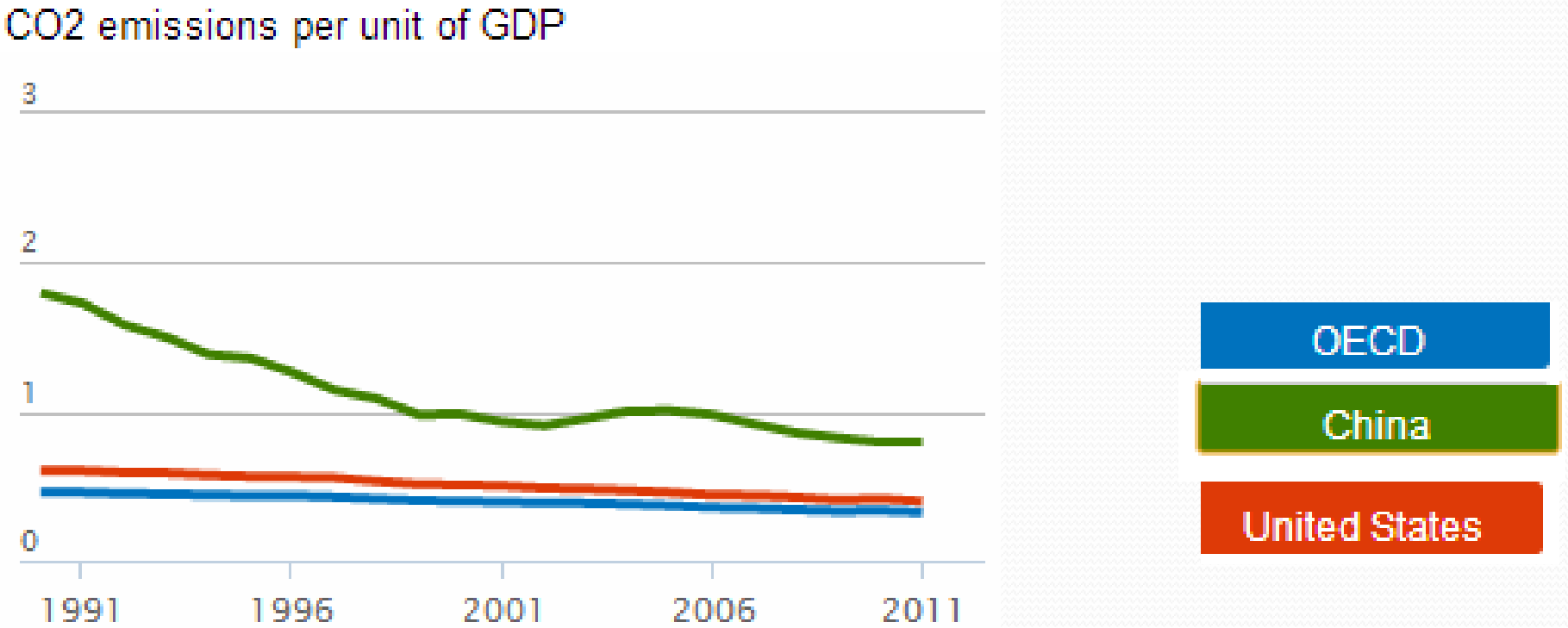
Overview of proposed indicator groups and topics covered

1	**The environmental and resource productivity of the economy**	• Carbon and energy productivity • Resource productivity: materials, nutrients, water • Multi-factor productivity
2	**The natural asset base**	• Renewable stocks: water, forest, fish resources • Non-renewable stocks: mineral resources • Biodiversity and ecosystems
3	**The environmental dimension of quality of life**	• Environmental health and risks • Environmental services and amenities
4	**Economic opportunities and policy responses**	• Technology and innovation • Environmental goods and services • International financial flows • Prices and transfers • Skills and training • Regulations and management approaches
	Socio-economic context and characteristics of growth	• Economic growth and structure • Productivity and trade • Labour markets, education and income • Socio-demographic patterns

http://www.oecd.org/greengrowth/greengrowthindicators.htm


Total CO2 emissions (1990 = 100)
600
400
200
0
1991
1996
2001
2006
2011


CO2 emissions per capita
30
20
10
0
1991
1996
2001
2006
2011


CO2 emissions per unit of GDP
3
2
1
0
1991
1996
2001
2006
2011
OECD
China
United States

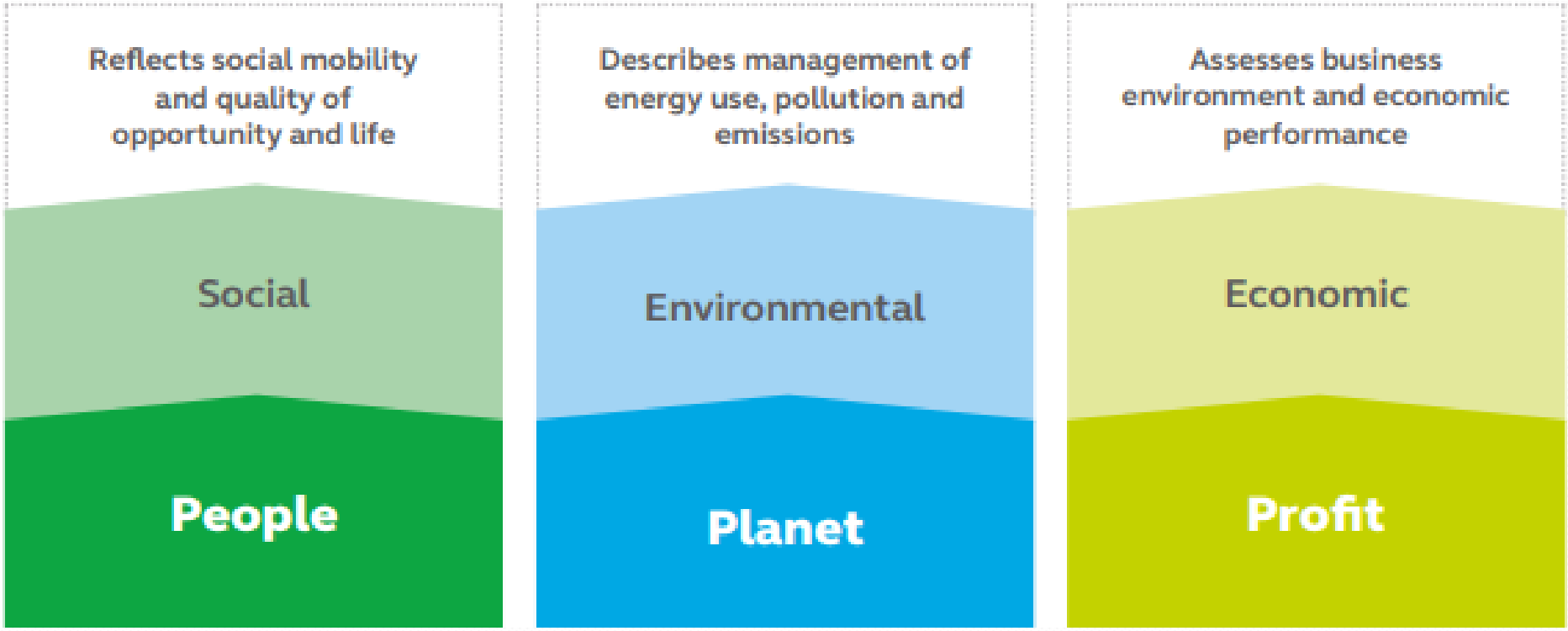
For Cities

Arcadis
sustainable cities index 2018. . .

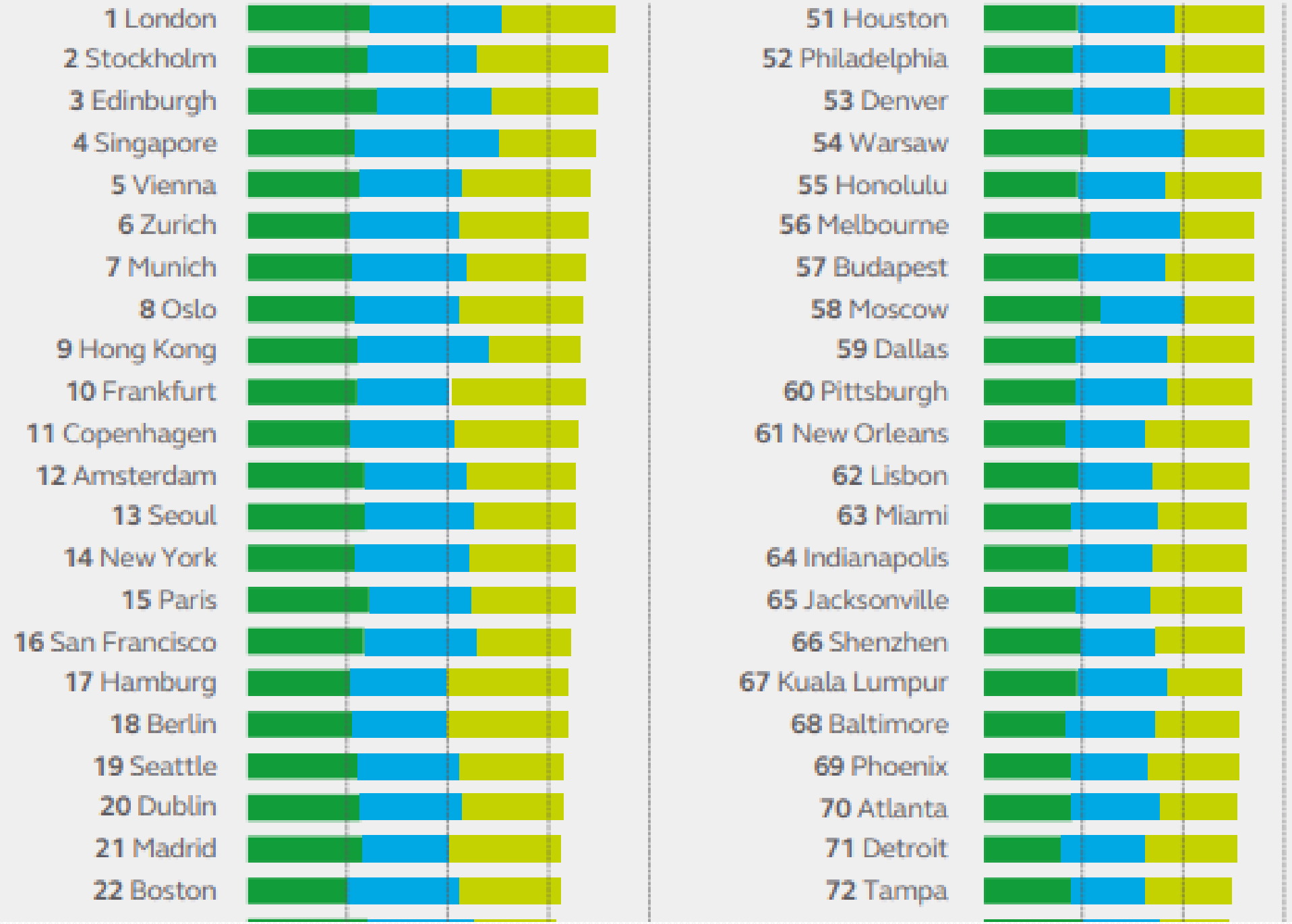
ARCADIS Design & Consultancy for natural and built assets

Citizen Centric Cities

The Sustainable Cities Index 2018



https://www.arcadis.com/


1 London
2 Stockholm
3 Edinburgh
4 Singapore
5 Vienna
6 Zurich
7 Munich
8 Oslo
9 Hong Kong
10 Frankfurt
11 Copenhagen
12 Amsterdam
13 Seoul
14 New York
15 Paris
16 San Francisco
17 Hamburg
18 Berlin
19 Seattle
20 Dublin
21 Madrid
22 Boston
51 Houston
52 Philadelphia
53 Denver
54 Warsaw
55 Honolulu
56 Melbourne
57 Budapest
58 Moscow
59 Dallas
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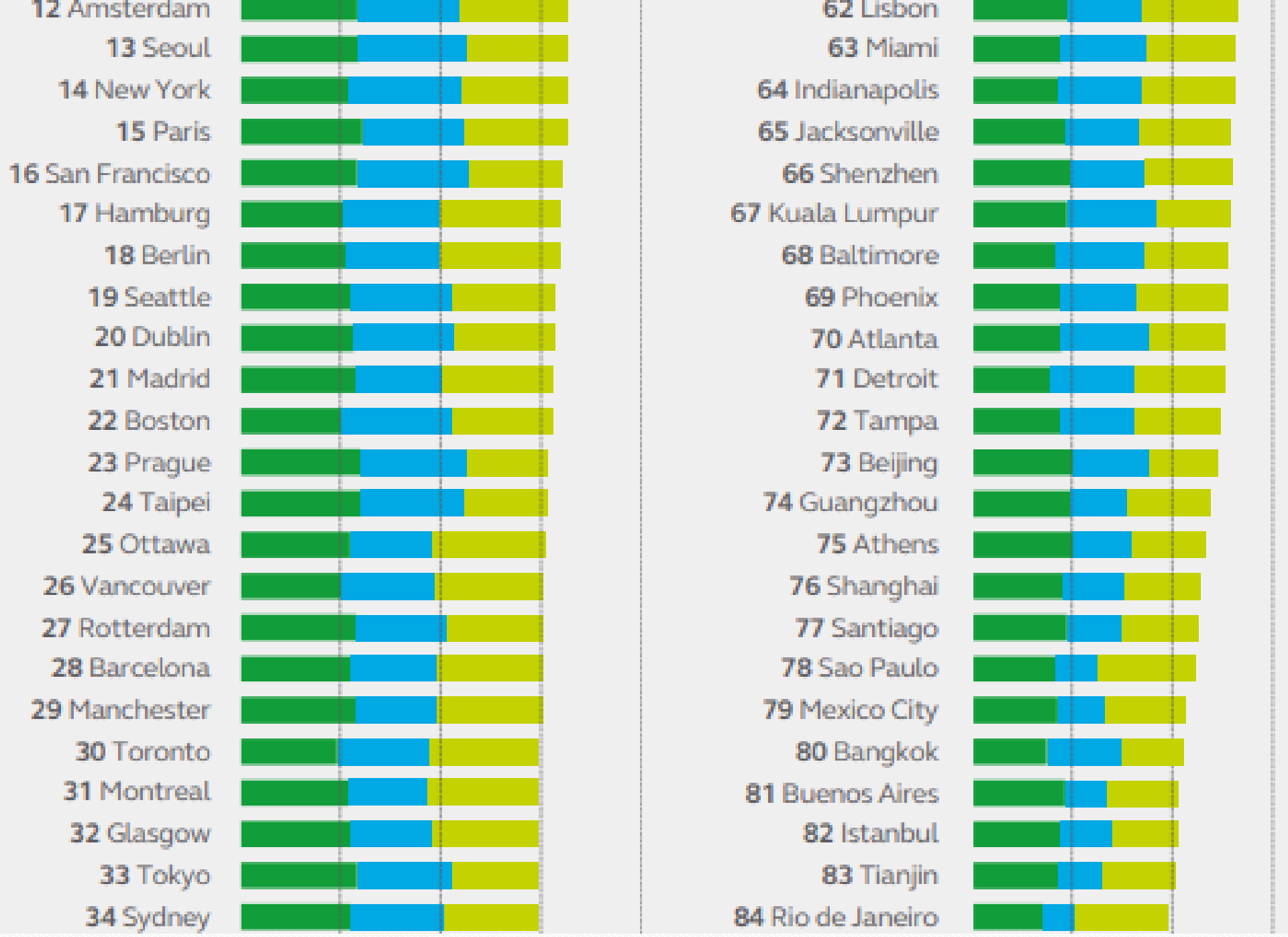
64 Indianapolis
65 Jacksonville
66 Shenzhen
67 Kuala Lumpur
68 Baltimore
69 Phoenix
70 Atlanta
71 Detroit
72 Tampa


12 Amsterdam
13 Seoul
14 New York
15 Paris
16 San Francisco
17 Hamburg
18 Berlin
19 Seattle
20 Dublin
21 Madrid
22 Boston
23 Prague
24 Taipei
25 Ottawa
26 Vancouver
27 Rotterdam
28 Barcelona
29 Manchester
30 Toronto
31 Montreal
32 Glasgow
33 Tokyo
34 Sydney
62 Lisbon
63 Miami
64 Indianapolis
65 Jacksonville
66 Shenzhen
67 Kuala Lumpur
68 Baltimore
69 Phoenix
70 Atlanta
71 Detroit
72 Tampa
73 Beijing
74 Guangzhou
75 Athens
76 Shanghai
77 Santiago
78 Sao Paulo
79 Mexico City
80 Bangkok
81 Buenos Aires
82 Istanbul
83 Tianjin
84 Rio de Janeiro

Life Cycle Assessment

http://unep.fr/shared/publications/pdf/DTIx0594xPA-Road.pdf

Life Cycle Assessment

- scientific approach that could help develop production and consumption policies (Young and Dhanda, 153)

- UNEP: LCSA
  - (E)-LCA ((environmental) life cycle assessment)
  - LCC (life cycle costing)
  - SLCA (social life cycle assessment)

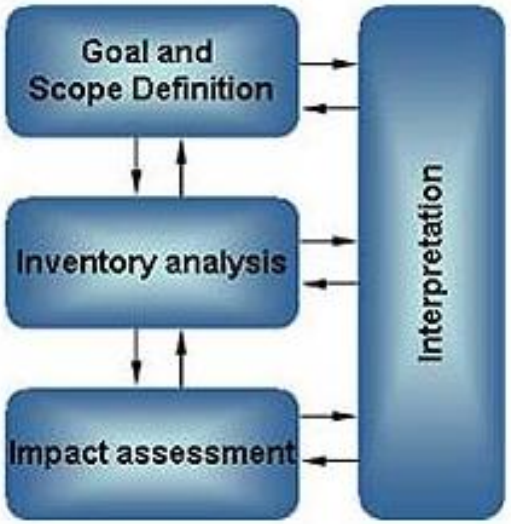
- Life Cycle Initiative (UN + SETAC) (http://www.lifecycleinitiative.org/)
- Life Cycle Initiative. (2011). *Towards Life Cycle Sustainability Assessment.* (https://www.unenvironment.org/resources/report/towards-life-cycle-sustainability-assessment-making-informed-choices-products)
- European Platform on Life Cycle Assessment (https://eplca.jrc.ec.europa.eu/)

Phases of LCA (UNEP)

- **Goal and Scope Definition**,
  - the product(s) or service(s) to be assessed are defined,
  - a functional basis for comparison is chosen
  - the required level of detail is defined

- **Inventory Analysis** of extractions and emissions,
  - Input: the energy and raw materials used,
  - Output: emissions to the atmosphere, water and land are quantified for each process,

- **Impact Assessment**,
  - the effects are grouped and quantified into a limited number of impact categories



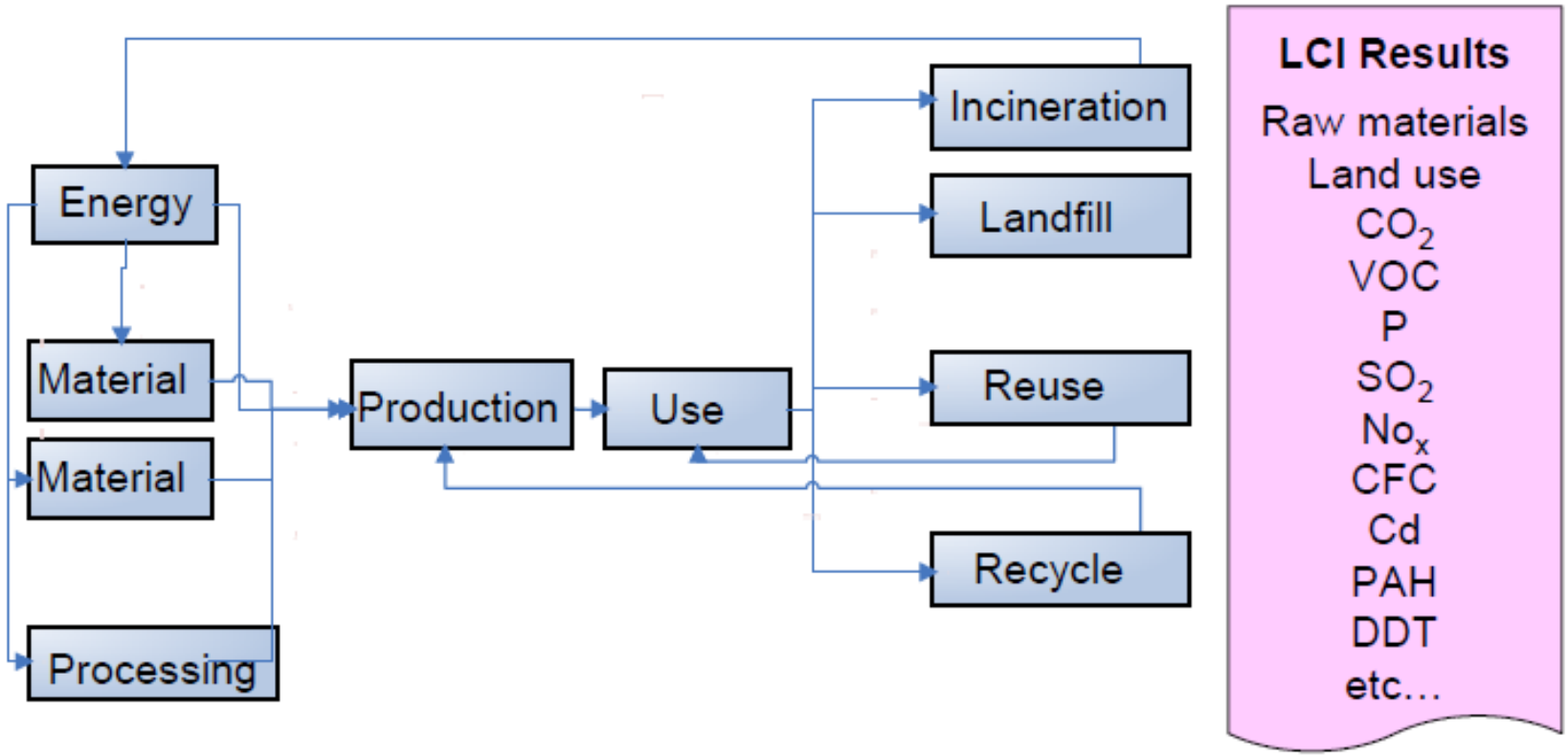
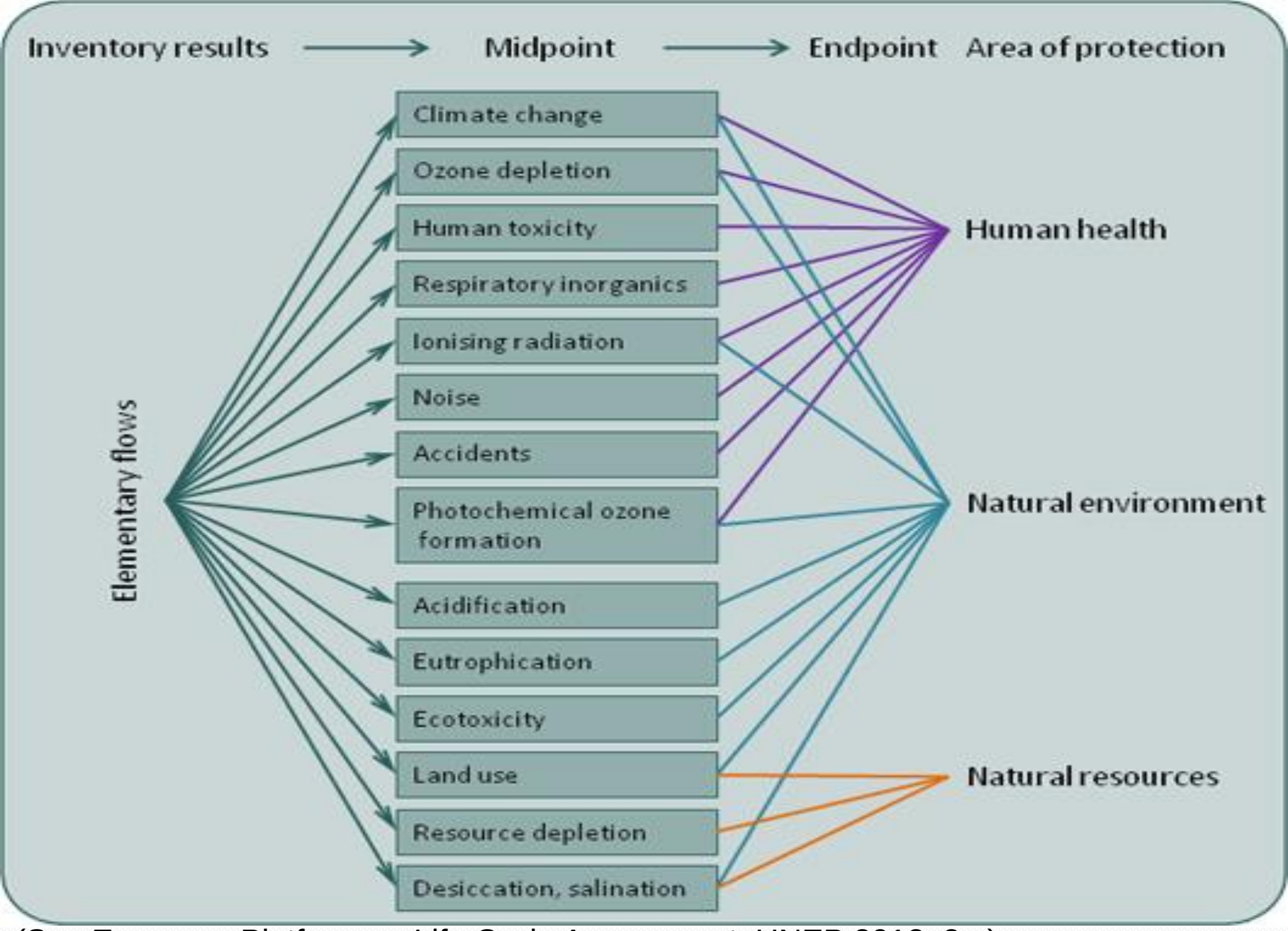


Figure 1. Flows of information needed for a life cycle inventory.

Life Cycle Initiative. (2011). *Towards Life Cycle Sustainability Assessment.* P.7 (http://www.unep.org/pdf/UNEP_LifecycleInit_Dec_FINAL.pdf)



(See European Platform on Life Cycle Assessment; UNEP 2012, 8p.)

Eutrophication?

- The process by which a body of water acquires a high concentration of nutrients, especially phosphates and nitrates. This leads to excessive growth of algae. As the algae die and decompose, high levels of organic matter and the decomposing organisms deplete the water of available oxygen, causing the death of other organisms, such as fish. It is a natural, slow-aging process for a water body, but human activity greatly speeds up the process.

Example: Wooden School Desk

(Gonzalez et al. 2008; in UNEP 2011, 9-13)
Life Cycle Initiative. (2011). *Towards Life Cycle Sustainability Assessment.* (http://www.unep.org/pdf/UNEP_LifecycleInit_Dec_FINAL.pdf)

- Goal and Scope
  - Wooden desk – To determine how the Mexican wooden furniture industry impacts on the natural environment
  - LCA used to evaluate the potential environmental impacts of the school desk
    - Harvesting of Forest Stewardship Council certified wood
    - Transportation
    - Cutting the logs into boards
    - Manufacture of boards into school desk
    - Distribution of desk to schools
    - Use of discard desks as fuel

Life Cycle Inventory

Table 1. Input/output table for wooden school desk (Gonzalez et al., 2008)

		Inputs				Data Source
PRODUCTION	Raw wood	Materials	Included in the next step: wood from yellow pine			Authors
	Sawmill process	Materials	Log from yellow pine	2.11E+01	kg	Authors
			Phenol for wood treatment	1.53E-06	kg	Ecoinvent*
		Water	Tap water	3.41E-02	kg	Ecoinvent*
		Energy	Electricity	1.40E-01	kWh	Authors
			Diesel	4.98E-03	lt	Authors
			Lubricant oil	7.66E-04	lt	Ecoinvent*
			Ethylene Glycol	1.70E-05	lt	Ecoinvent*
			Gasoline	4.98E-03	lt	Authors
	Dry boards process	Materials	Sawn wood	1.37E+01	kg	Authors
			Saw dust	1.50E+00	kg	Authors
		Water	Tap water	9.80E-01	m^3	Ecoinvent*
		Energy	Electricity	7.94E+01	kWh	Authors
			Diesel	1.76E+00	lt	Authors
			Gasoline	1.76E+00	lt	Authors
	School furniture	Materials	Sawn kiln dried boards	1.36E+01	kg	Authors
			Sealer polyurethane	3.40E-01	kg	Authors
			Lacquer polyurethane	3.40E-01	kg	Authors
			Sealer and Lacquer cans from aluminium	4.00E-02	kg	Authors
			Screws, galvanized	4.00E-01	kg	Authors
		Energy	Electricity	8.57E+00	kWh	Authors
TRANSPORTATION			Of sawn wood in the sawmill process (28 tonne truck)	843	kgkm	Ecoinvent*
			Of sawn wood in the drying process (16 tonne truck)	15	kgkm	Ecoinvent*
			Of school desks to the city (16 tonne truck)	570	kgkm	Ecoinvent*
			Of school desks to the school (16 tonne truck)	190	kgkm	Ecoinvent*
FINAL DISPOSAL (Energy recovery)		Transportation	Of waste to the final disposal (16 tonne truck)	380	kgkm	Ecoinvent*

Outputs				Economic Allocation
Products	Tree logs per truck load	550.3	kg	
Products	Sawn wood	1.37E+01	kg	80%
By products	Sawdust	7.40E+00	kg	20%
Emissions to water and air	**			
Products	Sawn Kiln Dried Wood Boards	1.36E+01	kg	
Solid waste	Lubricants	2.69E-04	lt	
Emissions to water and air	**			
Products	School desk (1 piece)	9.50E+00	kg	95%
By-products	Sawdust	4.10E+00	kg	5%
Emissions to water and air	**			
Emissions to water and air (potential impacts after classification and characterization)	CO_2 eq	3.43E-01	kg	
	CFC-11 eq	4.70E-08	kg	
	1,4-DCB eq (HTP***)	4.62E-03	kg	
	1,4-DCB eq (FAETP***)	2.63E-03	kg	
	1,4-DCB eq (TETP***)	1.89E-04	kg	
	C_2H_4 eq	6.42E-05	kg	
	SO_2 eq	1.88E-03	kg	
	PO_4--- eq	3.94E-04	kg	
Waste disposal	One piece of furniture	9.50E+00	kg	100%
Avoided resource use	Natural gas	2.57E+00	m^3	
By-products	steam			

*http://www.ecoinvent.ch/

**More than 400 emissions to air and water had been quantified; however, for the purposes of this publication they are not listed here but summarized in Table 2 and Fig. 3.

*** HTP: Human toxicity potential; FAETP: Freshwater aquatic ecotoxicity potential; TETP: Terrestrial ecotoxicity potential.

Impacts . . .

Table 2. Potential life cycle impacts table for wooden school desk – wood extraction and board sawing (Gonzalez et al., 2008).

CML Impact category	Units	Oil for tree felling	Other board sawing inputs	Total for 21.08 kg boards	Allocation factor	13.7 kg boards
Abiotic depletion	kg Sb eq	6.67E-02	4.03E-02	1.07E-01	8.00E-01	8.56E-02
Global warming	kg CO_2 eq	1.23E+01	5.56E+00	1.79E+01	8.00E-01	1.43E+01
Ozone layer depletion	kg CFC-11 eq	0.00E+00	0.00E+00	0.00E+00	8.00E-01	0.00E+00
Human toxicity	kg 1,4-DCB eq	5.15E-02	1.58E+00	1.64E+00	8.00E-01	1.31E+00
Fresh water toxicity	kg 1,4-DCB eq	0.00E+00	2.62E-01	2.62E-01	8.00E-01	2.10E-01
Terrestrial toxicity	kg 1,4-DCB eq	0.00E+00	2.40E-02	2.40E-02	8.00E-01	1.92E-02
Photochemical oxidation	kg C_2H_4	5.47E-03	3.54E-03	9.00E-03	8.00E-01	7.20E-03
Acidification	kg SO_2 eq	1.52E-01	3.35E-02	1.85E-01	8.00E-01	1.48E-01
Eutrophication	kg PO_4 eq	4.38E-03	7.62E-03	1.20E-02	8.00E-01	9.60E-03

DCB - Dichlorobenzene

Normalization

- Largest as 100%

Highest normalized value occur in Terrestrial ecotoxicity

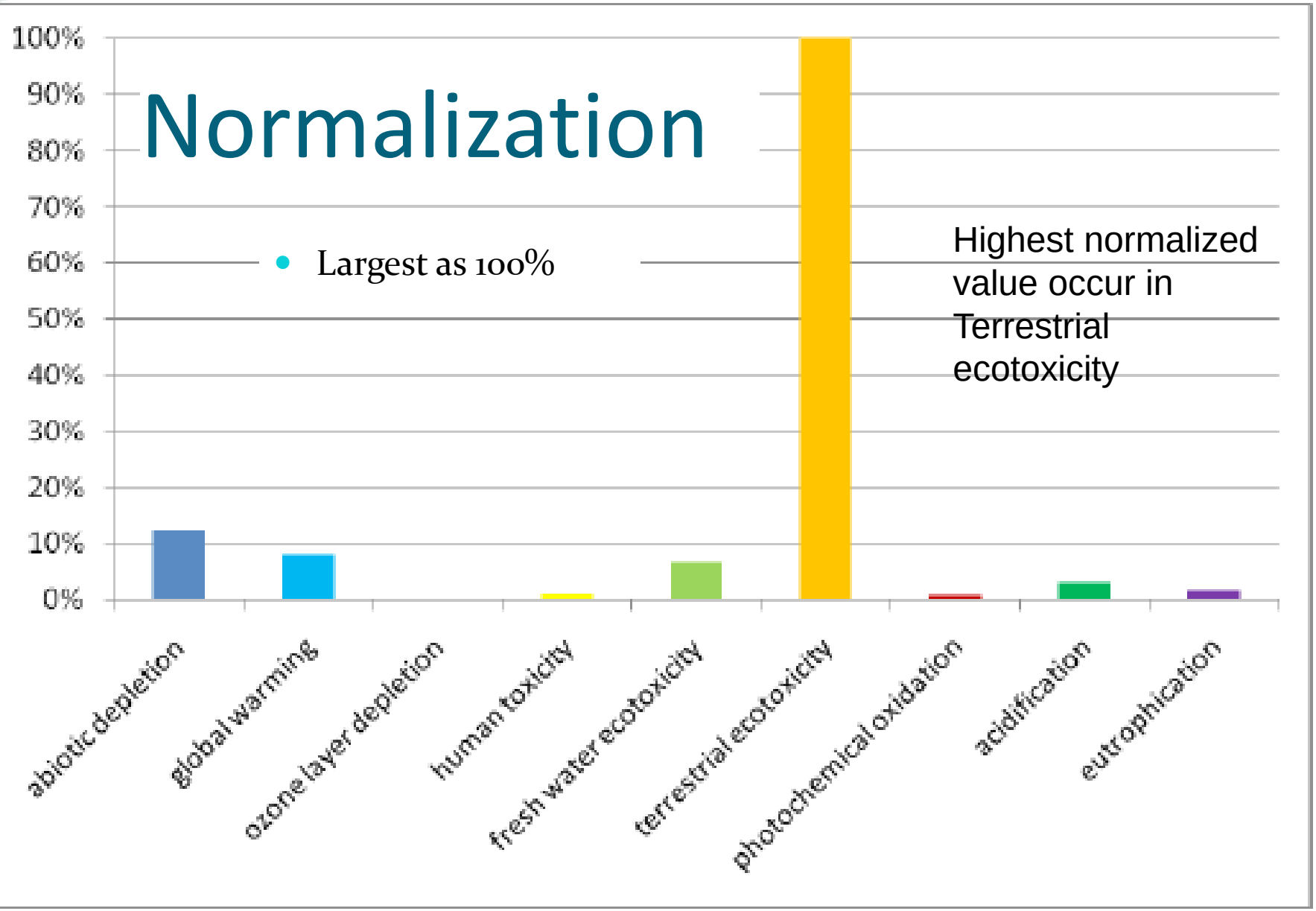


Figure 3. Normalized results per impact category of a school desk made from FSC certified wood (based on data from Gonzalez et al., 2008).

Conclusion

- All things considered. . .
  - Board drying consumes most electricity
    - Needs to explore methods to cut and dry the boards with lower (or no) fossil fuel consumption
  - Identifying ways to use the waste sawdust
  - Redesigning the desks to last more than eight years