CIRAIG™

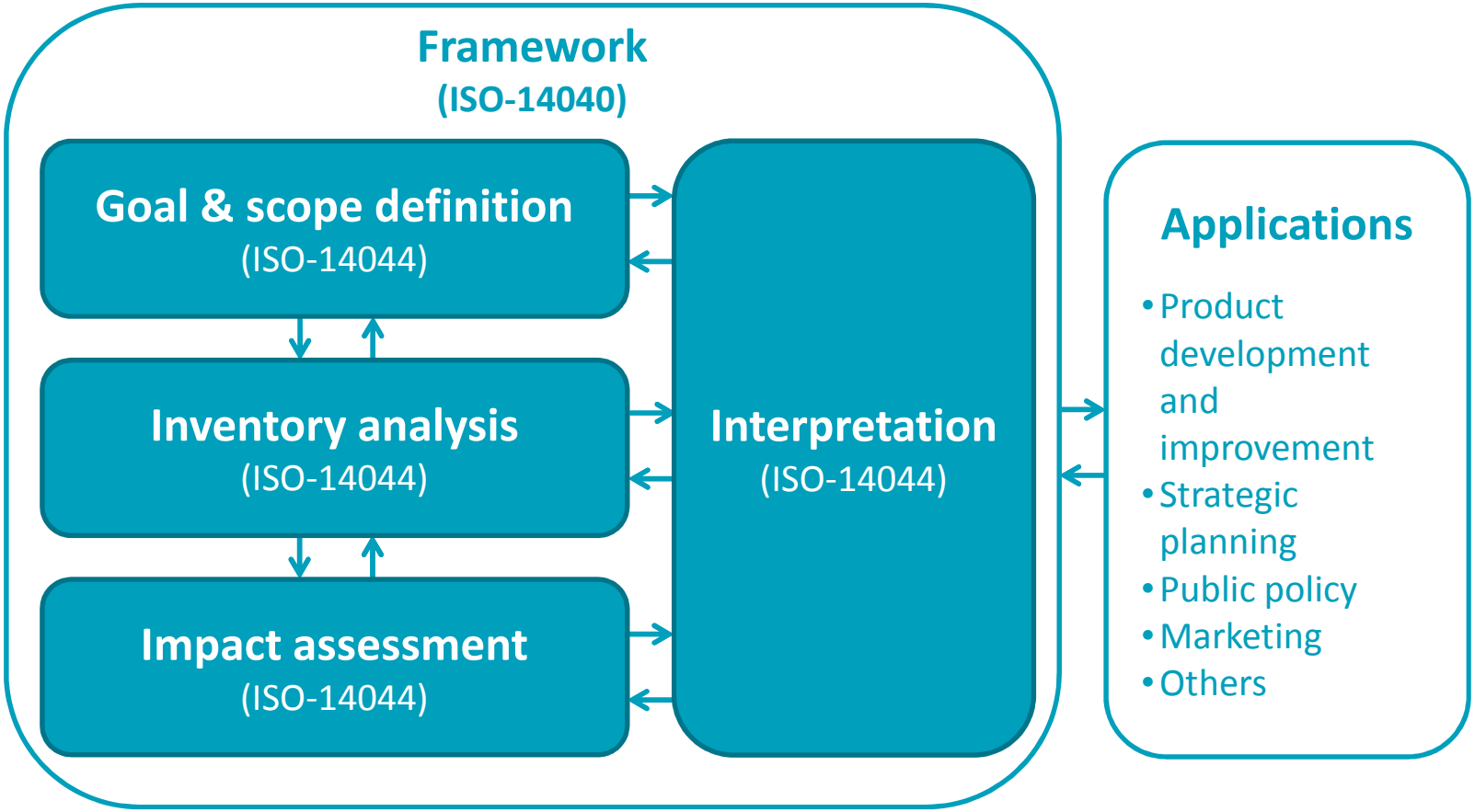
International Reference Centre for the
Life Cycle of Products, Processes and Services

LIFE CYCLE IMPACT ASSESSMENT

Manuele Margni maneuele.margni@polymtl.ca

ESG UQÀM POLYTECHNIQUE MONTRÉAL

The ISO process



Iterative process

- The collected data may lead to the modification of the scope of the study
- The goal itself can also be revised

CIRAIG™

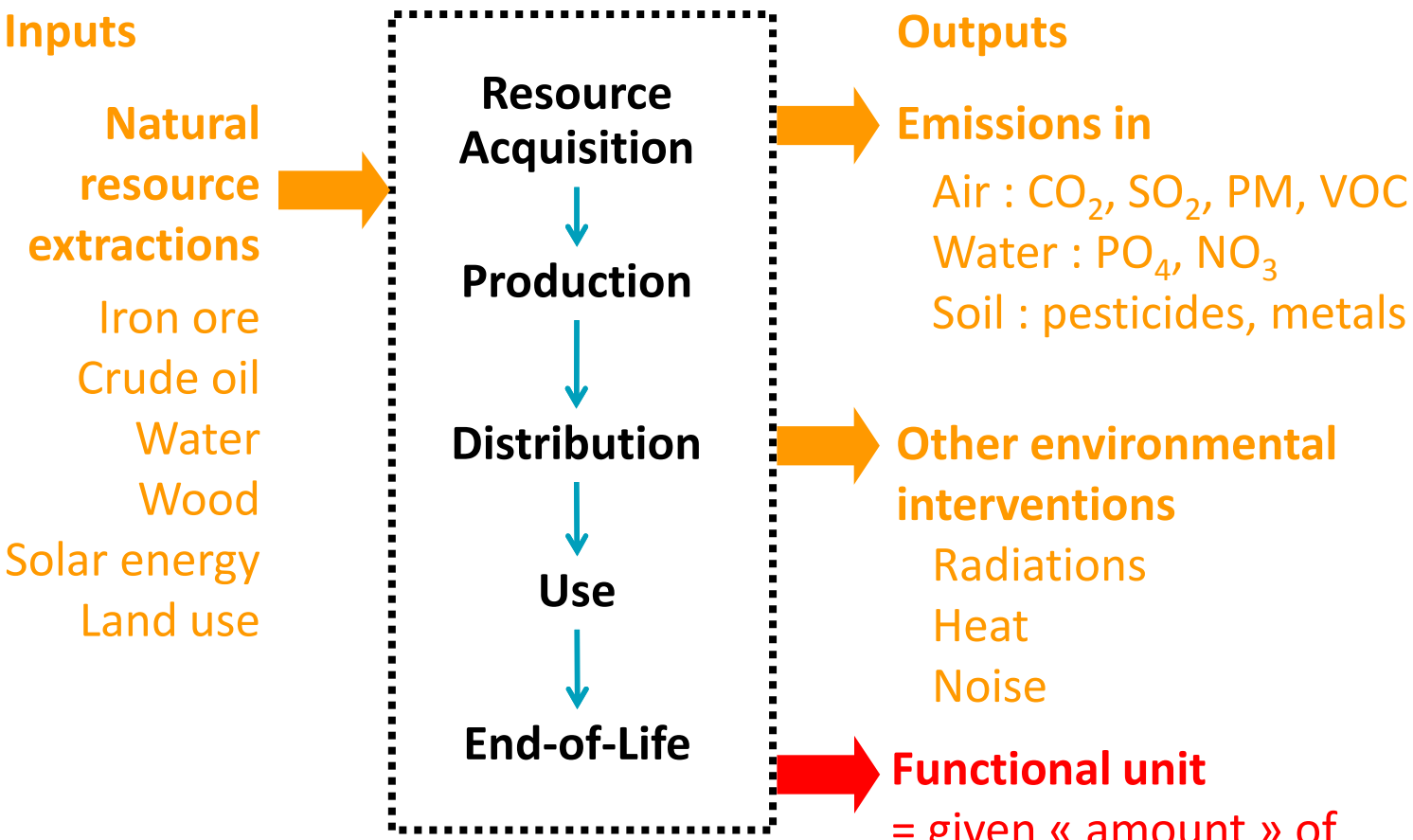
Purpose of Life Cycle Impact Assessment

- Aims at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product

- to better understand the environmental significance of Life Cycle Inventory results

CIRAIG™

Life cycle inventory



CIRAIG™

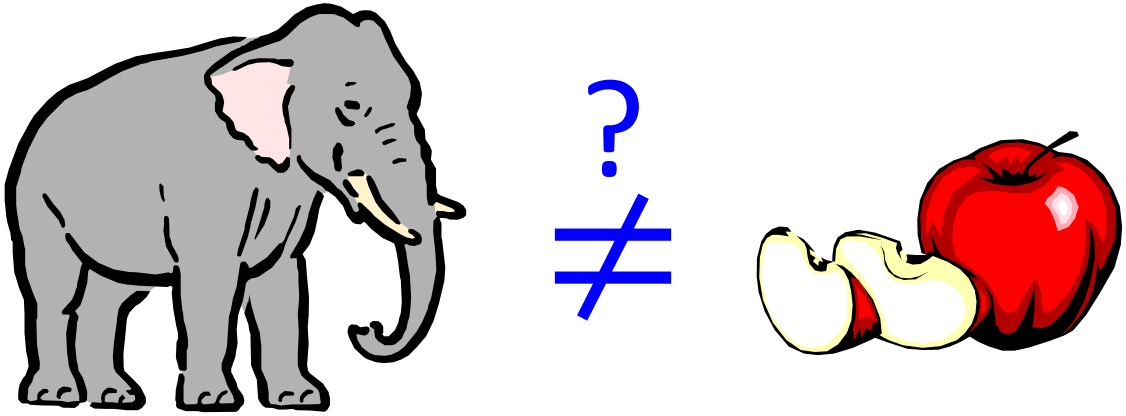
Problem = weigthing pollutants

Weighting is not straightforward

➔ like comparing apples and oranges

When considering the amounts emitted and the very different nature of the extractions and emissions included in inventory

➔ more like comparing an elephant and an apple!



CIRAIG™

Life cycle impacts assessment

Elementary flows

Inputs:

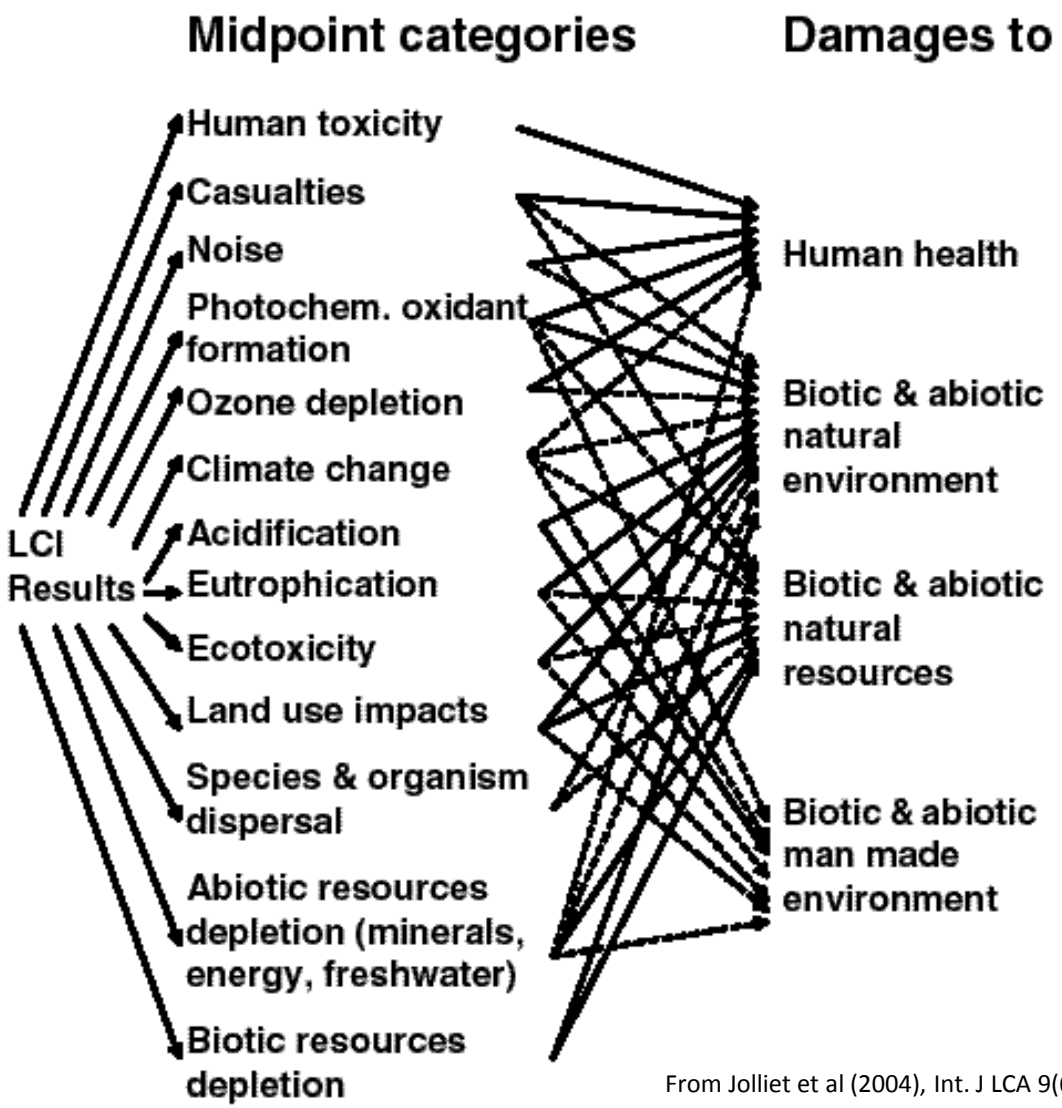
Iron ore
Crude oil
Water
Wood
Solar energy
Land use
…

Outputs :

CO_2
SO_2
PM
VOC
PO_4
NO_3
Pesticides
Metals
…

CIRAIG™

UNEP/SETAC Life Cycle Initiative LCIA framework



From Jolliet et al (2004), Int. J LCA 9(6)

CIRAIG™

Cause-effect chain

It represents a series (or network) of interconnected environmental mechanisms

It allows to describe the pathways leading to endpoints within each impact category

CIRAIG™

Cause-effect chain and indicator for climate change

Global warming

Cause and effect chain = a sequence of Environmental mechanisms

1. GHG emission (elementary flow)
2. Infrared radiative forcing (1^{st} order effect) — Midpoint Category indicator
3. Increase in global temperatures (2^{nd} order effect)
4. Sea level rise due to water expansion and glaciers melting (3^{rd} order effect)

…

n. Damage to human health and ecosystems (n^{th} order effect) — Damage Category indicator

CIRAIG™

Midpoint vs. Damage Impact categories

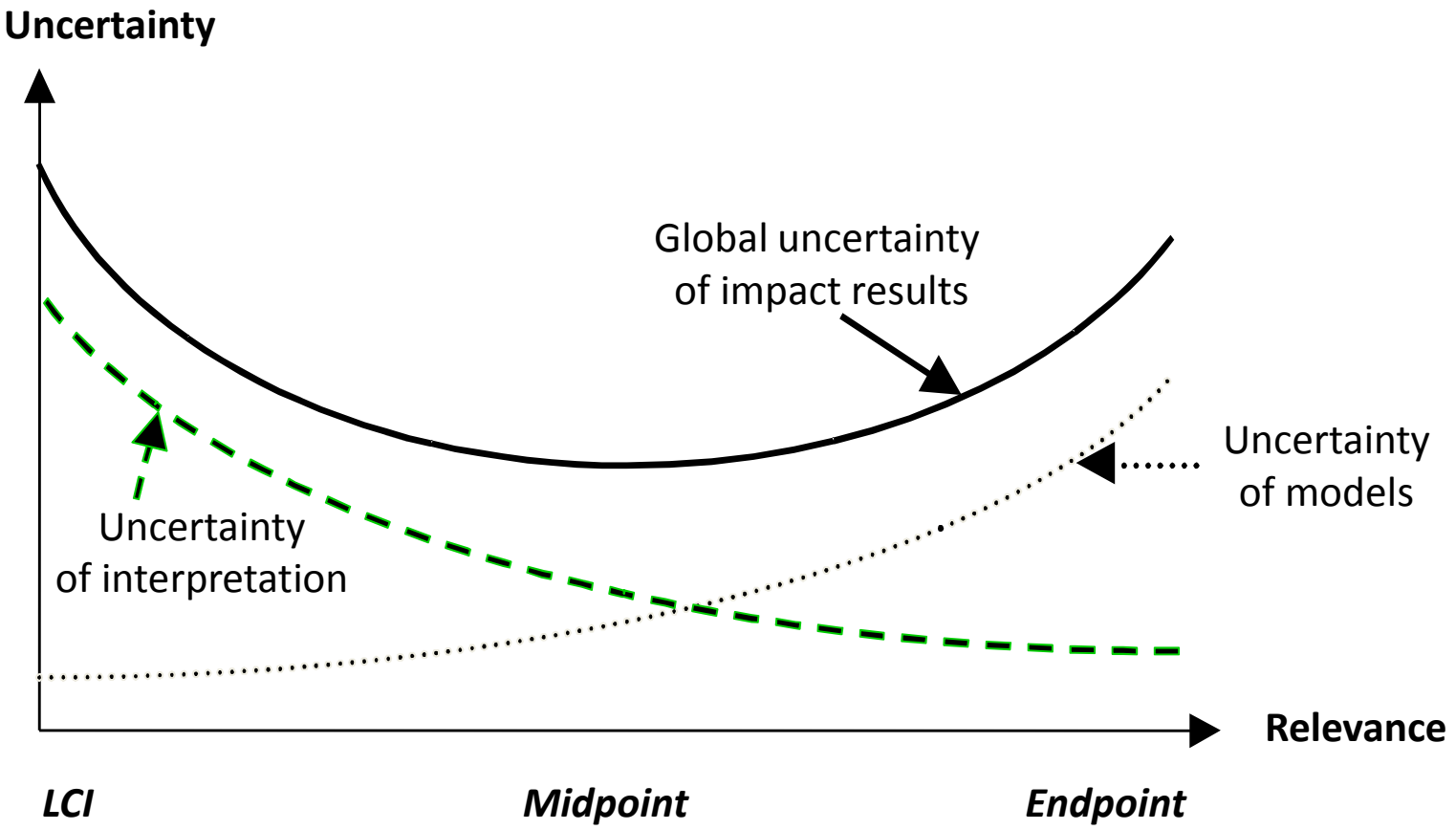
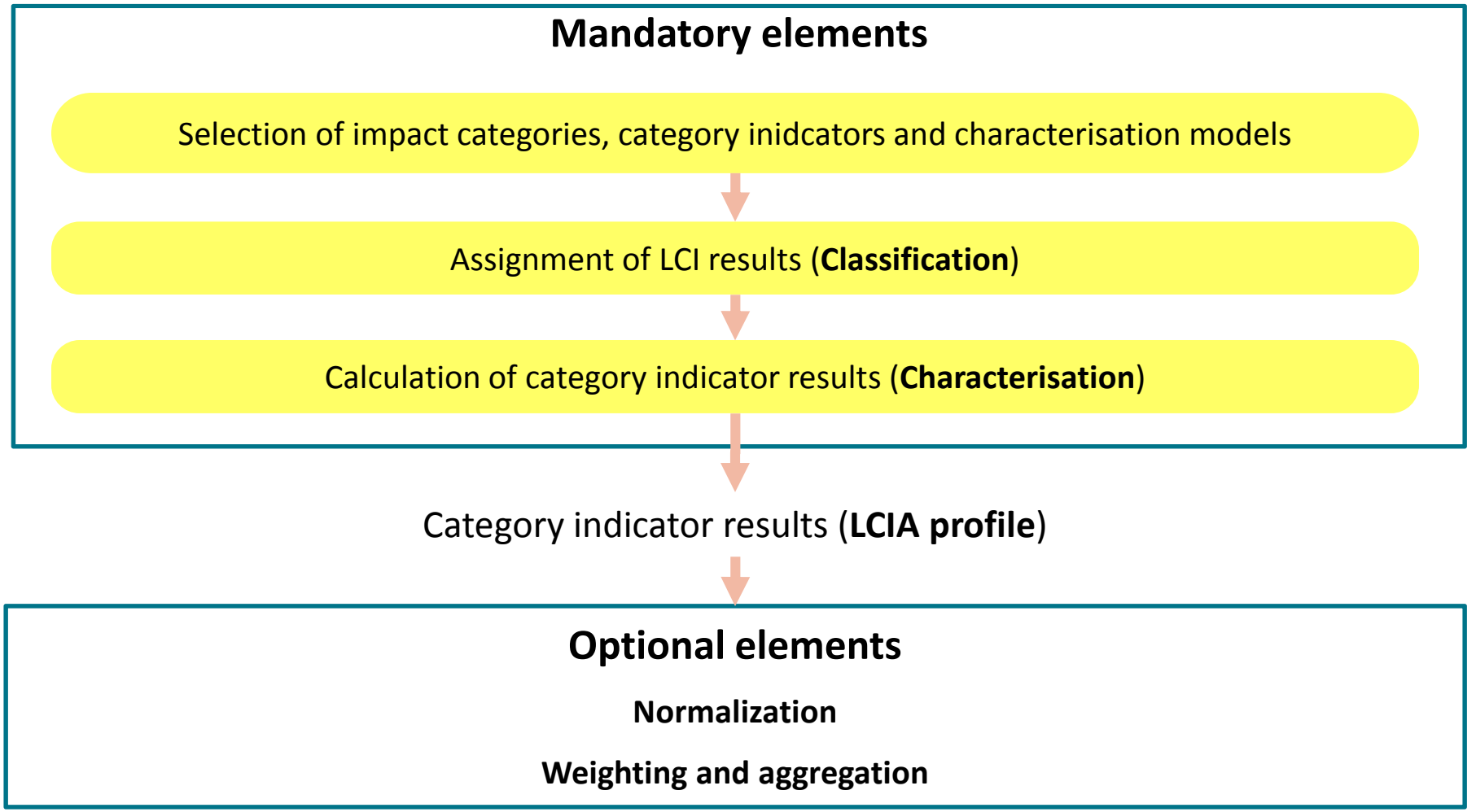


Figure of J.Potting, M.Hauschild and O.Jolliet

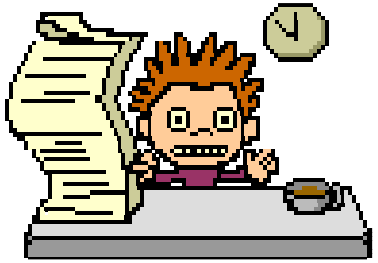
CIRAIG™

The LCIA procedure



CIRAIG™

Classification - Definition

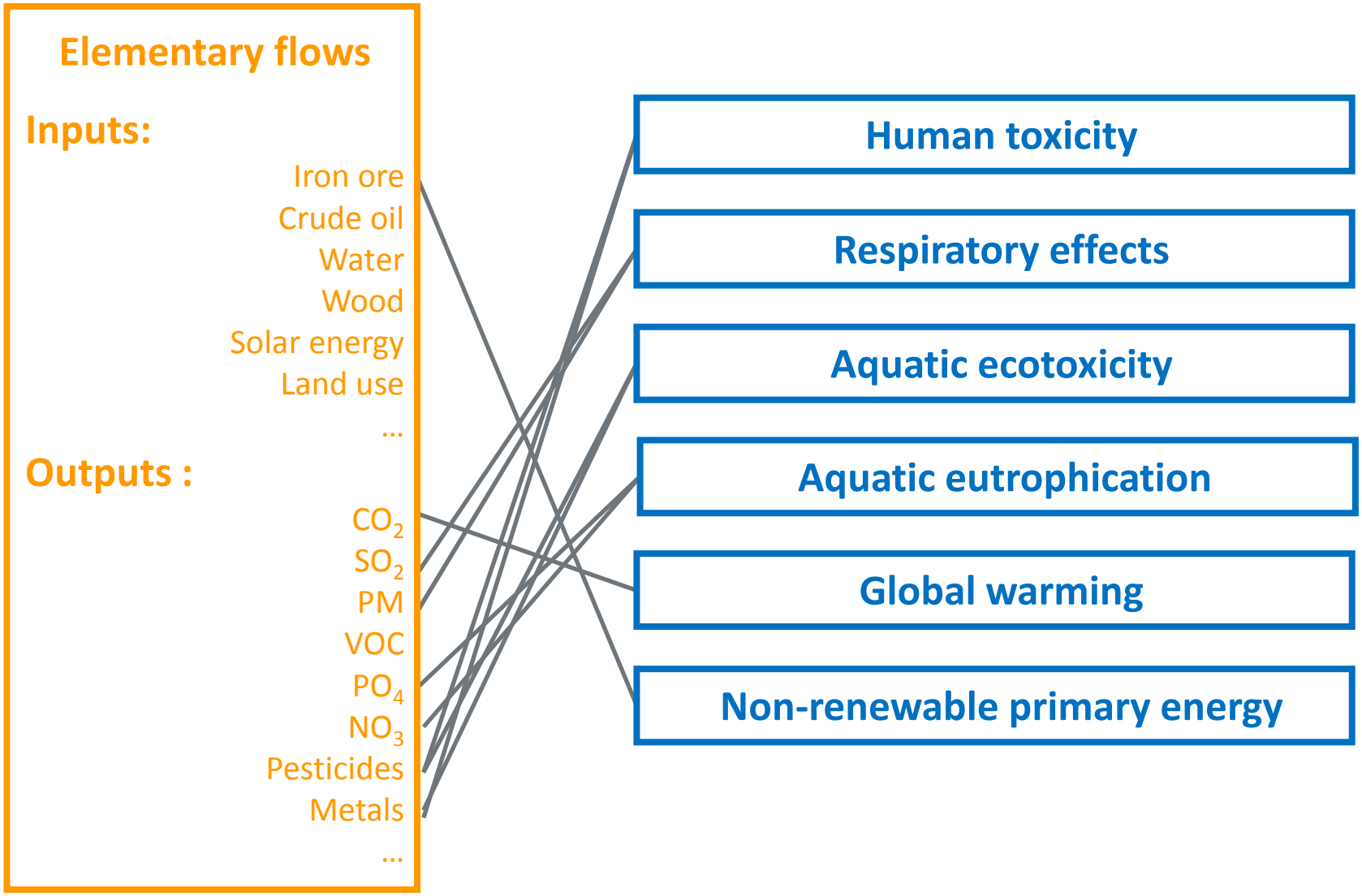


Assignment of LCI results to the selected impact categories

Example: CO_2, CH_4 et N_2O affect the global warming potential.

This element is required to proceed to the LCIA phase.

Classification



CIRAIG™

Classification – In which category?

1. In parallel

   Ex: SO_2 → acidification
   → human health (through inhalation)

2. In series

   a) directly

      Ex: metals → ecotoxic effects → toxic effects (through food chain)

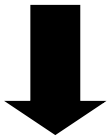
   b) indirectly

      Ex: SO_2 → acidification
      → Al mobilisation
      → ecotoxic effects

CIRAIG™

Characterisation: definition

It implies to convert the assigned LCI results into commun units within a given impact category



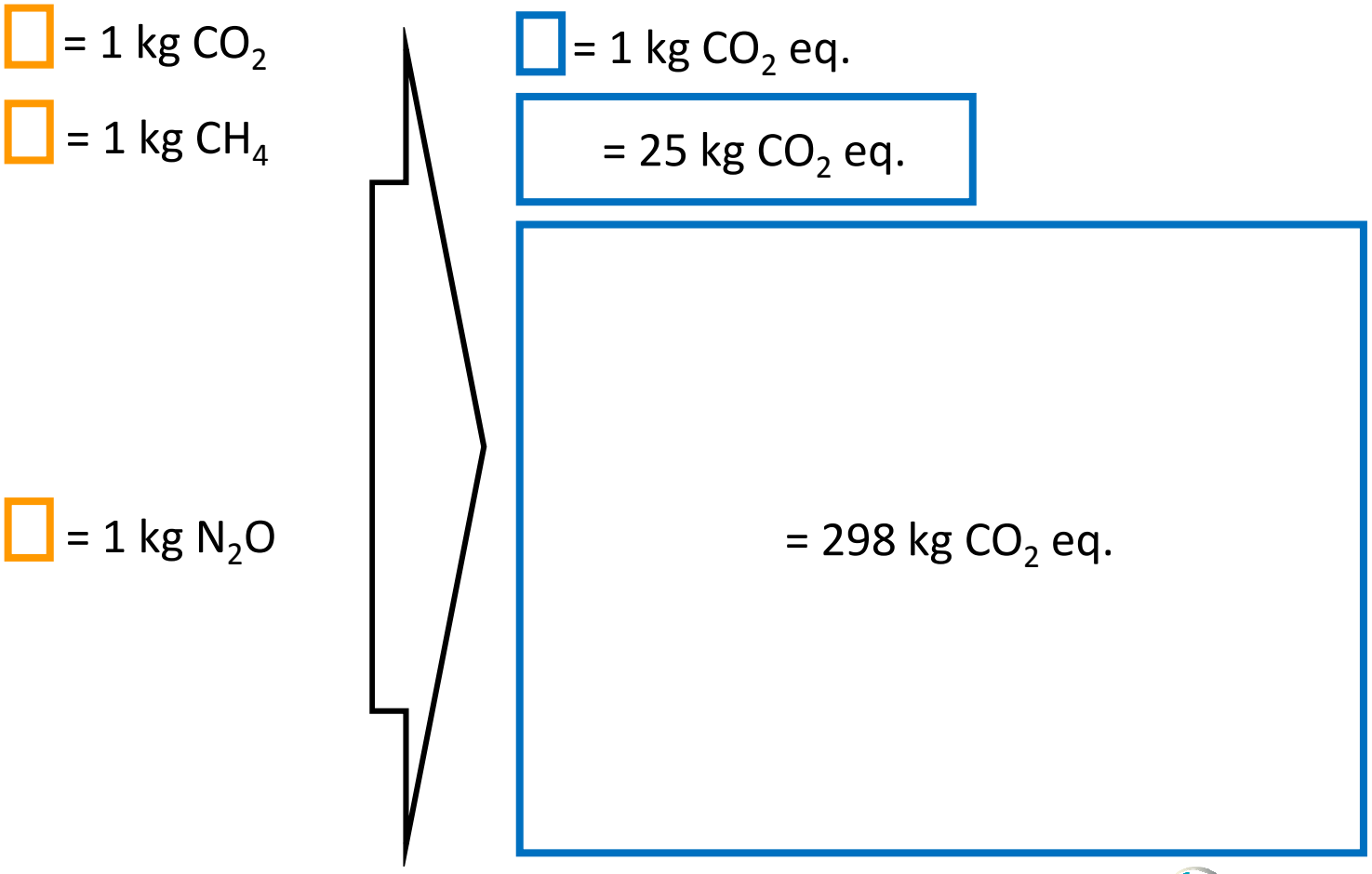
Calculation of category indicator results in numerical format

1. Contribution of inputs and outputs to different impact categories are evaluated.
2. The contributions to the same impact category are summed up.

CIRAIG™

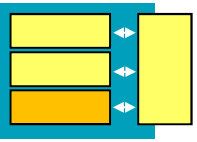
Characterisation: example

Global warming



CIRAIG™

Characterisation model



Global warming

- Developed by the IPCC
- Used to calculate the characterisation factors
- Considers the infrared radiative forcing generated by a greenhouse gas emitted in the atmosphere over different time horizons (20, 100 ot 500 years)
- Two key parameters: atmospheric lifetime and heat absorption

CIRAIG™

Characterisation factor

Global warming

Characterisation factor = Global warming potential (GWP)

Unit = kg CO_2 eq./kg gas

$$GWP_i = \frac{\int_0^T a_i . C_i(t).dt}{\int_0^T a_{CO_2} . C_{CO_2}(t).dt}$$

where:

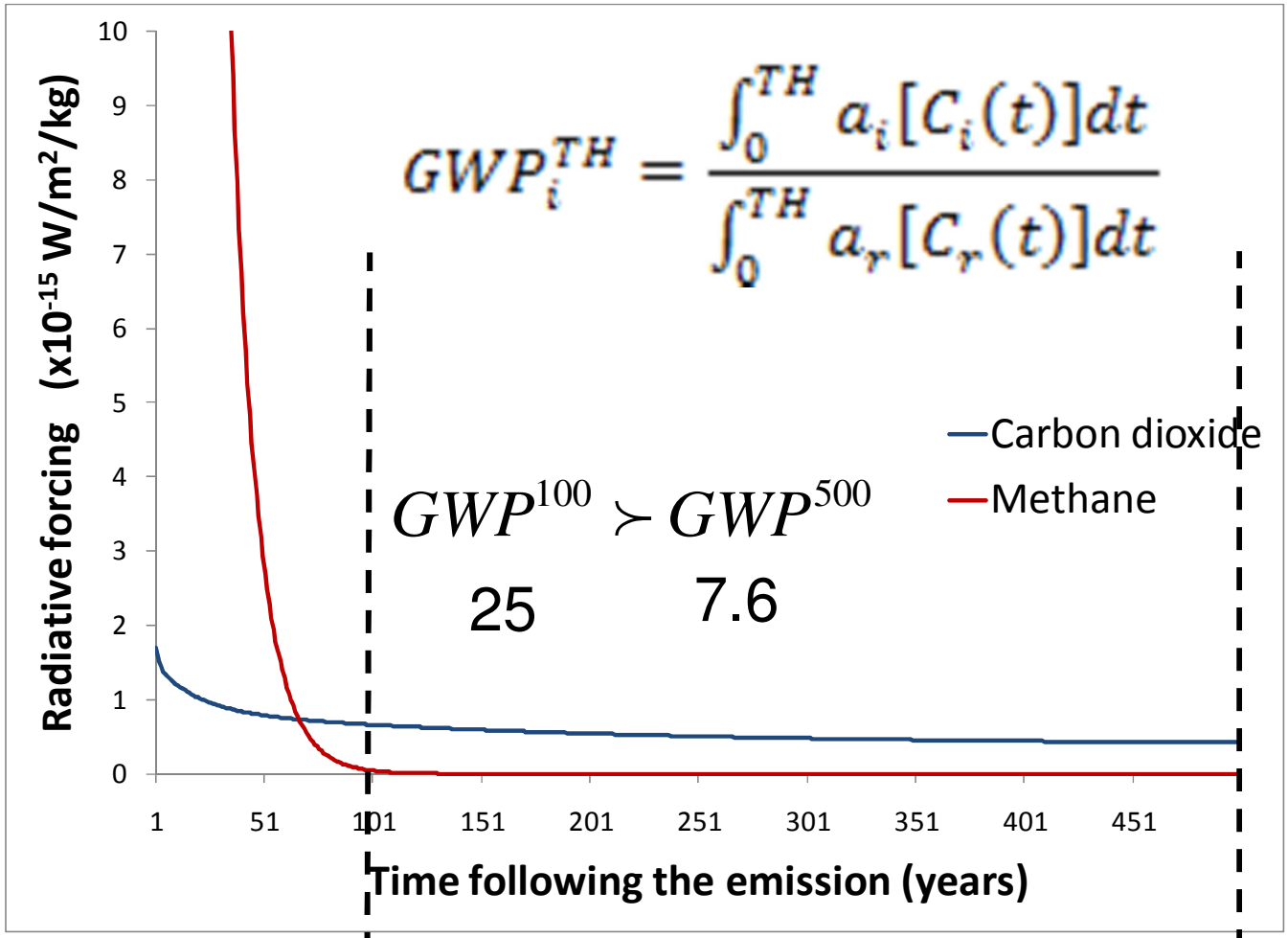
a_i	radiative efficiency per unit of concentration of gaz i
$C_i(t)$	concentration of gaz i at time t
T	time horizon

CIRAIG™

Table 2.14. *Lifetimes, radiative efficiencies and direct (except for CH_4) GWPs relative to CO_2. For ozone-depleting substances and their replacements, data are taken from IPCC/TEAP (2005) unless otherwise indicated.*

Industrial Designation or Common Name (years)	Chemical Formula	Lifetime (years)	Radiative Efficiency (W m^{-2} ppb^{-1})	Global Warming Potential for Given Time Horizon			
				SAR‡ (100-yr)	20-yr	100-yr	500-yr
Carbon dioxide	CO_2	See below[a]	[b]1.4x10^{-5}	1	1	1	1
Methane[c]	CH_4	12[c]	3.7x10^{-4}	21	72	25	7.6
Nitrous oxide	N_2O	114	3.03x10^{-3}	310	289	298	153
Substances controlled by the Montreal Protocol							
CFC-11	CCl_3F	45	0.25	3,800	6,730	4,750	1,620
CFC-12	CCl_2F_2	100	0.32	8,100	11,000	10,900	5,200
CFC-13	$CClF_3$	640	0.25		10,800	14,400	16,400
CFC-113	CCl_2FCClF_2	85	0.3	4,800	6,540	6,130	2,700
CFC-114	$CClF_2CClF_2$	300	0.31		8,040	10,000	8,730
CFC-115	$CClF_2CF_3$	1,700	0.18		5,310	7,370	9,990
Halon-1301	$CBrF_3$	65	0.32	5,400	8,480	7,140	2,760
Halon-1211	$CBrClF_2$	16	0.3		4,750	1,890	575
Halon-2402	$CBrF_2CBrF_2$	20	0.33		3,680	1,640	503
Carbon tetrachloride	CCl_4	26	0.13	1,400	2,700	1,400	435
Methyl bromide	CH_3Br	0.7	0.01		17	5	1
Methyl chloroform	CH_3CCl_3	5	0.06		506	146	45
HCFC-22	$CHClF_2$	12	0.2	1,500	5,160	1,810	549
HCFC-123	$CHCl_2CF_3$	1.3	0.14	90	273	77	24
HCFC-124	$CHClFCF_3$	5.8	0.22	470	2,070	609	185
HCFC-141b	CH_3CCl_2F	9.3	0.14		2,250	725	220
HCFC-142b	CH_3CClF_2	17.9	0.2	1,800	5,490	2,310	705
Perfluorinated compounds							
Sulphur hexafluoride	SF_6	3,200	0.52	23,900	16,300	22,800	32,600
Nitrogen trifluoride	NF_3	740	0.21		12,300	17,200	20,700
PFC-14	CF_4	50,000	0.10	6,500	5,210	7,390	11,200
PFC-116	C_2F_6	10,000	0.26	9,200	8,630	12,200	18,200

Différence between GWP100 and GWP500



100 ans

GWP100 = 25 kgCO2/kgCH4

500 ans

GWP100 = 7.6 kgCO2/kgCH4

LCIA in practice

1. Choice of LCIA method
   (pre-established choice of impact categories, category indicators, characterisation model and factors)
2. Classification
3. Characterisation
   (calculation of category indicator results or impact scores)

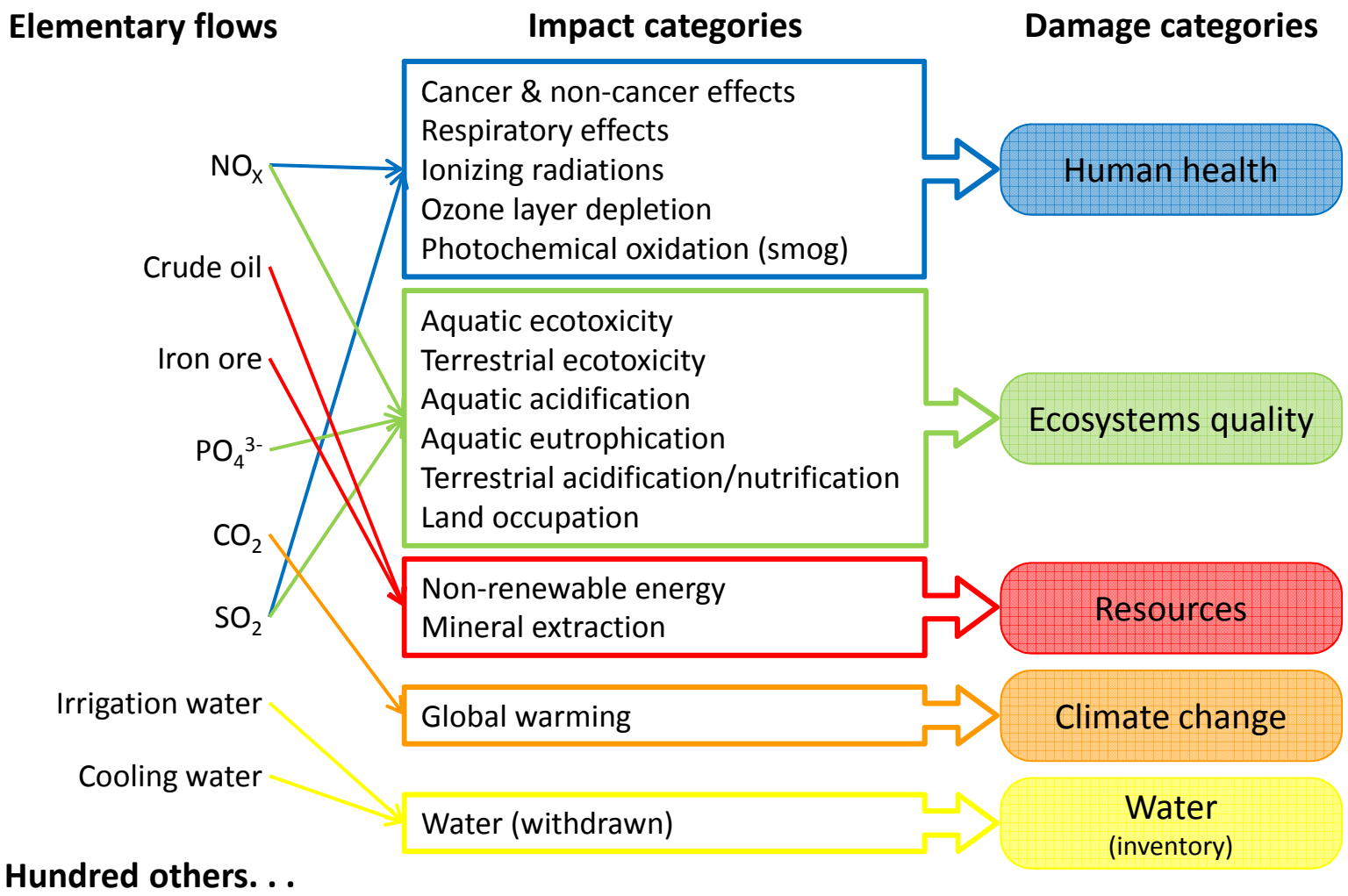
$$S_j = \sum_i CF_{ji} \cdot m_i$$

where:

- S_j Impact score for category j (ex. in kg CO_2 eq.)
- CF_{ji} Characterisation factor of elementarey flow i for impact category j (ex. in kg CO_2 eq./kg of i)
- m_i Elementary flow realted to functional unit (ex. kg of i)

CIRAIG™

IMPACT 2002+ Life cycle impact assessment methodology



CIRAIG™

IMPACT2002+ – Midpoints

Midpoint category		Indicator unit
Carcinogens	C	kg C_2H_5Cl eq. (air)
Non-carcinogens	NC	kg C_2H_5Cl eq. (air)
Respiratory – inorganics	RI	kg $PM_{2.5}$ eq. (air)
Ionizing radiations	IR	Bq C^{14} eq. (air)
Ozone layer depletion	OL	kg CFC-11 eq. (air)
Respiratory – organics	RO	kg C_2H_6 eq. (air)
Aquatic ecotoxicity	AE	kg Triethylene glycol eq. (water)
Terrestrial ecotoxicity	TE	kg Triethylene glycol eq. (water)
Terrestrial acidification/nutrification	TAN	kg SO_2 eq. (air)
Land occupation	LO	m^2.yr organic arable land eq.
Aquatic acidification	AA	kg SO_2 eq. (air)
Aquatic eutrophication	AE	kg PO_4^{3-} eq. (water)
Global warming	GW	kg CO_2 eq. (air)
Non-renewable primary energy	NE	MJ primary
Mineral extraction	ME	MJ surplus

CIRAIG™

IMPACT2002+ – Endpoints

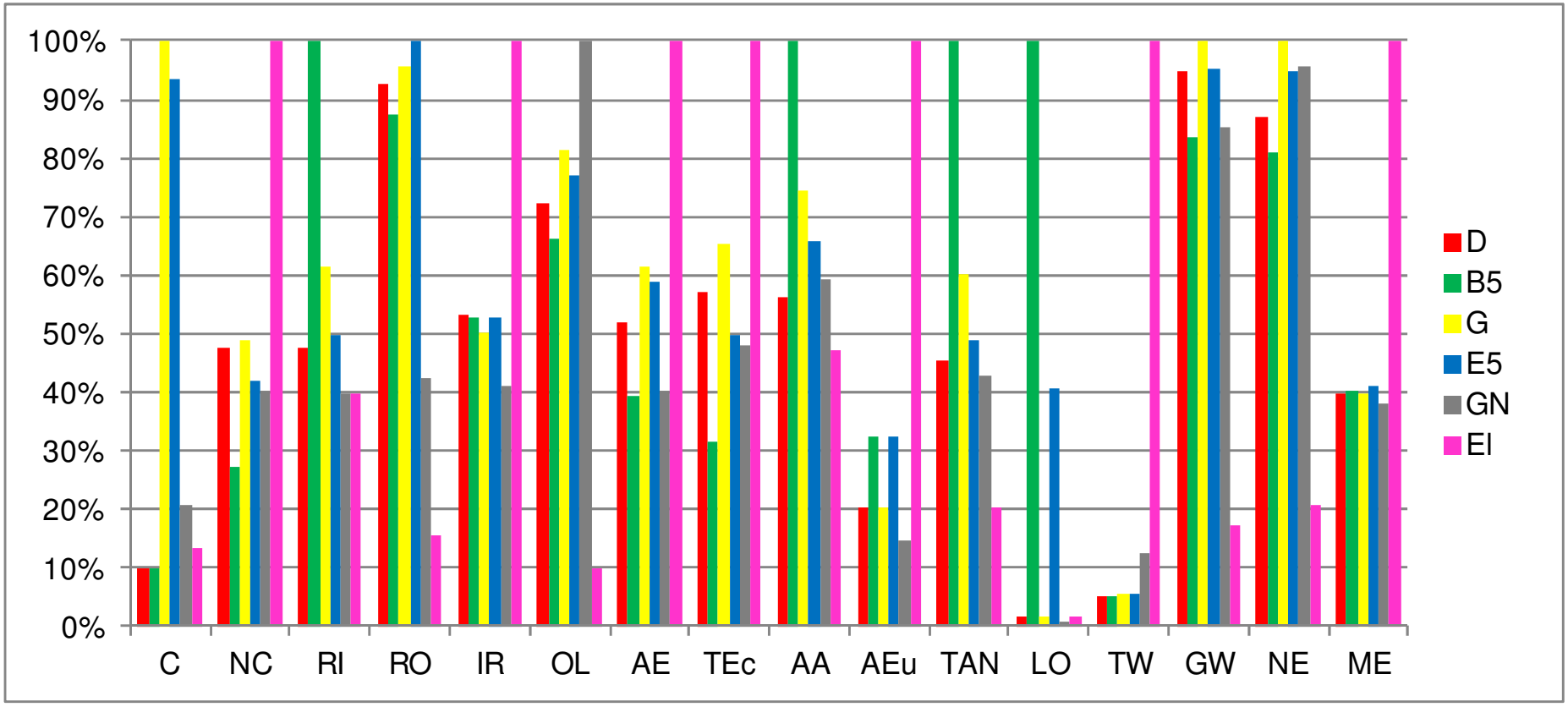
Endpoint category		Indicator unit
Human health	HH	DALY
Ecosystem quality	EQ	PDF.m^2.yr
Climate change	CC	kg CO_2 eq.
Resources	R	MJ primary

DALY (Disability Adjusted Life Years): years of life (in good health) loss, takes into account premature deaths and time spent sick

PDF.m^2.yr : Potentially Disappeared Fraction of species over a certain area over a certain time

CIRAIG™

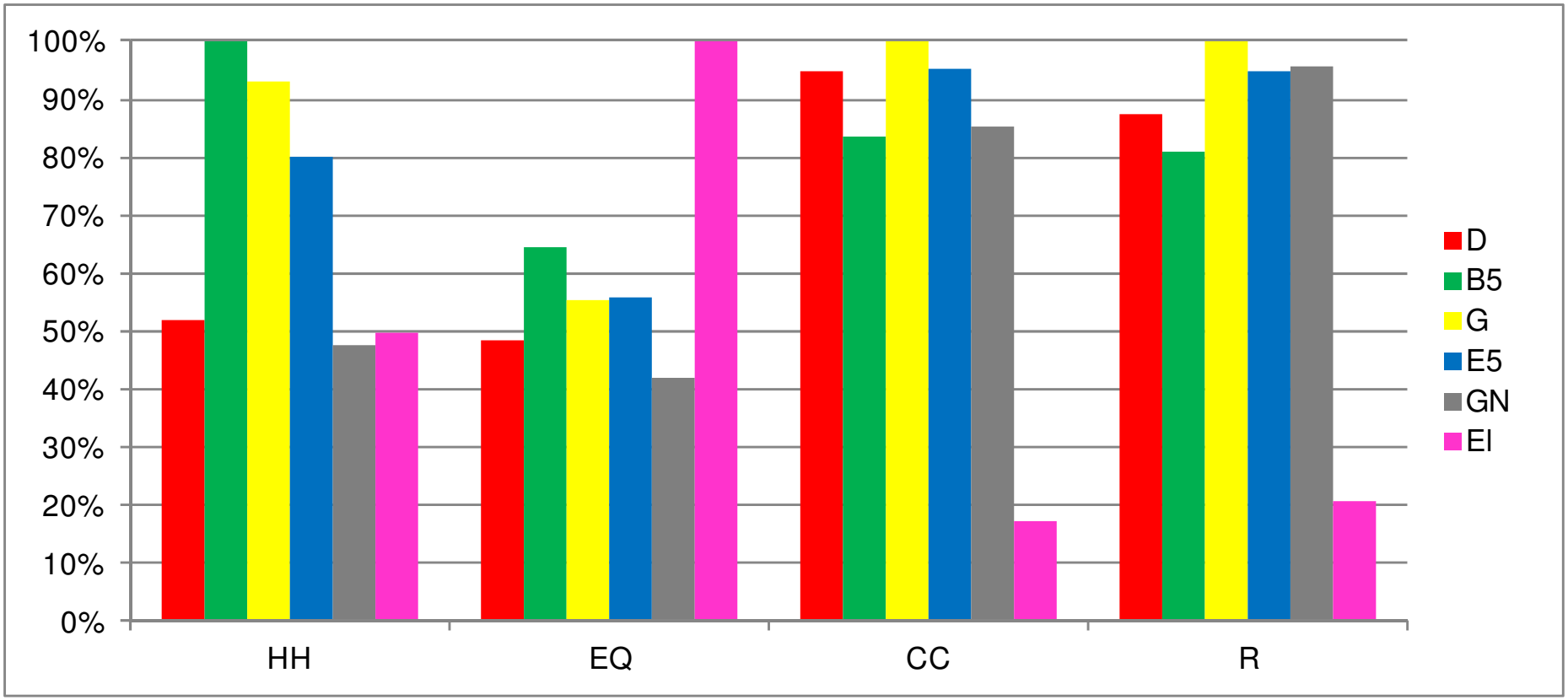
IMPACT2002+ – Midpoints profile for the cars



Diesel	Biodiesel 5%	Gasoline	Ethanol 5%	Natural gas	Electricity

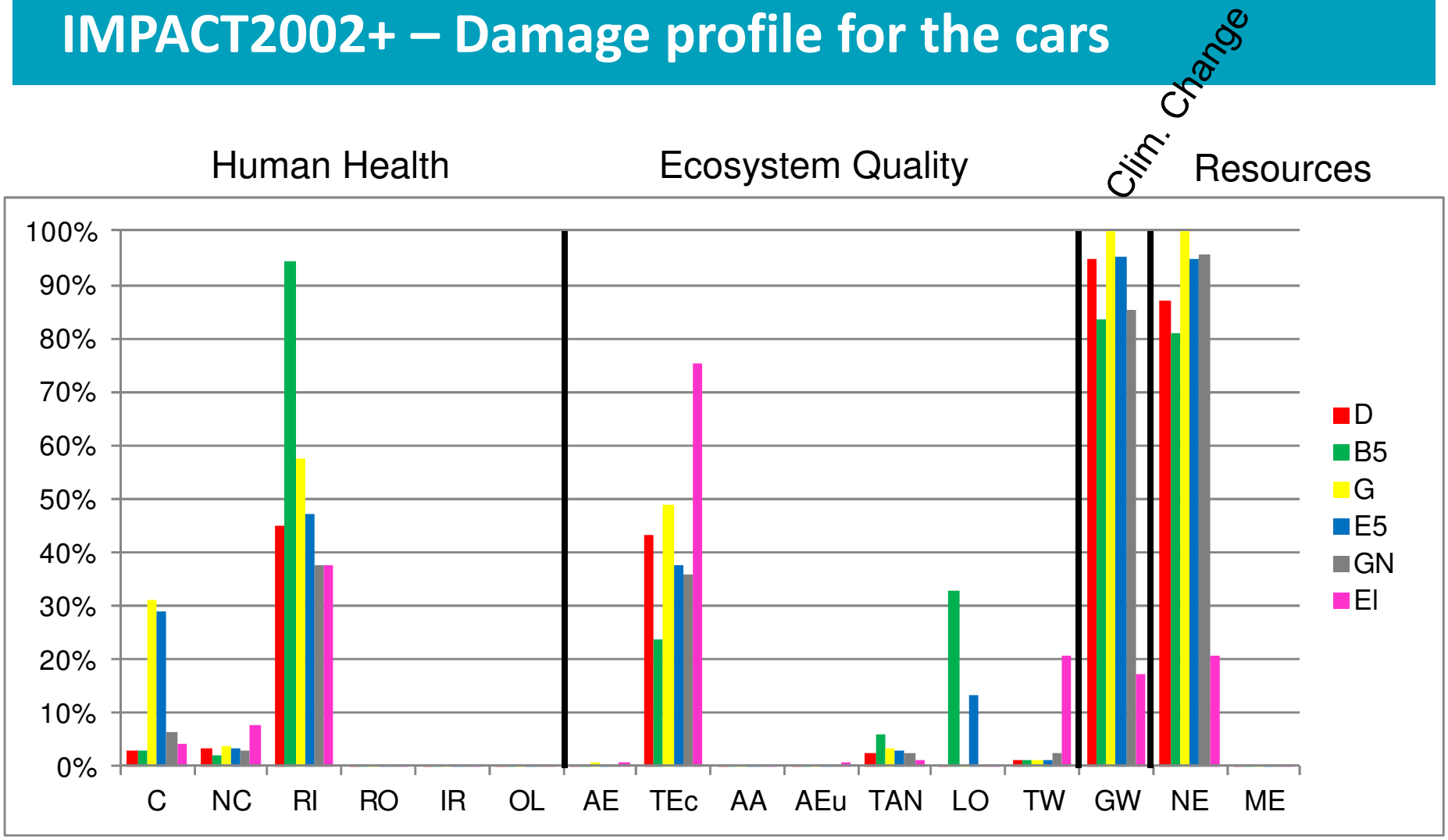
CIRAIG™

IMPACT2002+ – Damage profile for the cars



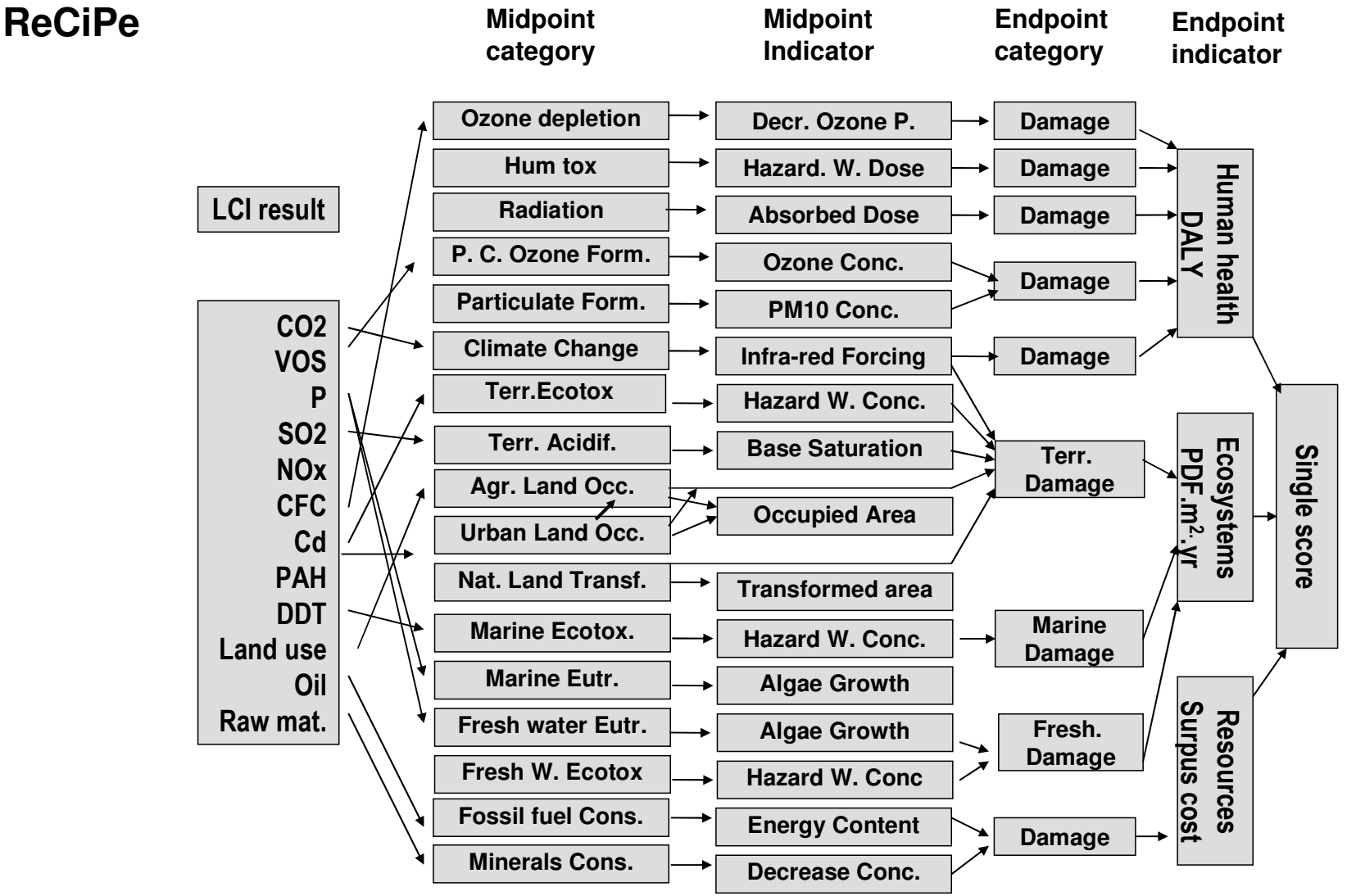
CIRAIG™

IMPACT2002+ – Damage profile for the cars

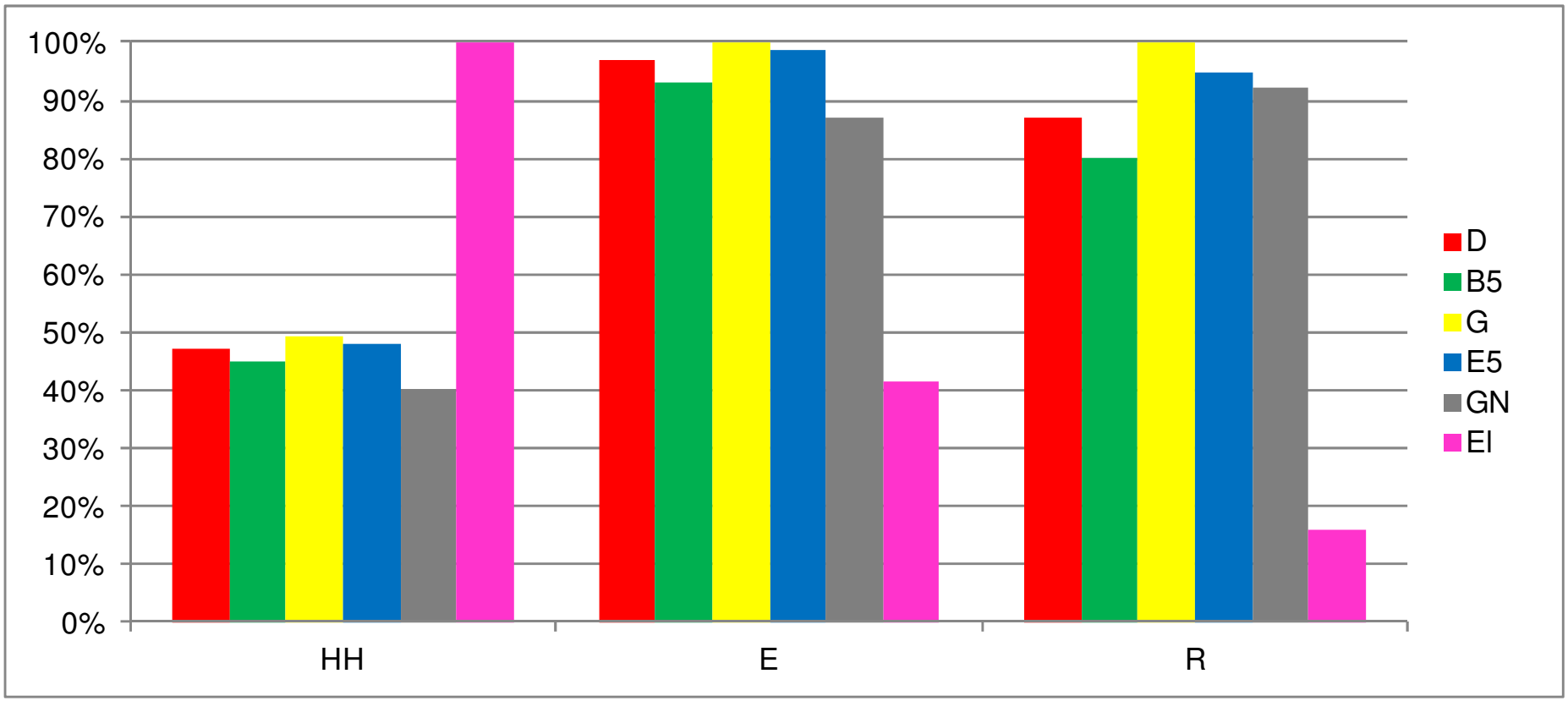


CIRAIG™

ReCiPe Life Cycle Impact Assessment Methodology



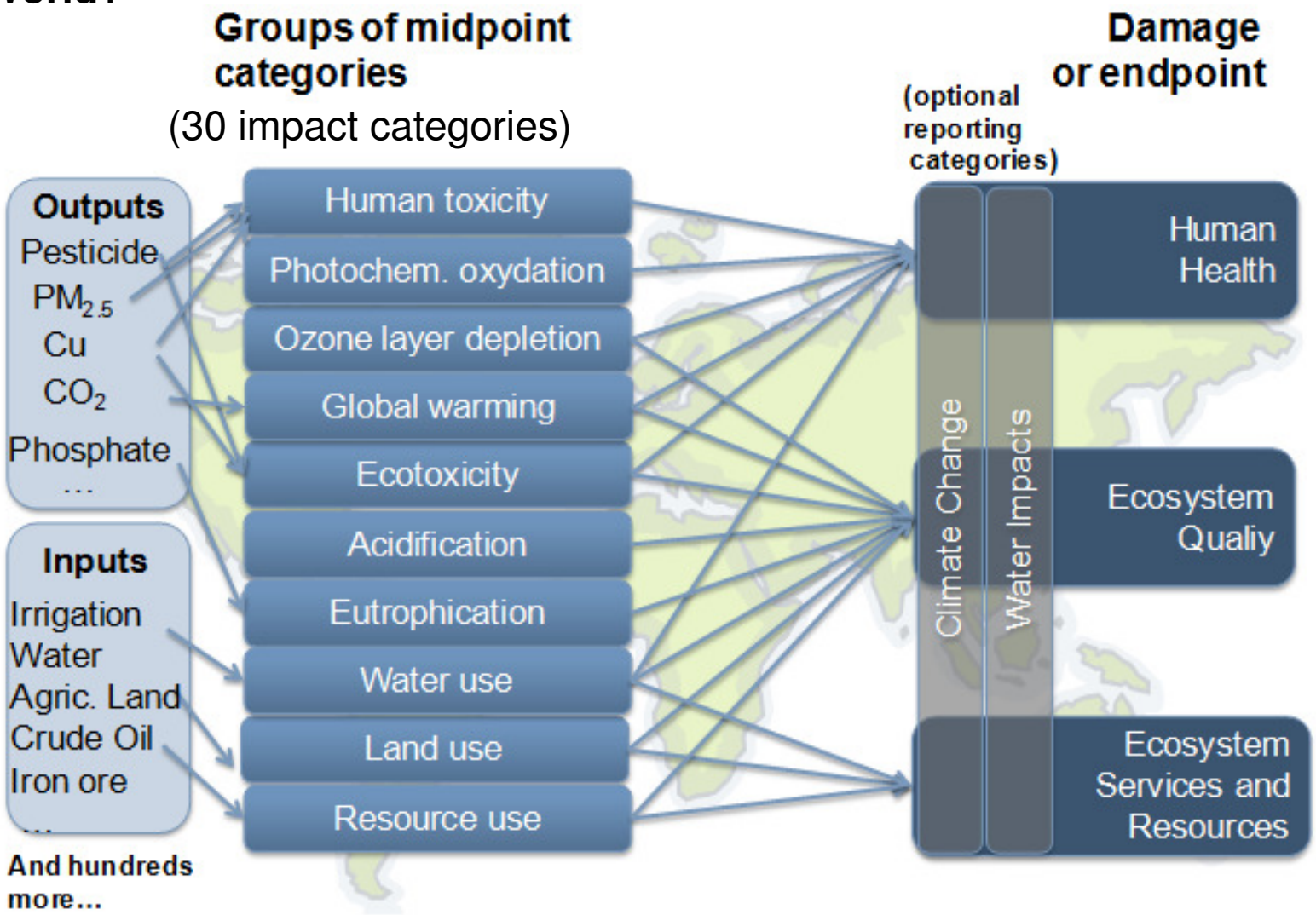
ReCiPe (Egalitarian) – Endpoints for the cars



CIRAIG™

IMPACT World+ Life Cycle Impact Assessment Methodology

IMPACT World+



Retrospective of LCIA methodological development

1984: Critical Volume (BUS)

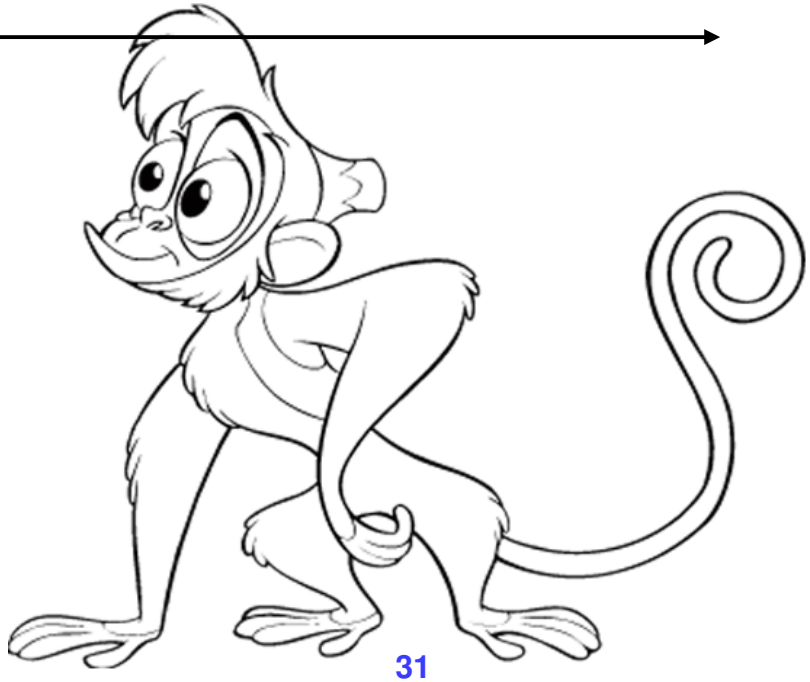
1991: Ecoscarcity

1995: Ecoindicator95 (Goedkoop)

1993: EPS (Steen)

1992: CML (Heijungs)

1997: EDIP97 (Wenzel)



At the beginning of ‘90

3 school of thoughts:

Ecoscarcity 1991, (or Ecopoints),
distance to target

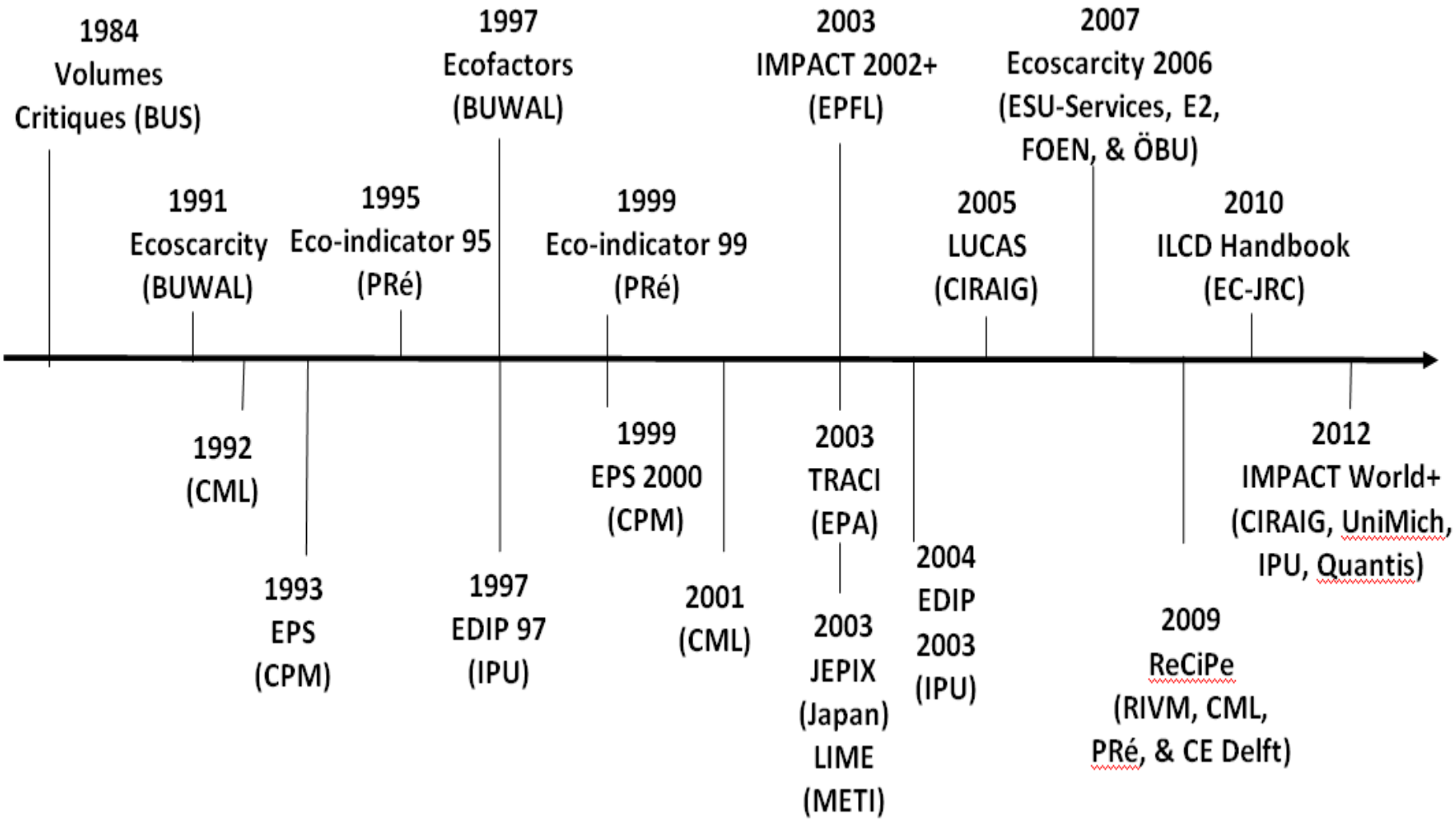
CML 1992, midpoint modeling

- **EDIP 97 and 2003, TRACI, …**

EPS 1993, damage modeling

- **Ecoindicator 99, IMPACT 2002+, LIME, ReCiPe, …**

Retrospective of LCIA methodological development



CIRAIG™

Classification of existing LCIA methodologies

Methodology oriented:

Midpoint	**Damages** (or Endpoint)	**Midpoint and Damages**
JEPIX	Ecoindicator 99	IMPACT 2002+
CML	EPS	LIME
(Swiss) Ecoscarcity		EPS 2000
EDIP		ReCiPe
LUCAS		IMPACT World+
ILCD Handbook		

CIRAIG™

Méthodologies ACVI et liens web

Eco-indicator 99: http://www.pre.nl/eco-indicator99/

EDIP 2003: http://ipt.dtu.dk/~mic/EDIP2003

EPS 2000d: http://eps.esa.chalmers.se/

CML 2001, (Dutch) Handbook on LCA:
http://www.leidenuniv.nl/cml/ssp/projects/lca2/lca2.html

Impact 2002+: http://www.impactmodeling.org

IMPACT World+: http://www.impactworldplus.org

JEPIX: www.jepix.org

LIME: http://www.jemai.or.jp/lcaforum/index.cfm

Swiss Ecoscarcity: http://www.e2mc.com/BUWAL297%20english.pdf

TRACI: http://epa.gov/ORD/NRMRL/std/sab/iam_traci.htm

LUCAS http://www.ciraig.org

ReCiPe http://www.lcia-recipe.net/

CIRAIG™

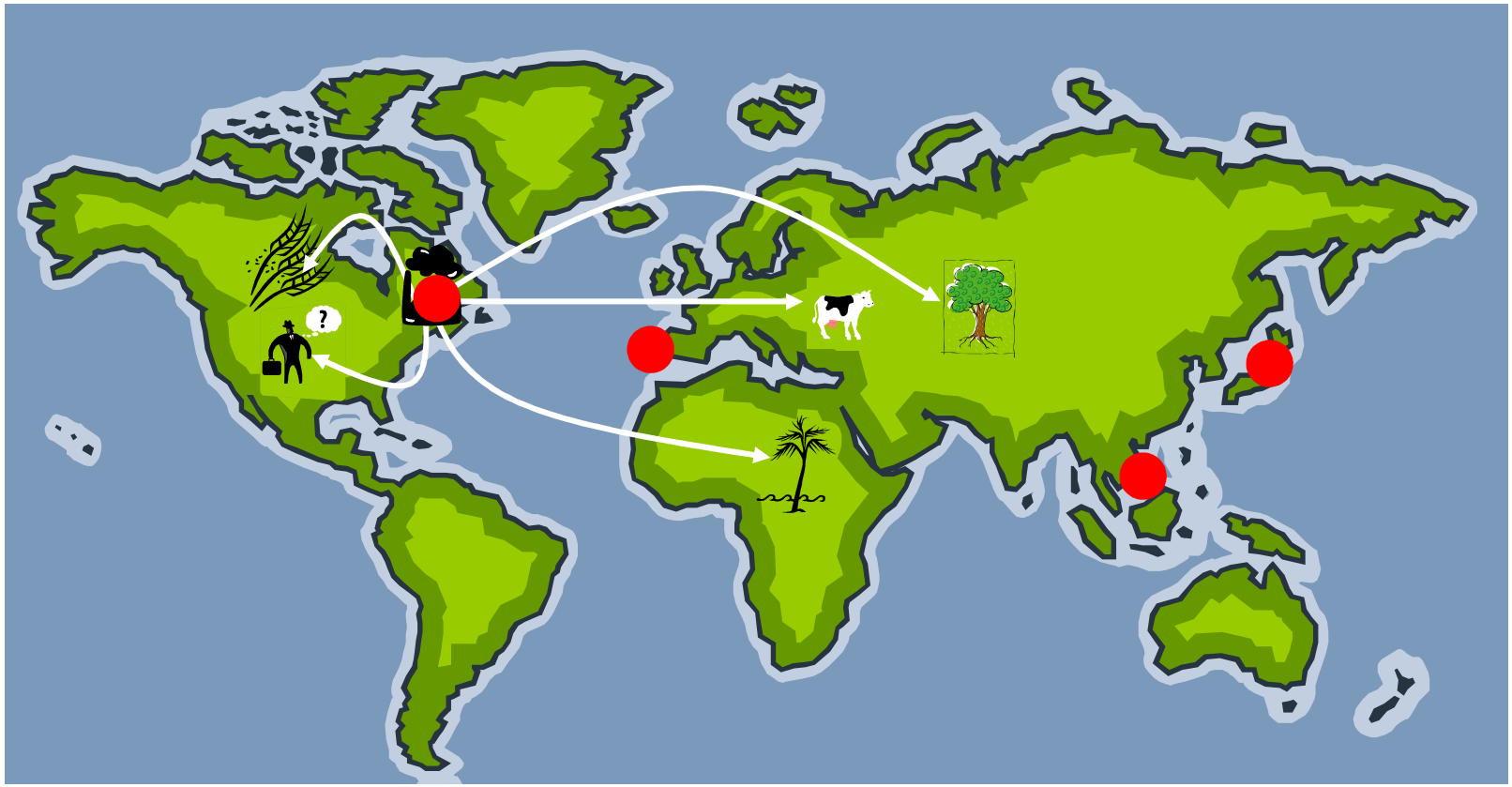
The need to evaluate a product systems within a global economy

A Barbie doll to illustrate the concept of global economy:

- Barbie's body is made of plastic produced in **Taiwan**,
- it is manufactured in **China**
- using moulds from the **USA** and **European** and **Japanese** machinery
- her nylon hair is **Japanese**
- her clothes are **Chinese**
- she then travels by boat to **150 different countries** to be sold

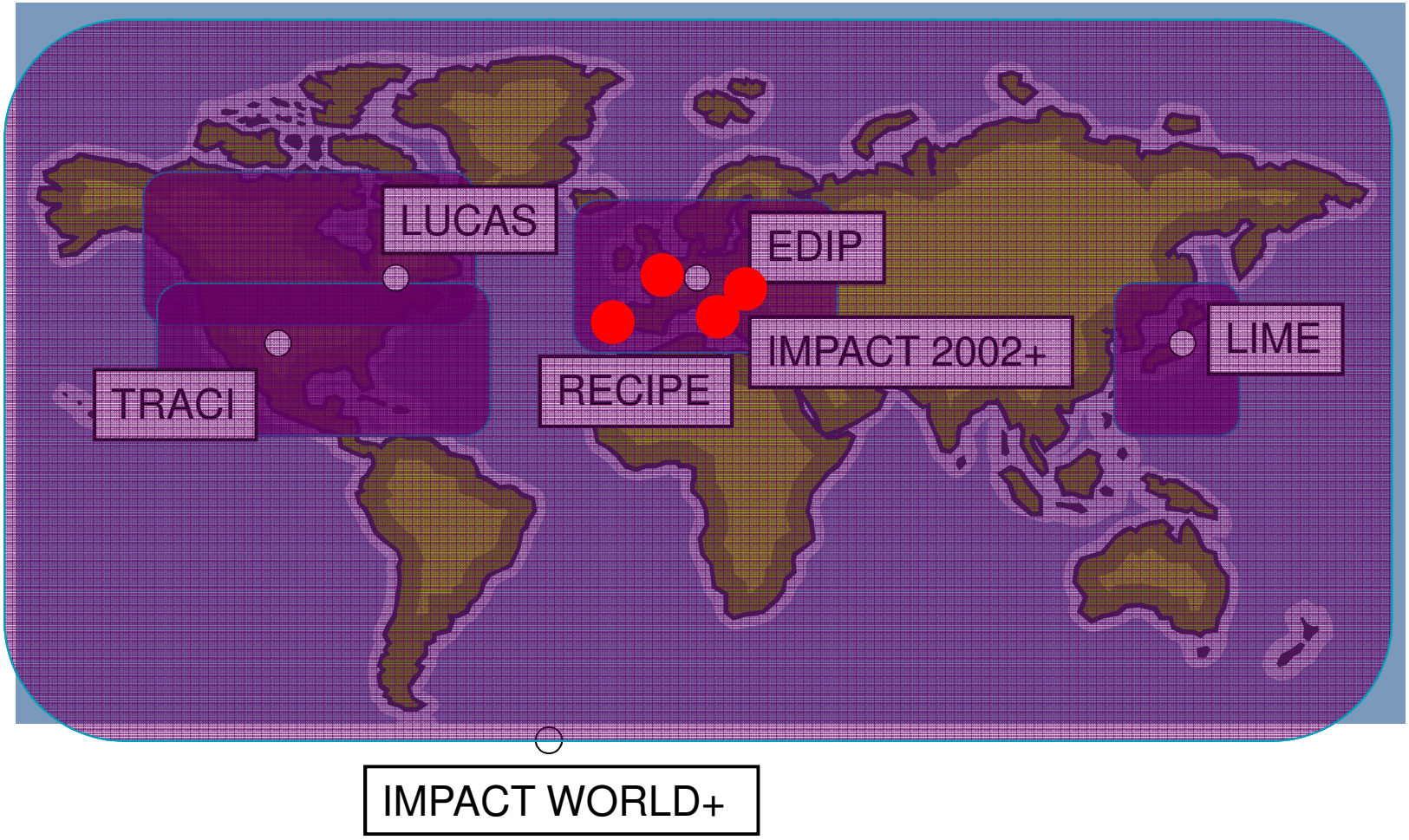
CIRAIG™

Evaluate a product systems within a global economy



CIRAIG™

Evaluate a product systems within a global economy



CIRAIG™

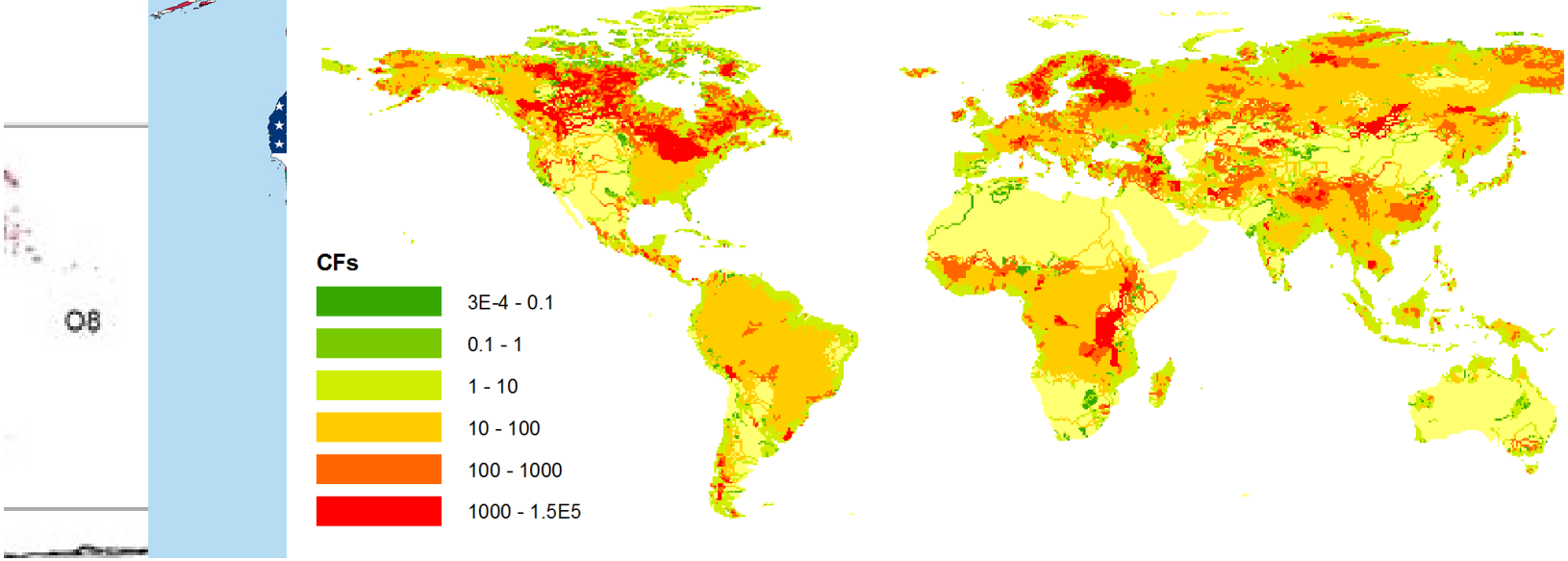
IMPACT World + LCIA at complementary scales

Global default characterization factor:

Continental characterization factors:

Country level characterization factors :

Fine resolution characterization factors :



IMPACT World + : a LCIA method that

- Accounts for regional specificity
- Ensures modelling the entire world in a consistent way
- Allows accounting for uncertainty and spatial variability
- Useful to both academic research and practitioners
- Compatible with regional developments of LCI DB
- Complementary to carbon and water footprint

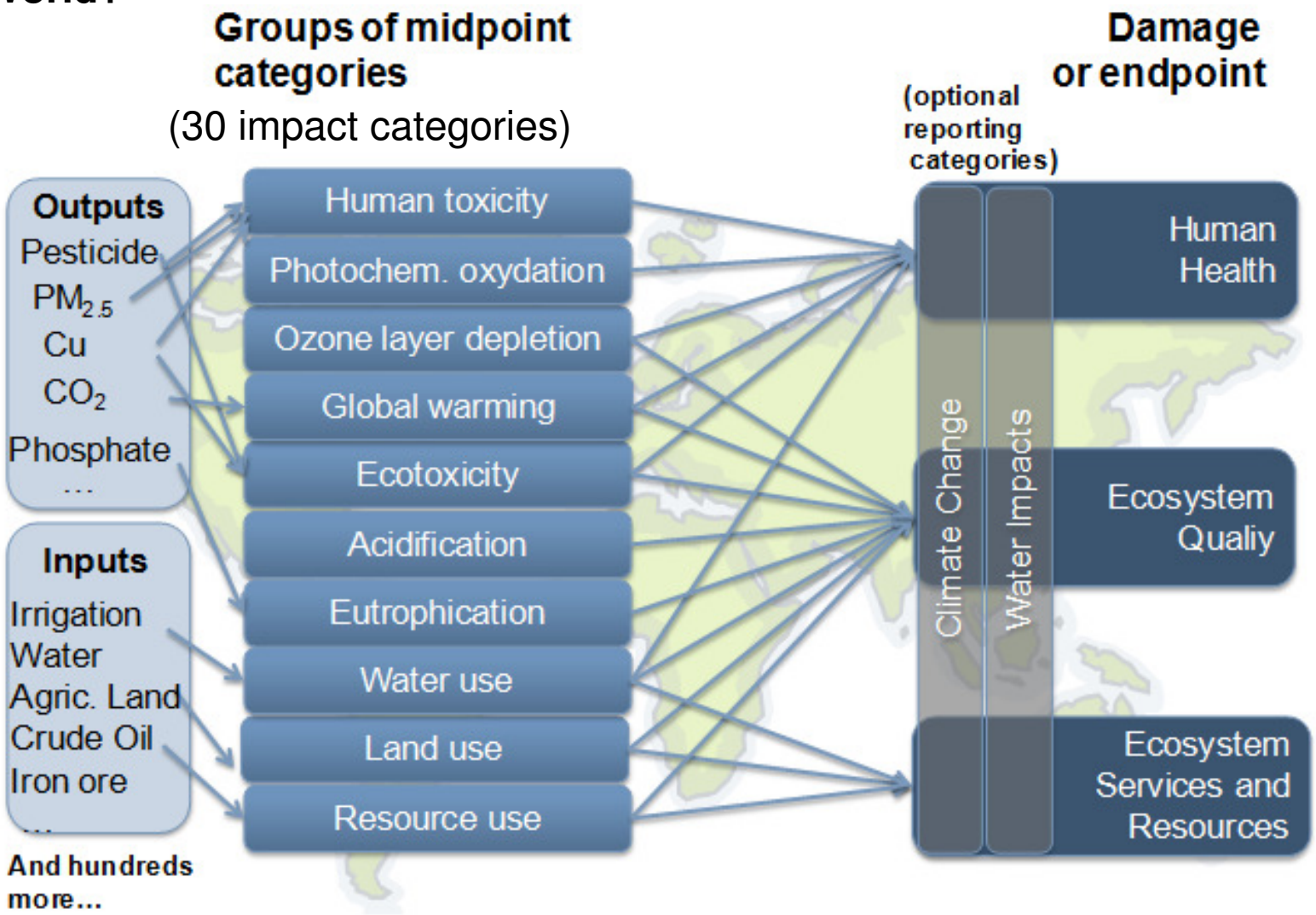
IMPACT World+ ™

Beta version available for download at:
http://www.impactworldplus.org/en/

CIRAIG™

IMPACT World+ Life Cycle Impact Assessment Methodology

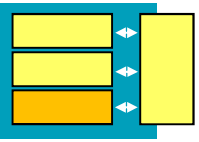
IMPACT World+



APPENDIX

CIRAIG

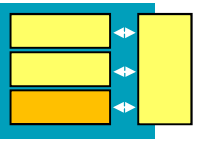
IMPACT2002+ – Midpoints



Midpoint category		Indicator unit
Carcinogens	C	kg C_2H_5Cl eq. (air)
Non-carcinogens	NC	kg C_2H_5Cl eq. (air)
Respiratory – inorganics	RI	kg $PM_{2.5}$ eq. (air)
Ionizing radiations	IR	Bq C^{14} eq. (air)
Ozone layer depletion	OL	kg CFC-11 eq. (air)
Respiratory – organics	RO	kg C_2H_6 eq. (air)
Aquatic ecotoxicity	AE	kg Triethylene glycol eq. (water)
Terrestrial ecotoxicity	TE	kg Triethylene glycol eq. (water)
Terrestrial acidification/nutrification	TAN	kg SO_2 eq. (air)
Land occupation	LO	m^2.yr organic arable land eq.
Aquatic acidification	AA	kg SO_2 eq. (air)
Aquatic eutrophication	AE	kg PO_4^{3-} eq. (water)
Global warming	GW	kg CO_2 eq. (air)
Non-renewable primary energy	NE	MJ primary
Mineral extraction	ME	MJ surplus

CIRAIG

Normalization



Calculation of the magnitude of category indicator results relative to reference information

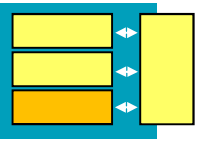
To obtain a better understanding of the relative importance of the impact/damage category indicator results for the studied system

Optional element, can be useful for communicating results

Required to proceed to weighting and aggregating results into a single score

CIRAIG

Normalization



Normalized LCIA profile = LCIA profile related to functional unit (FU) / LCIA profile related to reference system (RS)

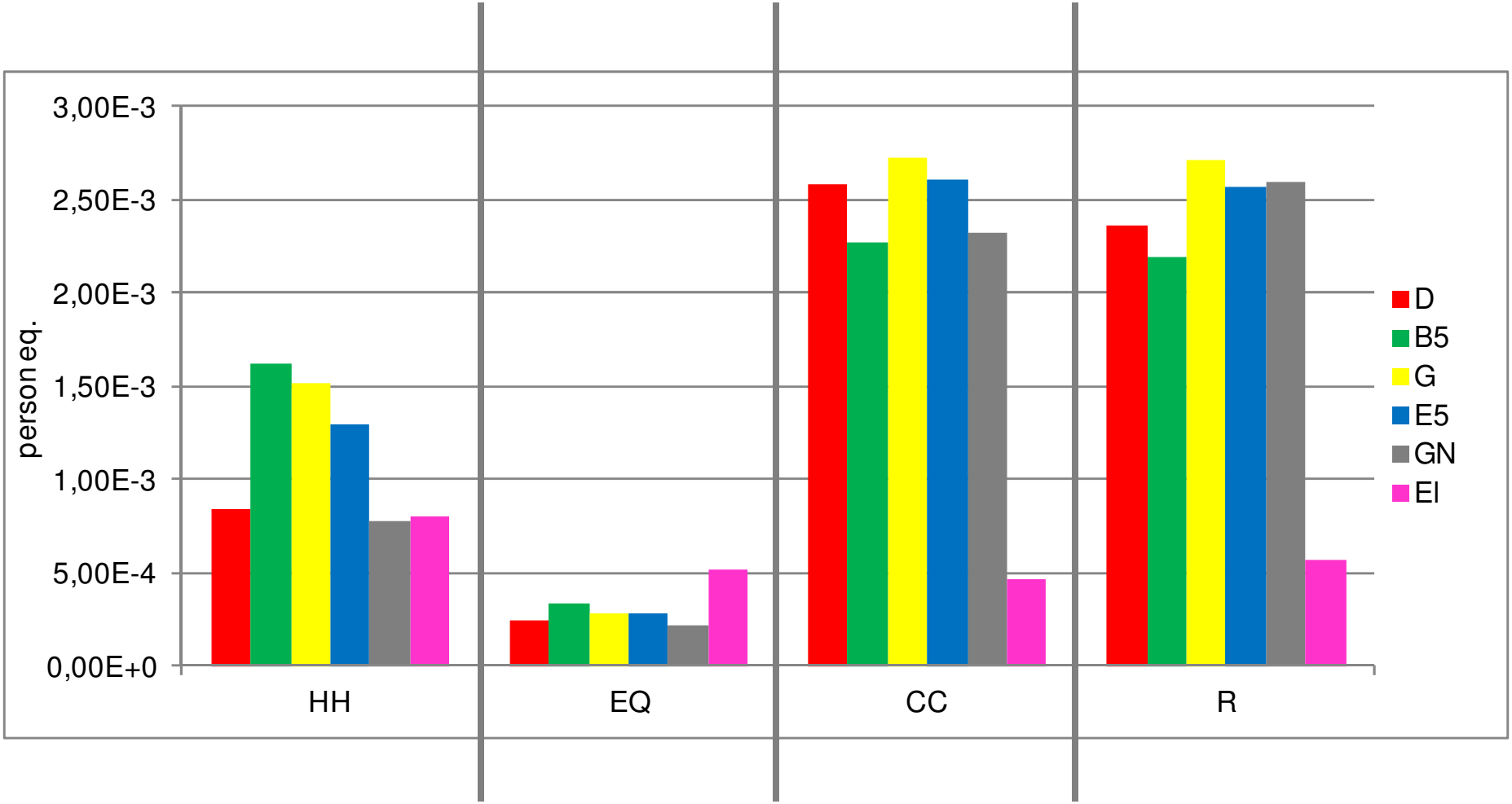
kg crude oil / FU kg CO_2 / FU kg PM / FU kg SO_2 / FU	⇨	kg C_2H_3Cl eq./ FU kg TEG eq. / FU kg CO_2 eq. / FU Primary MJ / FU	⇨	DALY / FU PDF.m^2.an / FU kg CO_2 eq. / FU MJ / FU
kg crude oil / RS kg CO_2 / RS kg PM / RS kg SO_2 / RS	⇨	kg C_2H_3Cl eq. / RS kg TEG eq. / RS kg CO_2 eq. / RS Primary MJ / RS	⇨	DALY / RS PDF.m^2.an / RS kg CO_2 eq. / RS MJ / RS

= RS eq. (Human health)
RS eq. (Ecosystem quality)
RS eq. (Climate change)
RS eq. (Resources)

Reference system can be:
- Other product system, ex. reference product
- Geographic area for a specific year, ex. Europe in 2008
- Geographic area for a specific year *per capita*, ex. Average European in 2008

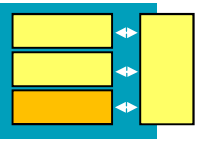
CIRAIG

IMPACT2002+ – Normalized endpoints for the cars



CIRAIG

Weighting



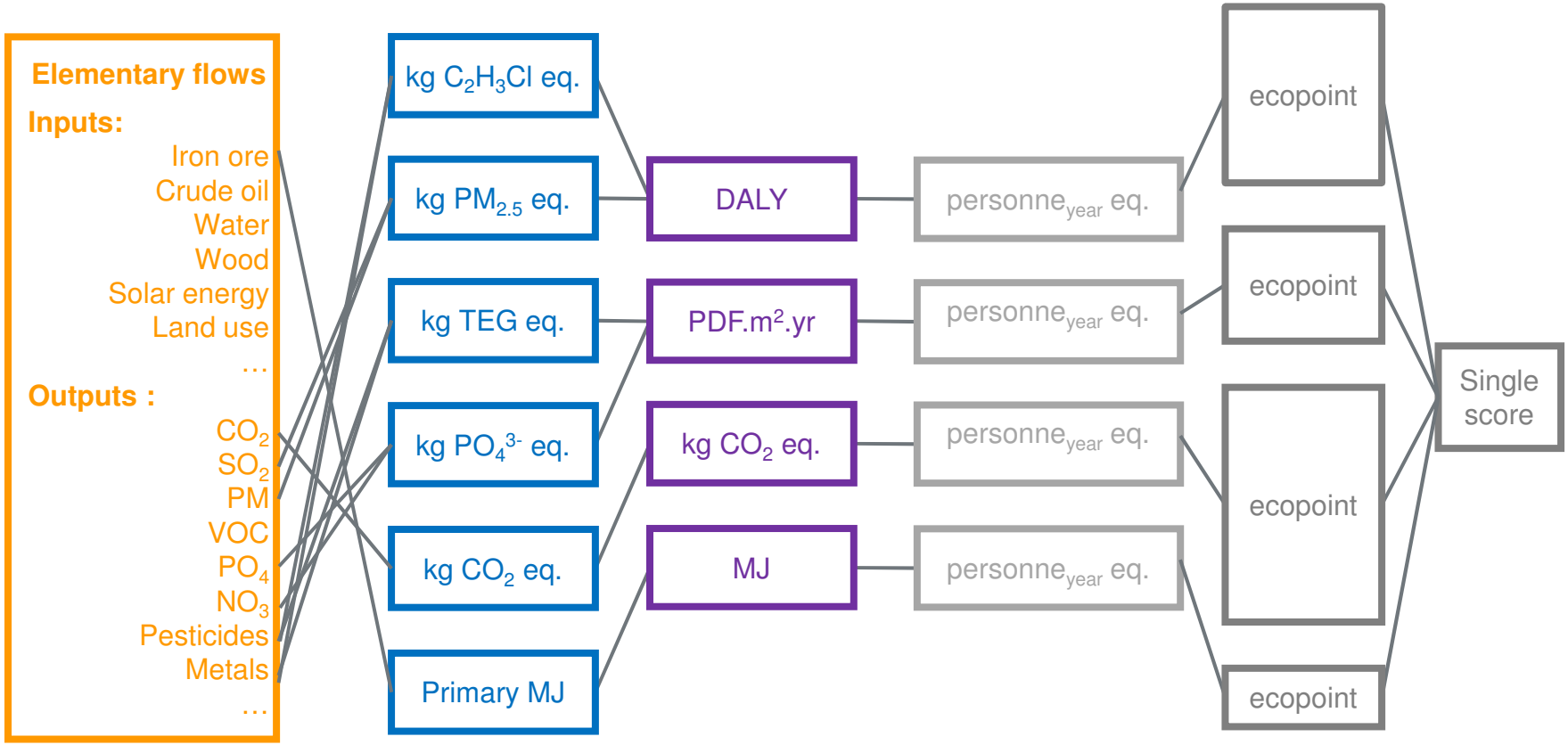
There is no scientific basis to aggregate results into single score ➔ social value choices

Weighting and aggregation not permitted for LCA used to support public comparative assertion

If weighting is to be done ➔ much easier to weight damages (endpoints) then amounts of actual emissions or of equivalent emissions (midpoints)

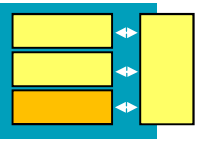
CIRAIG

Weighting & aggregation



CIRAIG

Weighting principles



1. « Willingness to pay » for a healthy life or a clean environment

   Ex: EPS

2. Costs of prevention or remediation (e.g. $ or MJ)

3. Experts or stakeholders panel

   Ex: Ecoindicator 99

4. « Distance to target » (e.g. legislative objectives)

   Ex: Ecopoints

CIRAIG