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Grey Energy and Environmental Assessment of Renewable Energy Systems

Conférence du jeudi, Cycle 2013 - 2014:
Enjeux de quelques nouvelles filières énergétiques

Genève, 8 May 2014

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Energy Group

Grey Energy, grey greenhouse gas emissions, and LCA – A long tradition in CH

Frischknecht R., Hofstetter P., Knoepfel I., Dones R., Zollinger E. 1994: Ökoinventare für Energiesysteme. Grundlagen für den ökologischen Vergleich von Energiesystemen und den Einbezug von Energiesystemen in Ökobilanzen für die Schweiz. 1. Gruppe Energie – Stoffe – Umwelt (ESU), Eidgenössische Technische Hochschule Zürich und Sektion Ganzheitliche Systemanalysen, Paul Scherrer Institut Villigen, Bundesamt für Energie (Hrsg.), Bern.

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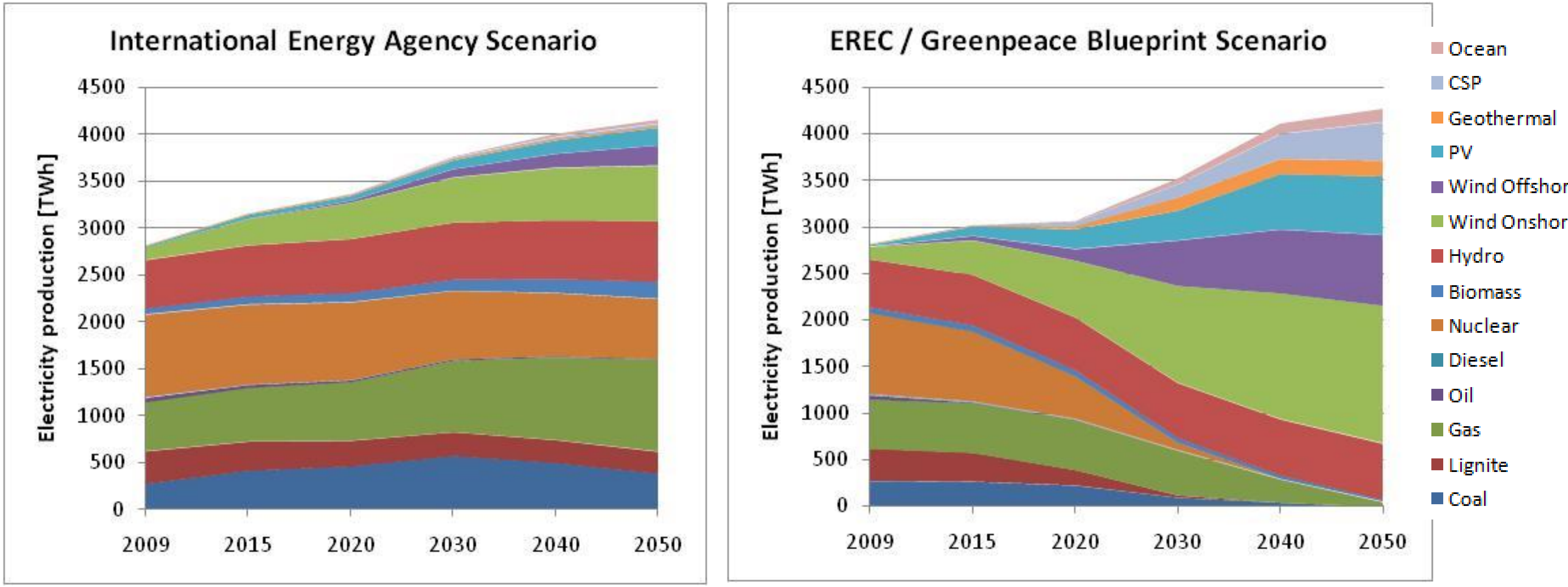
World Electricity Demand: Future?



Increase of RES

→ What are the indirect effects?

Contents

- LCA methodology
- Overview of results for renewable energy
- Pitfalls and limits
- Conclusions

(Environmental) Life Cycle Assessment - LCA
Analyse du cycle de vie - ACV
Analisi/Valutazione del ciclo di vita
Ökobilanz

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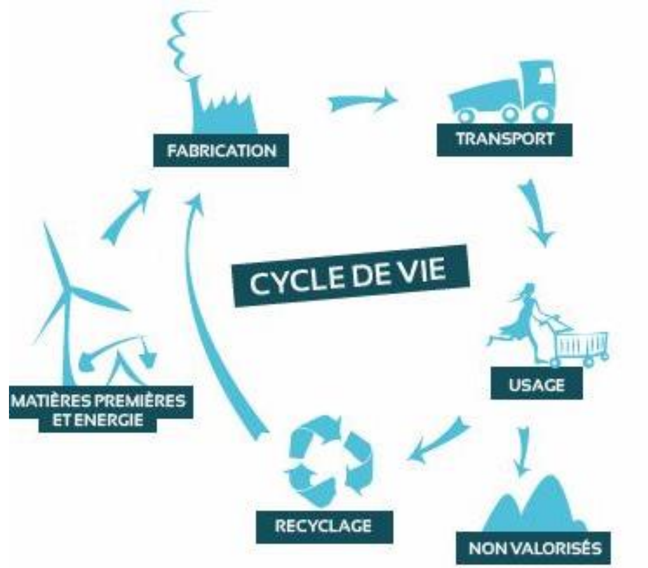
- Assessment of Environmental impacts
- of Products/Processes or Services
- throughout the Life Cycle: resource extraction, manufacturing, product use, waste management



Source: ADEME

LCA – General framework

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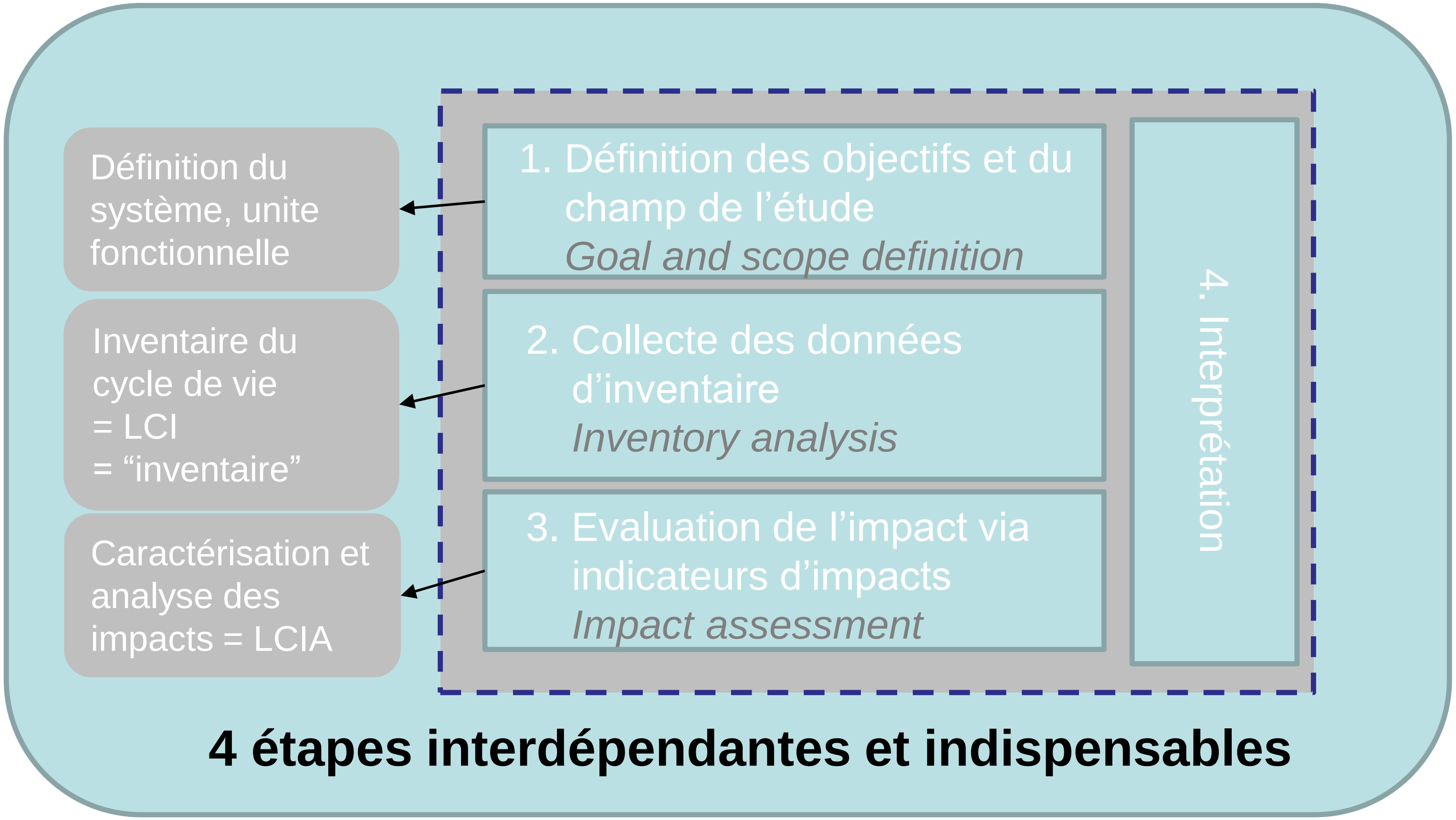


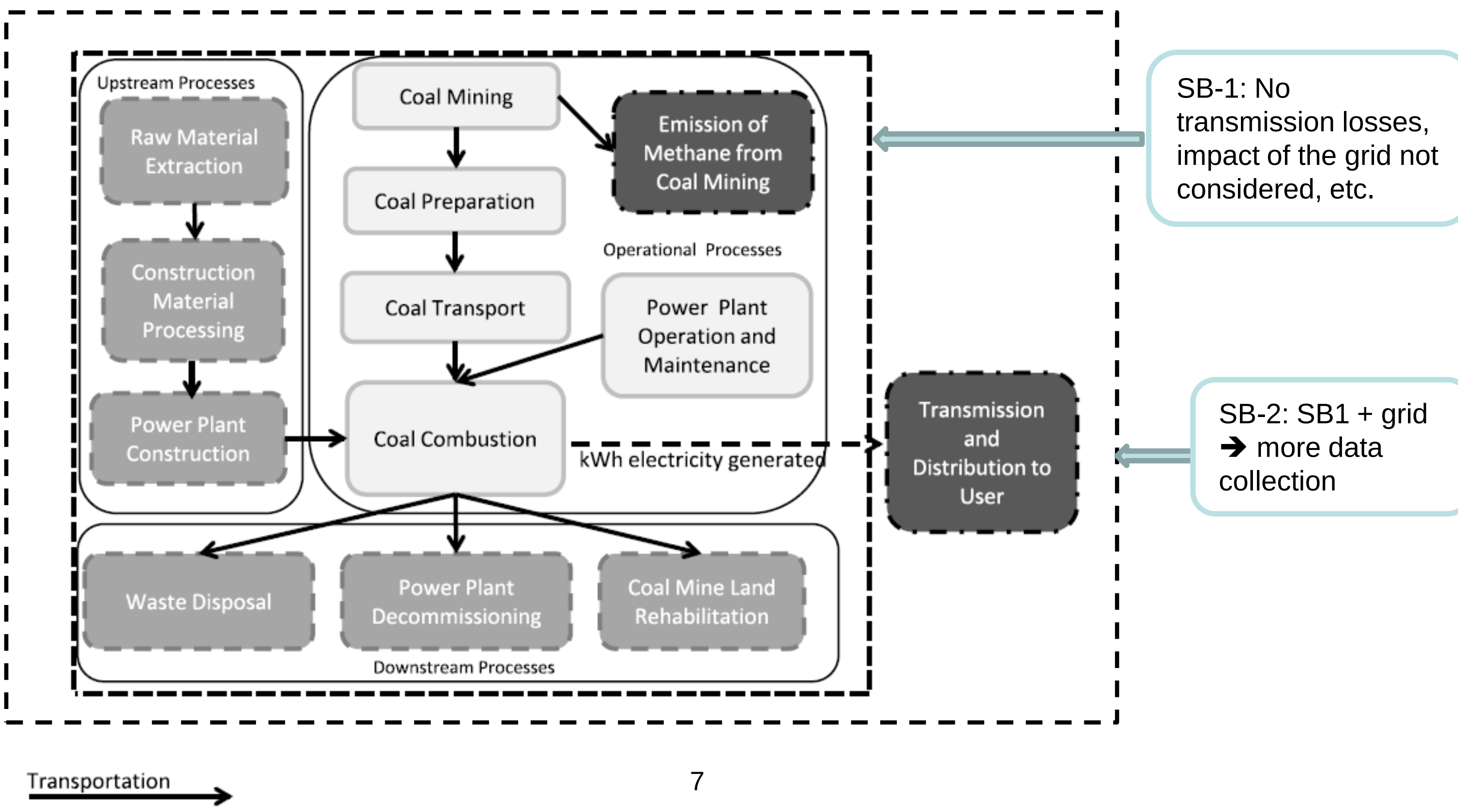
- Direct applications:

- Product development & improvement ➔ eco-design
- Strategic planning
- Public policy making
- Marketing, etc.

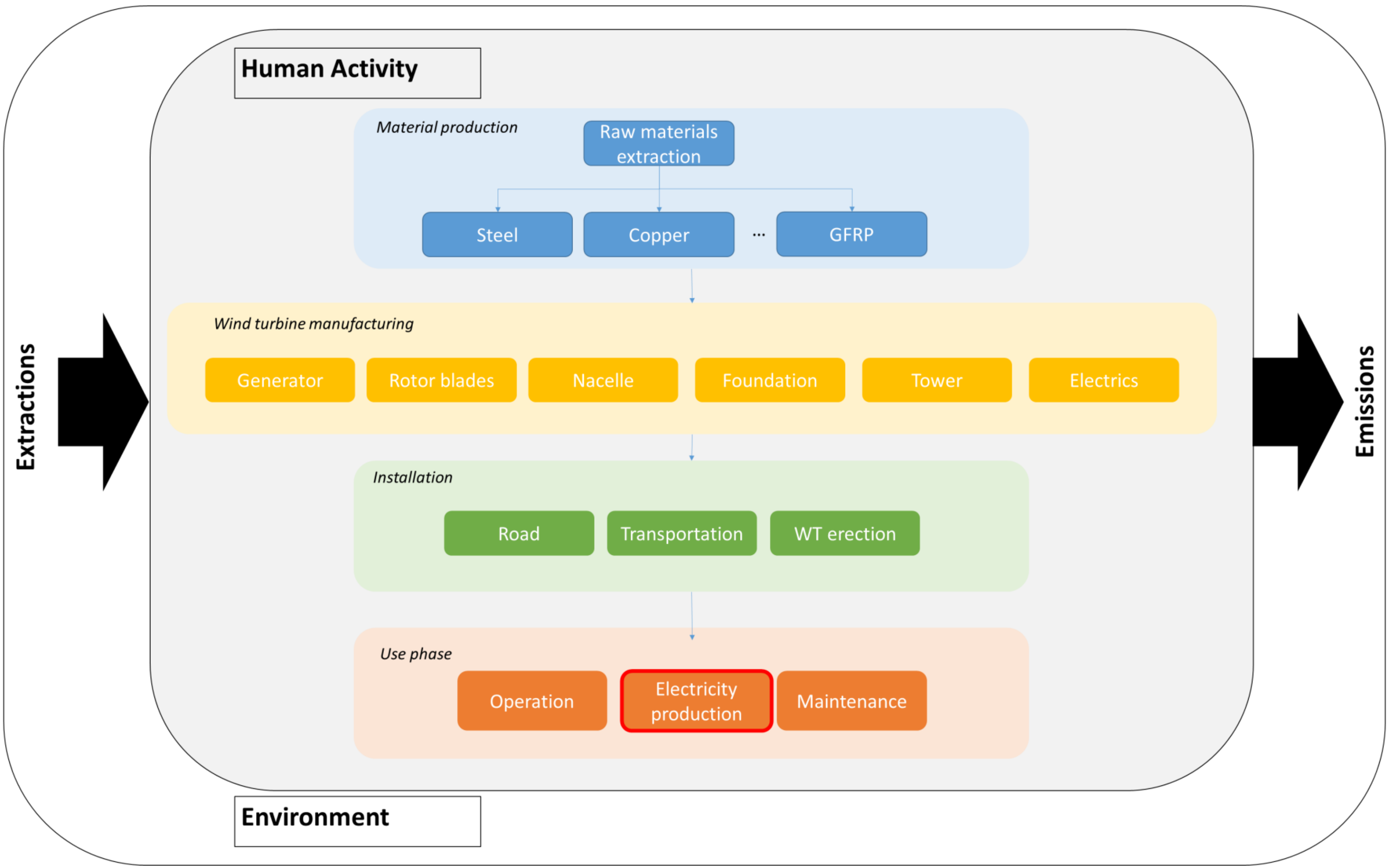
Source:
ISO 14040 & 14044

Step 1: Goal and scope – Functional unit and System boundaries

- Functional unit: unit to which the impacts will refer: 1 kWh at power plant? Or 1 kWh at end user? 1 kWh regardless of the point in time?
- Boundaries: what is considered?

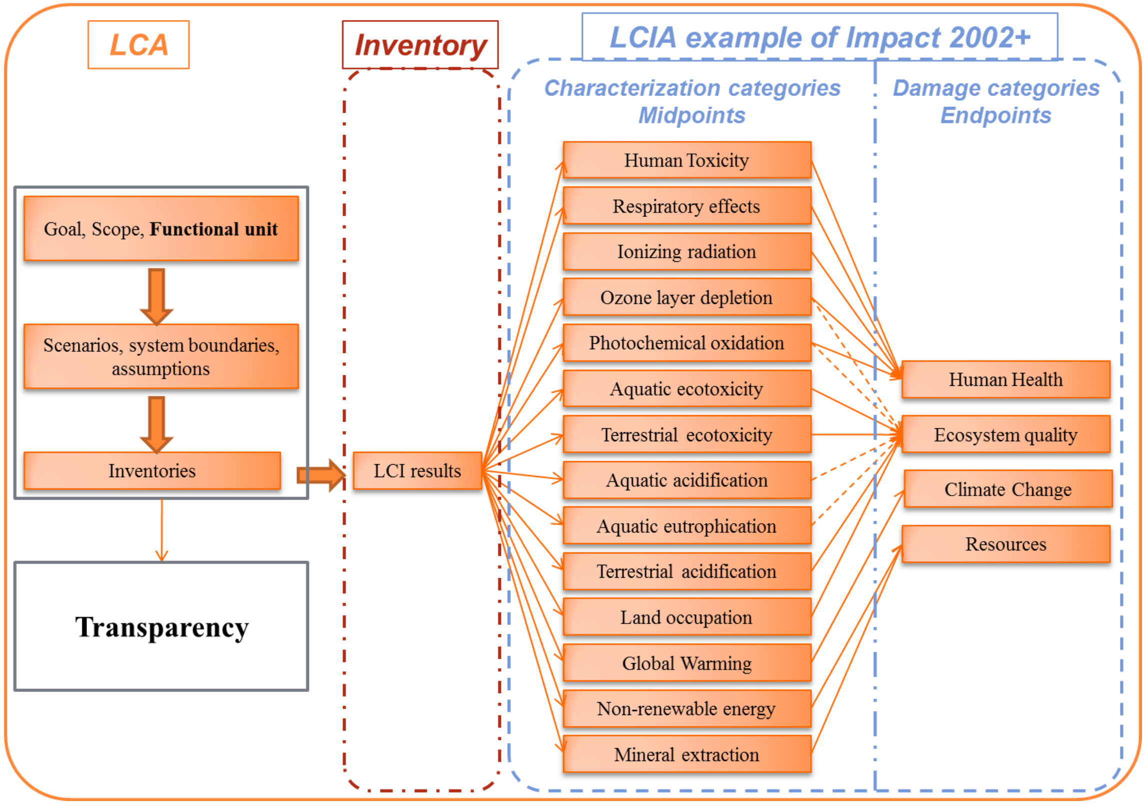


Step 2: Inventory analysis
Flow diagramme for a product system



Step 3: From flow diagramme to environmental impacts

- LCIA: Life Cycle Impact Assessment
- Convert all the emissions with a same impact on the environment into a single unit
  - kg of CO2 equivalent
  - kg of Sb equivalent, etc.



In more detail:
CF = *f* (location, t, Δt, interaction, …)

Environmental Impact Categories (ReCiPe method)

Midpoint level

1. Climate change (CC)
2. Ozone depletion (OD)
3. Terrestrial acidification (TA)
4. Freshwater eutrophication (FE)
5. Marine eutrophication (ME)
6. Human toxicity (HT)
7. Photochem. oxidant formation (POF)
8. Particulate matter formation (PMF)
9. Terrestrial ecotoxicity (TET)
10. Freshwater ecotoxicity (FET)
11. Marine ecotoxicity (MET)
12. Ionising radiation (IR)
13. Agricultural land occupation (ALO)
14. Urban land occupation (ULO)
15. Natural land transformation (NLT)
16. Water depletion (WD)
17. Mineral resource depletion (MRD)
18. Fossil fuel depletion (FD)

Endpoint level

Damage to

1. Human health (HH)
2. Ecosystem diversity (ED)
3. Resource availability (RD)

Note:
(Grey) Energy is included in No.18 (some do, others don't…)

Goedkoop, Heijungs, Huijbregts, De Schryver, Struijs, van Zelm: ReCiPe method, 2009

So, what is Grey Energy…?

Grey energy = embodied energy = indirect energy (next to direct energy related to operation of a device)

SIA (cahier technique 2032) *): „cumulative non-renewable energy use“

Cumulative energy demand (CED) acc. to VDI
= cumul. non-renewable + cumul. renewable energy demand

And: Gross Energy Requirements (GER), “energy“, “primary energy“ etc.

*) http://www.sia.ch/fileadmin/content/download/sia-norm/korrigenda_sn/2032-C1_2010_d.pdf:
SIA Merkblatt 2032: Gesamte Menge nicht erneuerbarer Primärenergie, die für alle vorgelagerten Prozesse, vom Rohstoffabbau über Herstellungs- und Verarbeitungsprozesse und für die Entsorgung, inkl. der dazu notwendigen Transporte und Hilfsmittel, erforderlich ist. Sie wird auch als kumulierter, nicht erneuerbarer Energieaufwand bezeichnet.

**) http://www.vdi.eu/guidelines/vdi_4600-kumulierter_energieaufwand_kea_begriffe_berechnungsmethoden/

Energy as proxy

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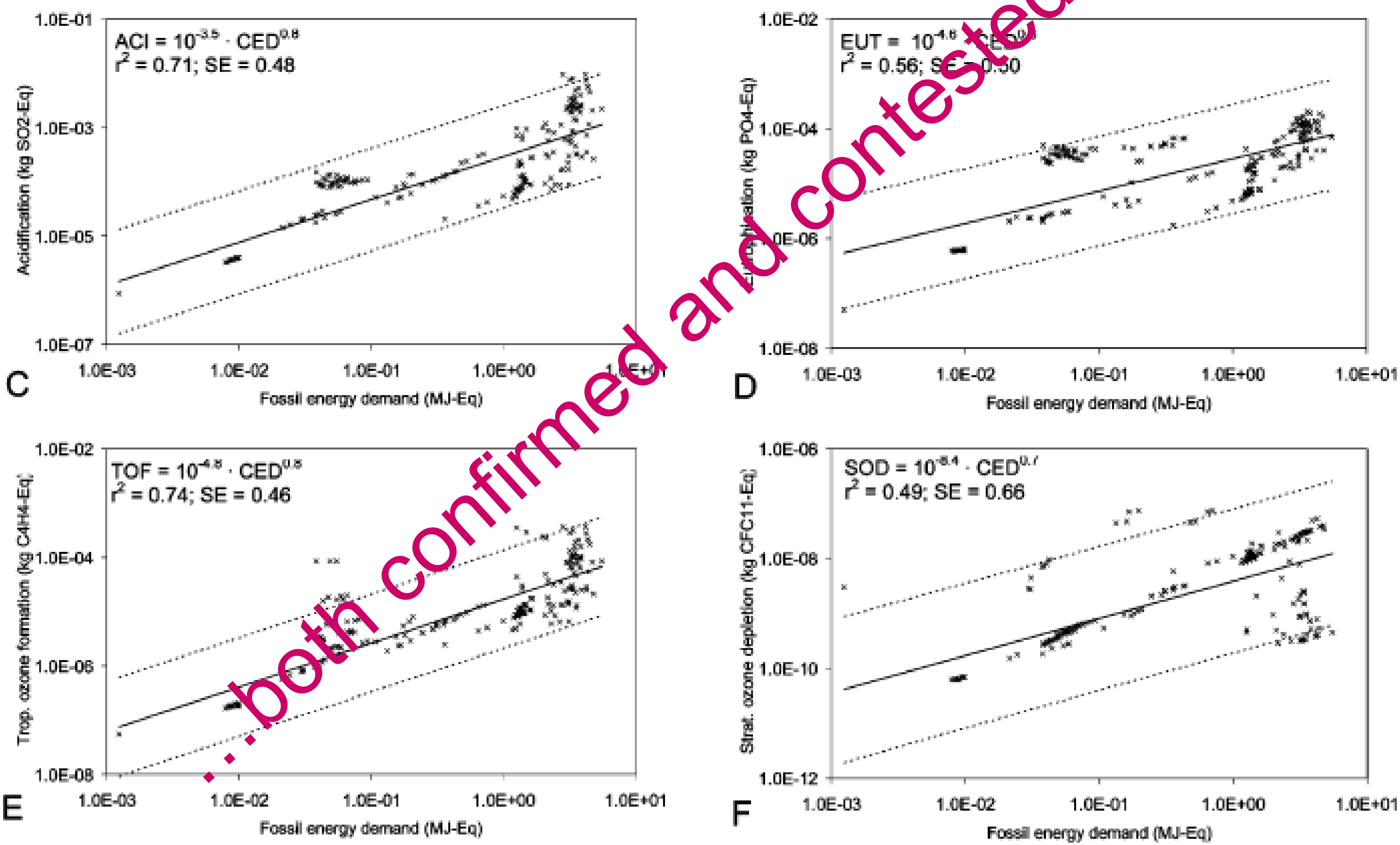

…both confirmed and contested

Huijbregts M.A.J. et al., 2006

Critical issues in LCAs

Phase	Problem
Goal and Scope Definition	Functional unit definition Boundary selection Consideration of alternative product systems
Life Cycle Inventory analysis	Allocation Negligible contribution ('cutoff criteria')
Life Cycle Impact Assessment	Impact category and methodology selection Spatial variation Local environmental uniqueness Time horizons
All phases	Data availability and quality

Simplified summary based on: Reap J., Roman, F., Duncan, S., Bras, B., 2008a, “A Survey of Unresolved Problems in Life Cycle Assessment”, International Journal of Life Cycle Assessment 13(4): 290-300

Renewable energy – Importance today

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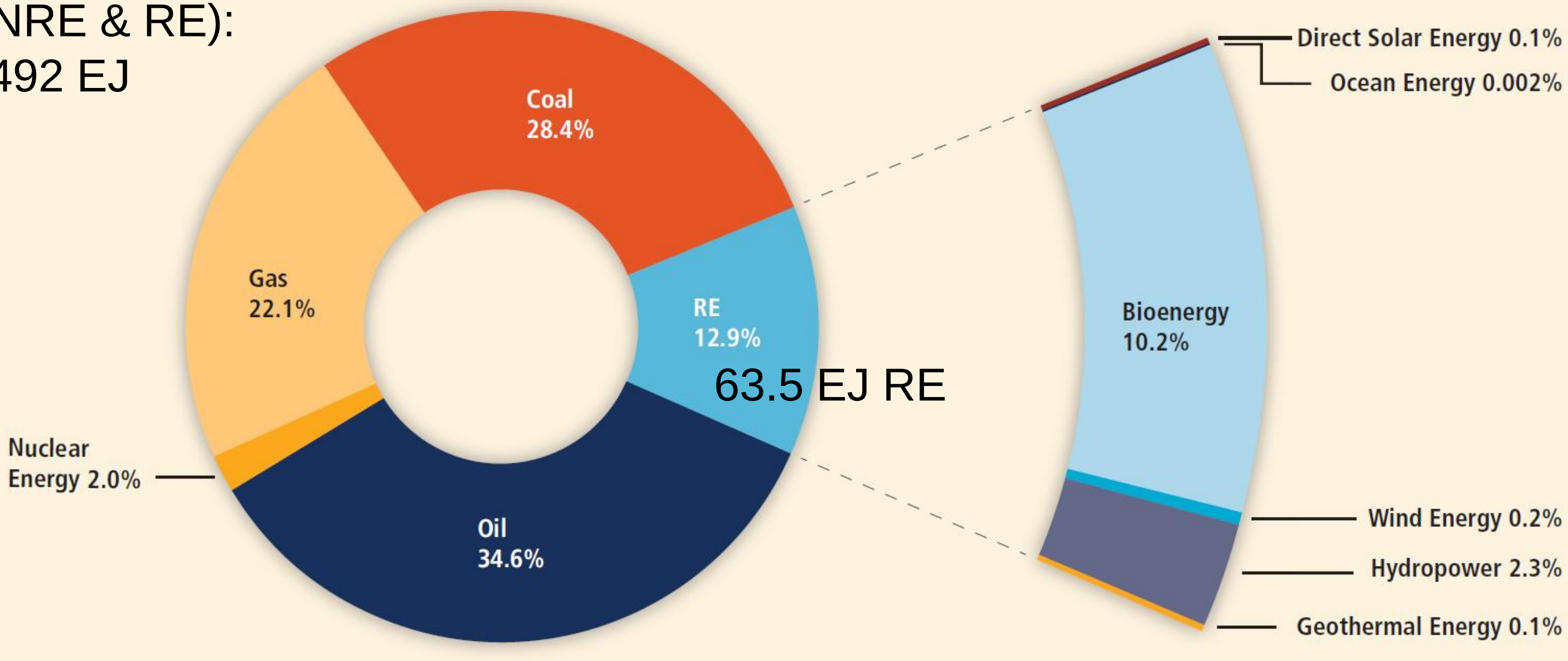
Total global energy demand in 2008 (NRE & RE):
492 EJ

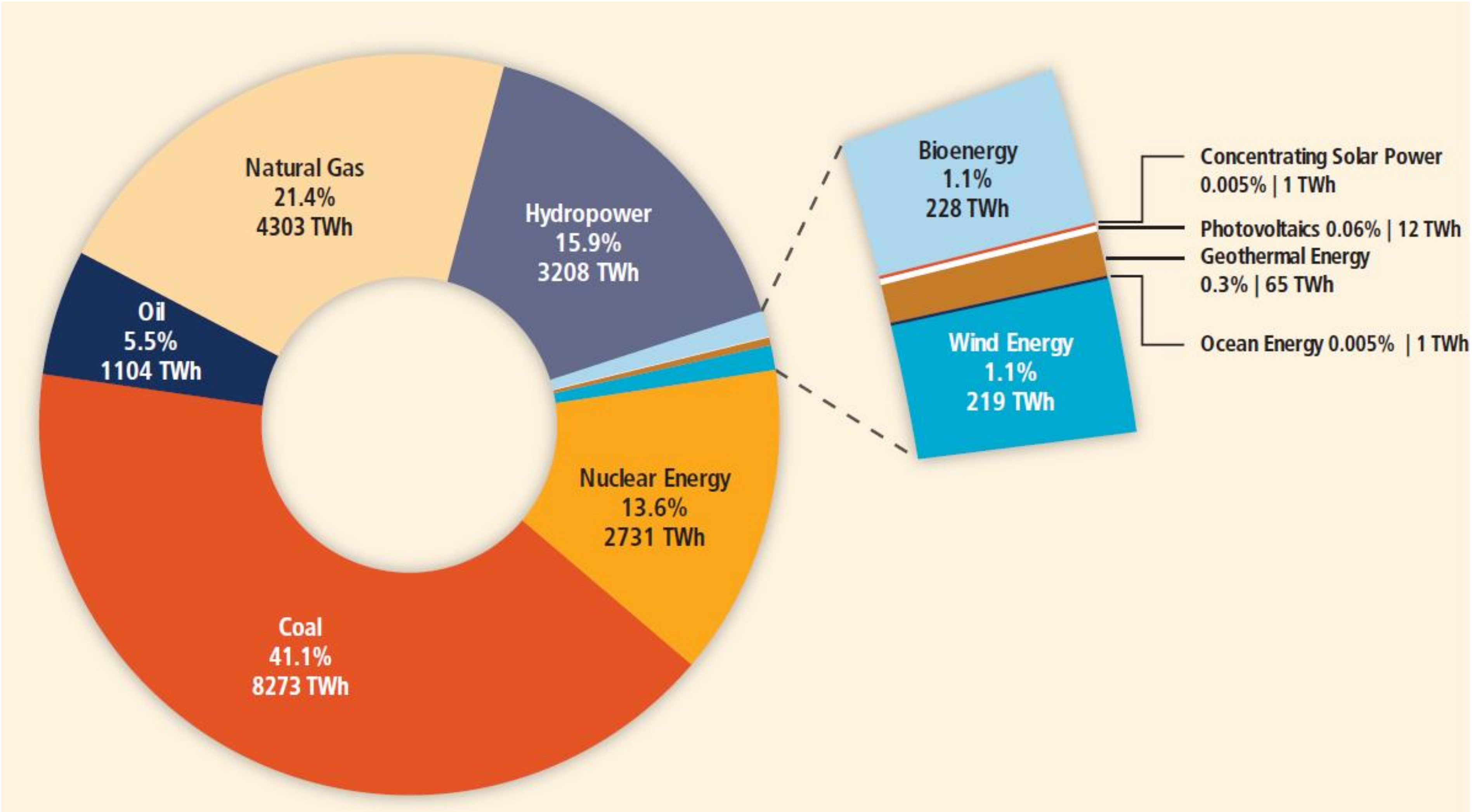


63.5 EJ RE

Accounting for primary energy in the SRREN: ‘Direct equivalent’ method: 1 kWh of electricity or heat from non-combustible sources is counted as kWh of primary energy
‘Direct equivalent’ method < ‘Physical energy content method’ and also < ‘Substitution method’

IPPC: Special Report ‘Renewable Energy Sources and Climate Change Mitigation’, 2012, p.174

Renewable electricity – Importance today



IPPC: Special Report ‘Renewable Energy Sources and Climate Change Mitigation’, 2012, p.175

Renewable energy – Evolution

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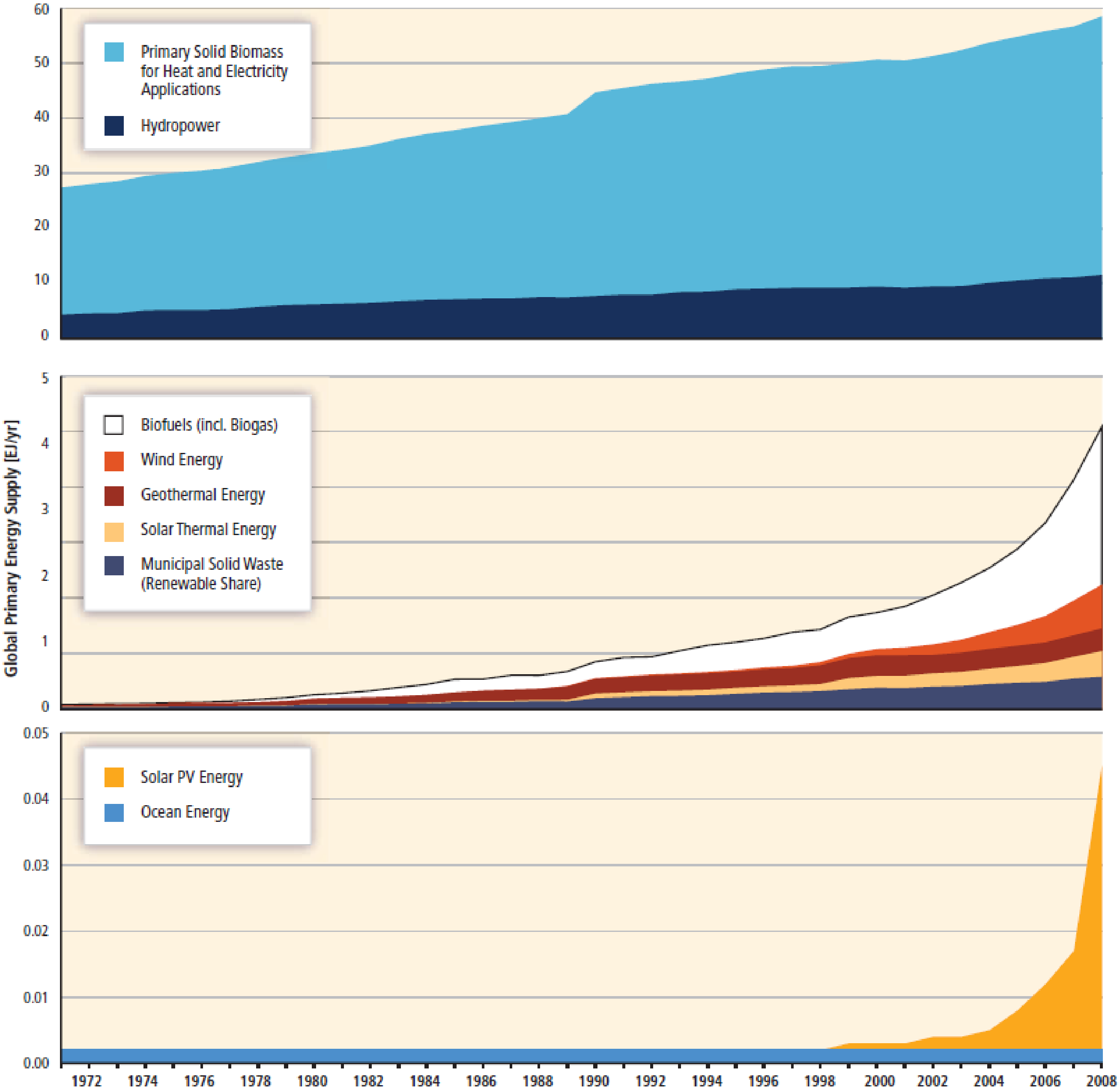
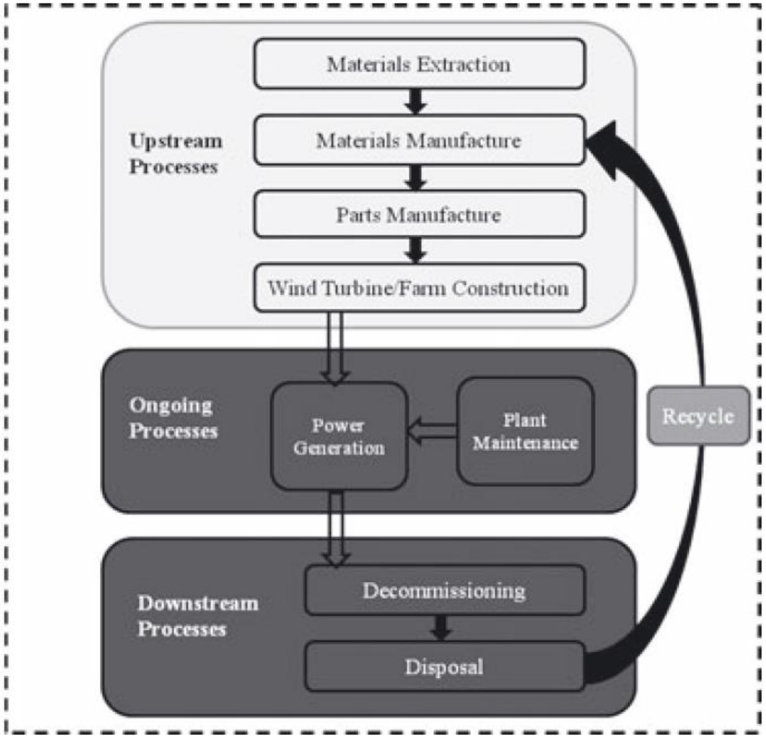


IPPC: Special Report ‘Renewable Energy Sources and Climate Change Mitigation’, 2012, p.176

LCAs OF RENEWABLE ENERGY SYSTEMS

Example of wind power electricity

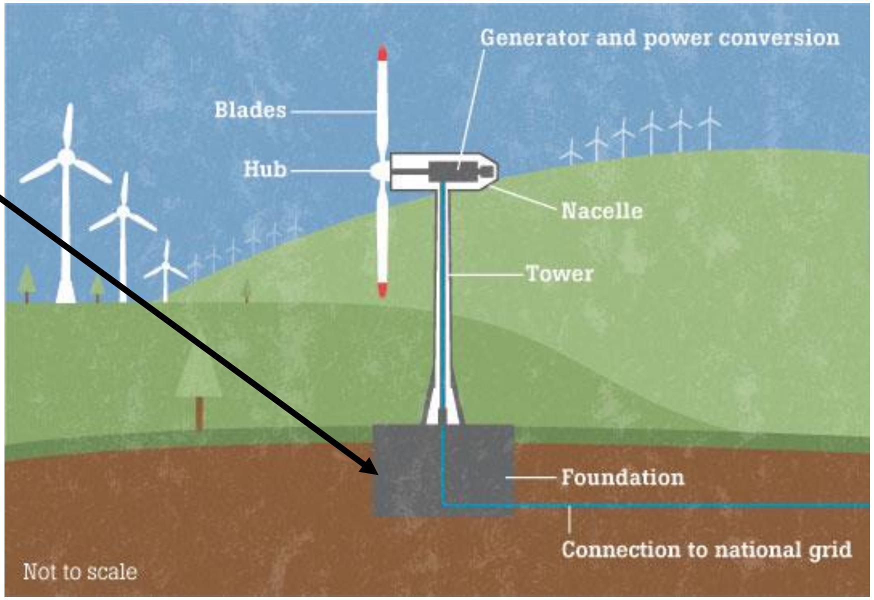
- **Goal**: Analyze wind electricity environmental impacts
- **Hypothesis**:
  - Wind turbine lifetime 20 years
  - 1344 h @ full load (LF = 15.3%)
  - Power from 800 kW to 2 MW
  - Country: Switzerland
- **FU**: kWh of electricity produced at the wind turbine
- **Source**: ecoinvent 3
- **Impact assessment methods**: CED and IPCC 2007 100 years, Impact 2002+



Wind turbine modelling

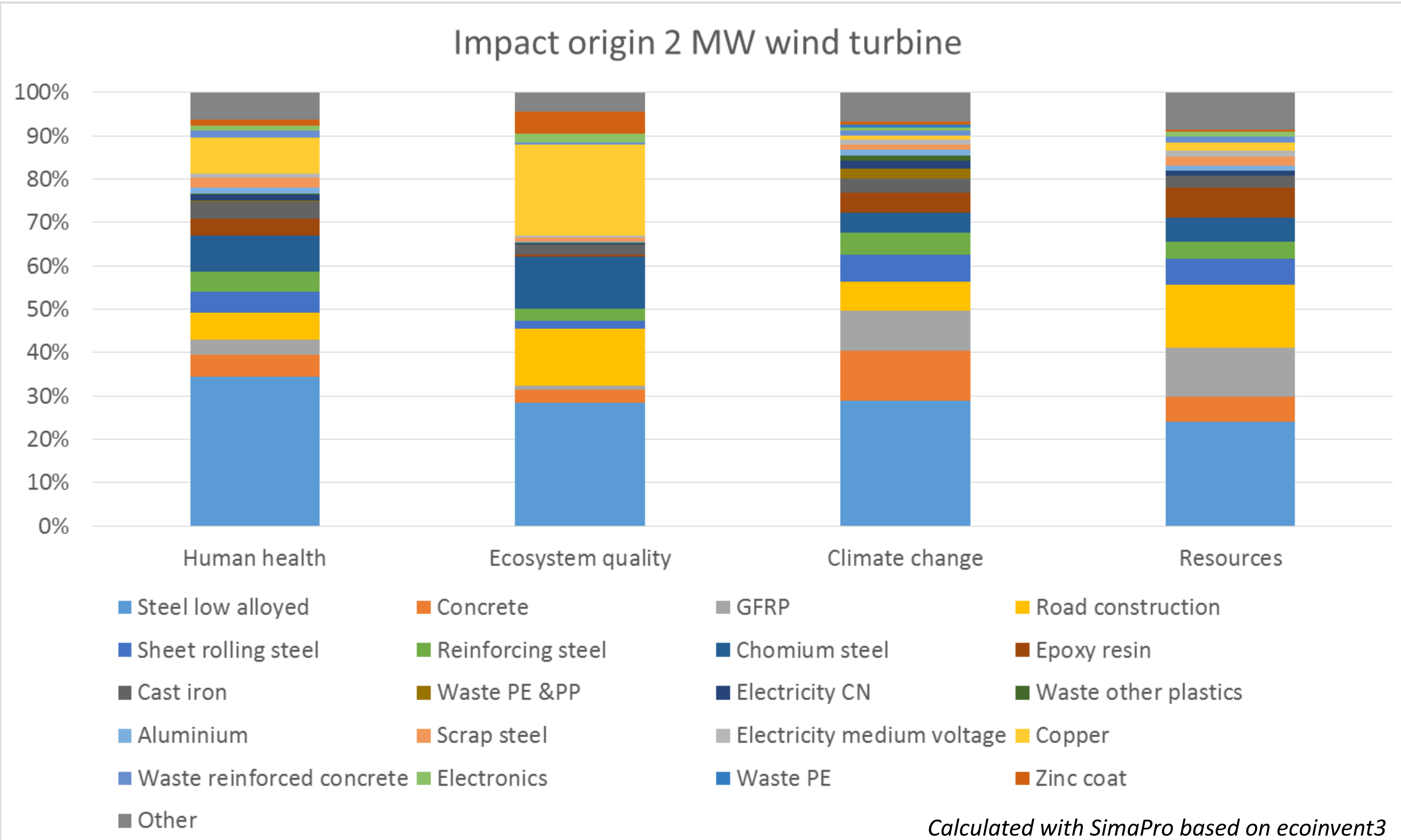
- Based on manufacturer data
  - Process flow analysis (material, energy, installation requirements) ➔ Primary data

Materials	Quantity	Unit
Aluminium	1139	kg
Waste plastic	7084	kg
Zinc coating	978	m2
Concrete	349	m3
GFRP	14168	kg
Copper	2811	kg
Cast iron	20649	kg
Reinforcing steel	26949	kg
Aluminium, cast alloy	536	kg
Zinc	203	kg
Steel, chromium steel	13303	kg
Electronics, for control units	439	kg
Epoxy resin	9445	kg
Polyethylene, high density	3082	kg
Steel, low-alloyed	195772	kg
Manufacturing		
Sheet rolling, chromium steel	13303	kg
Sheet rolling, steel	195772	kg
Welding, arc, steel	295	m
Excavation, hydraulic digger	349	m3
Road	7985	my
Waste		
Waste Steel	209278	kg
Waste polyethylene	3082	kg
Waste reinforced concrete	865376	kg
Waste glass	7084	kg
Electronics scrap	439	kg
Waste PE product	9445	kg
Scrap copper	2811	kg
Aluminium scrap, post-consumer	1675	kg
Electricity (various origin)	**144029**	**kWh**

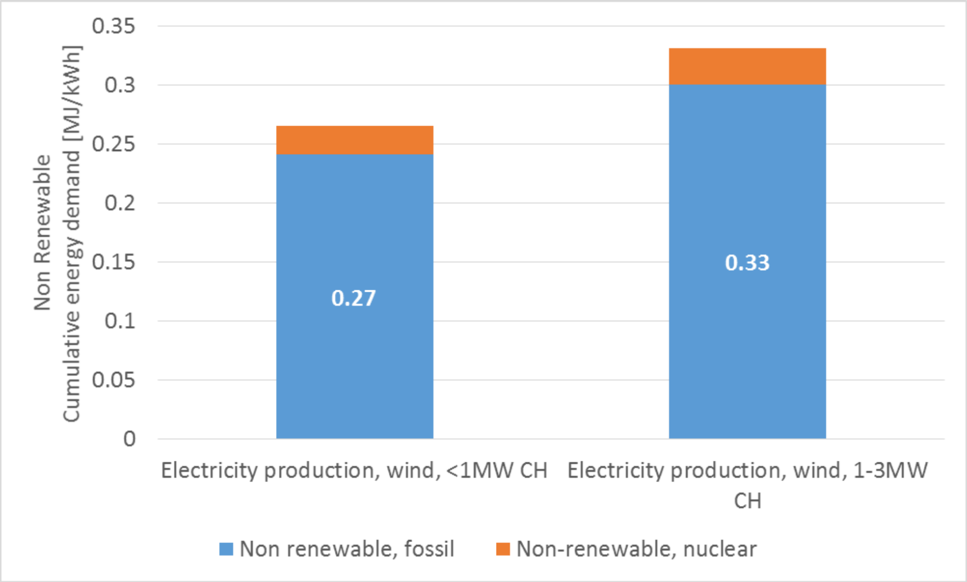


- LCI from ecoinvent V3 ➔ emissions/extraction to/from the environment
- Next step ➔ impact assessment

Impact of a 2 MW wind turbine (manufacturing)



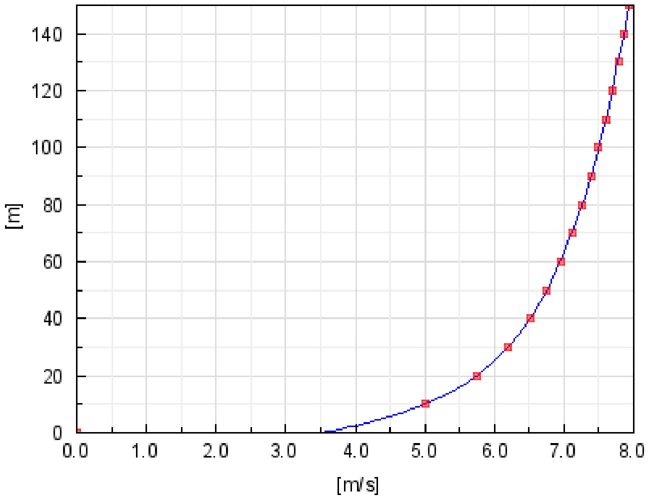
Impact of the produced electricity



Calculated with SimaPro based on ecoinvent3

- Strongly dependent on the production parameters
  - Wind speed profile
  - Lifetime
  - WT availability (i.e. maintenance)

- Negative size effect?
  - Assumption: Same load factor for the two wind turbines
  - ➔ Wind speed increase with h: higher load factor should be considered (800kW: h=60m, 2MW: h=85m)
  - Possible bias : Material / MW_{cap} , Caduff et al. (2012) mass not linearly correlated with P



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Representativeness of LCA results

- Are single indicator values sufficient to characterize the environmental impacts of the energy systems?
- Is there one single wind turbine that represents all technologies? Locations?

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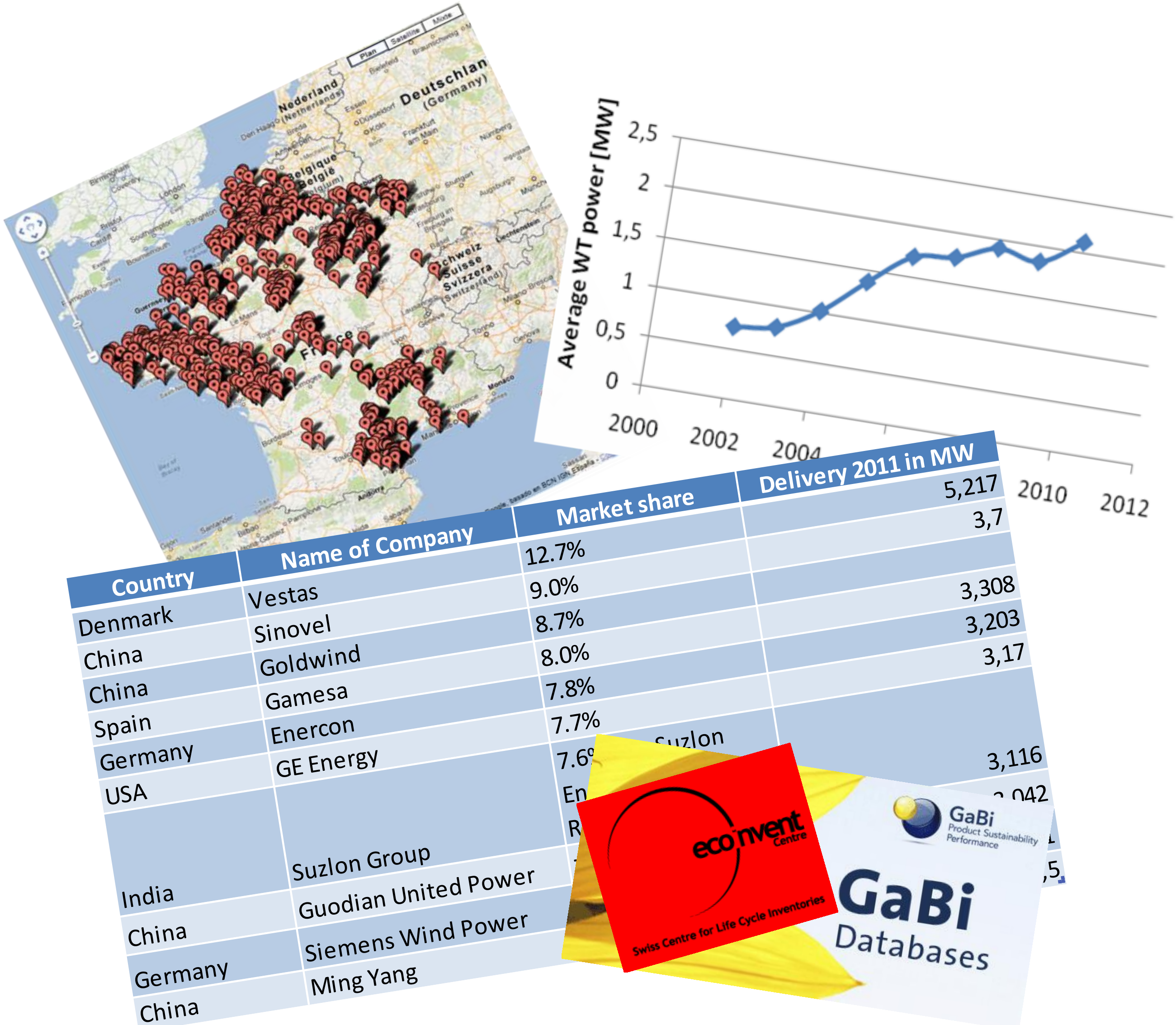
Representativeness of LCA results

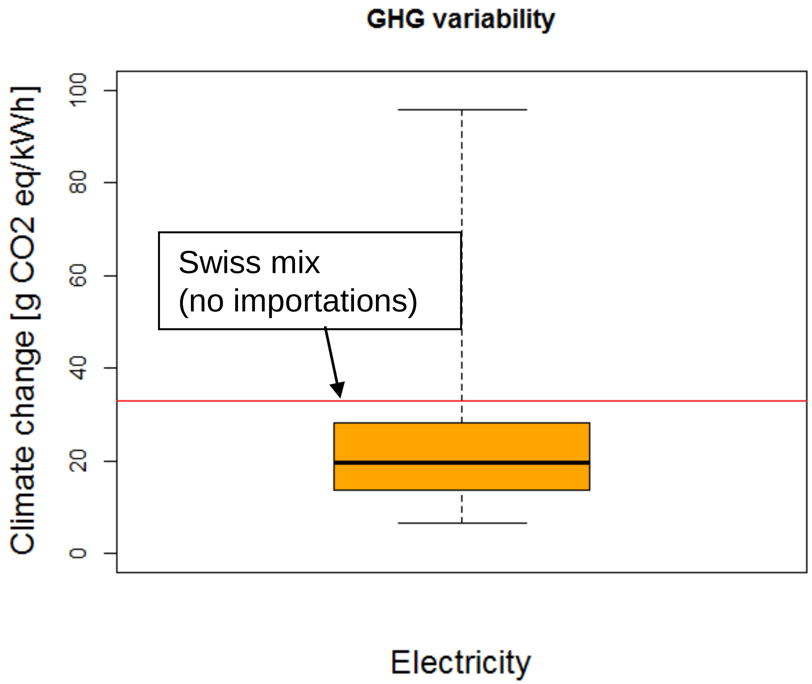


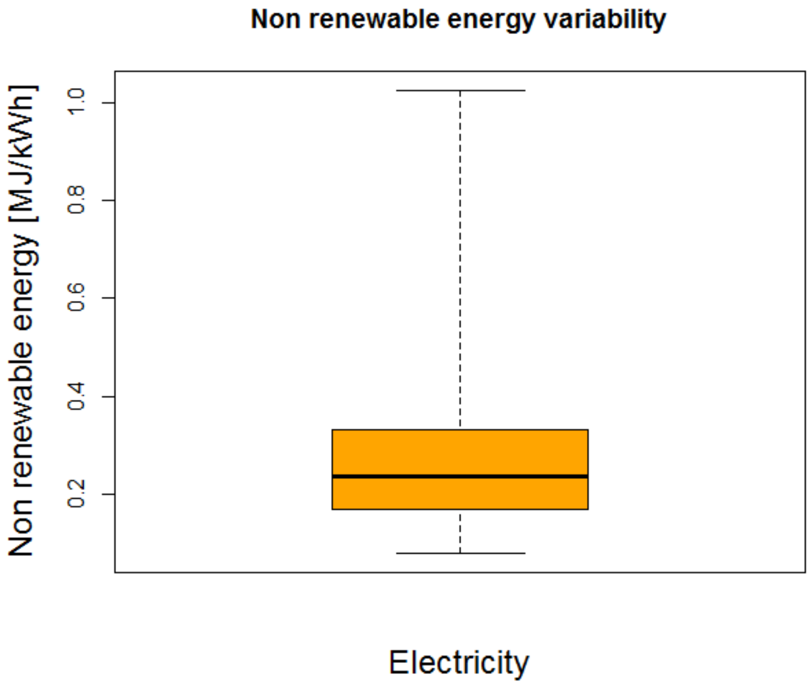
- Several possible variability sources

-Wide range of existing typologies

- Technological (Wind turbine size, material shares…)
- Geographical (wind speed, land roughness…)
- Methodological (LCI database, impact method…)

Impact variability: focus on wind



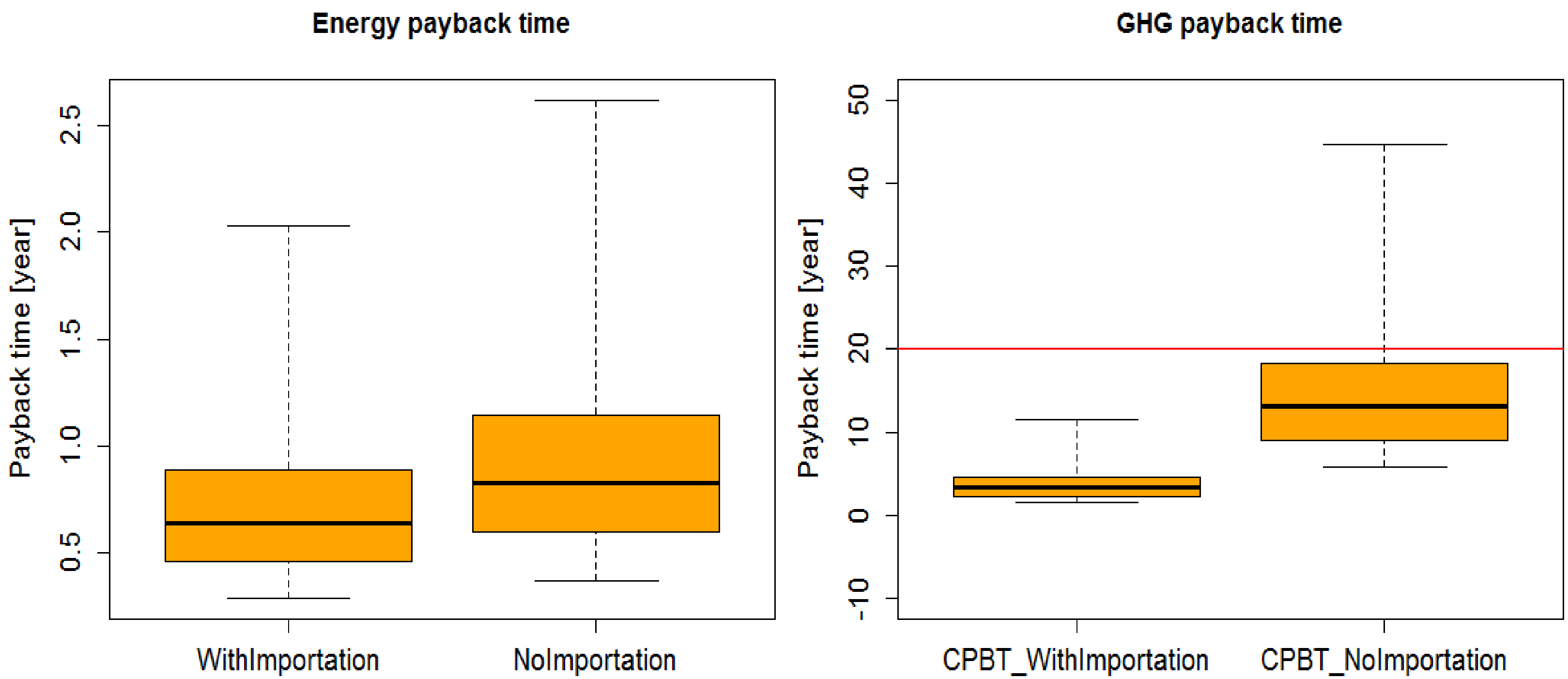


- Single value to characterize the environmental impact of an energy system ➔ not relevant
- System heterogeneity ➔ variability

➔ To be considered to correctly plan the energy transition

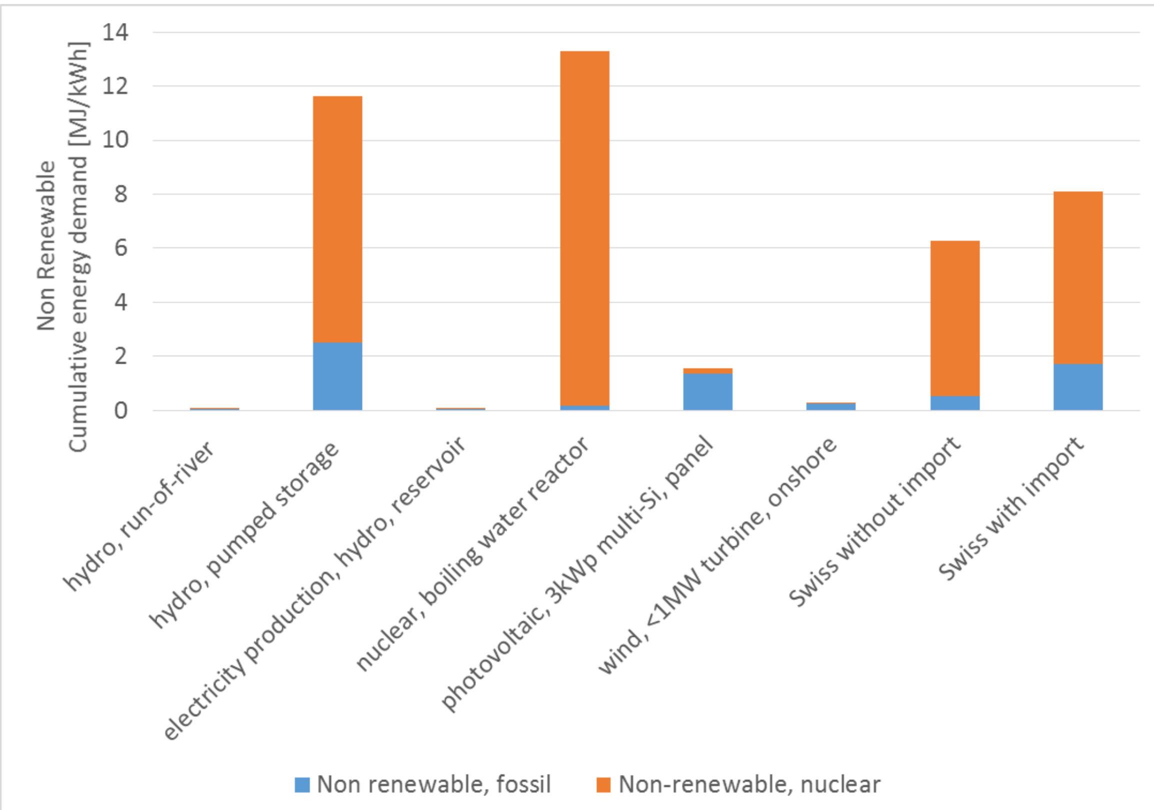
Impact Payback Time

- How long does it take to «reimburse» the environmental impacts of WTs?



- Reference for the substitution is crucial
  - Be careful with «newspaper articles»
- An efficient and multi-dimensional Energy planning strategy is essential

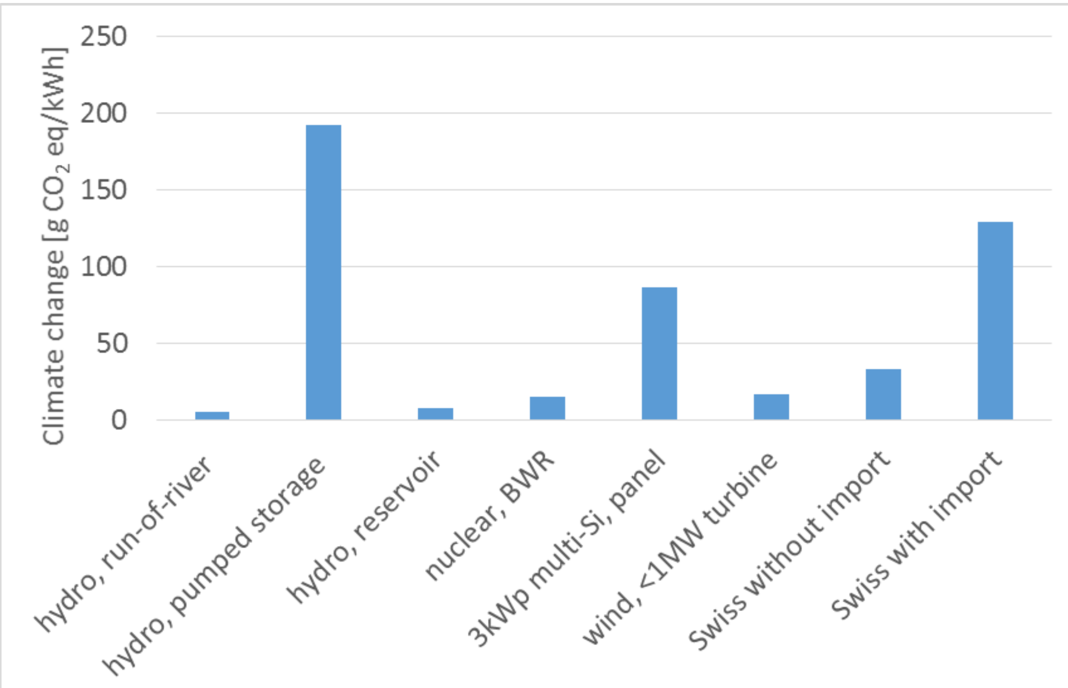
Non-renewable cumulative energy demand of different energy systems



- Pumping storage
  - Electricity from grid (η=70%)
- Nuclear (primary energy factor)
  → Large influence on the mix impact
- PV: Energy intensive technology (produced in China)

Calculated with SimaPro based on ecoinvent3

Climate change impact of different energy systems



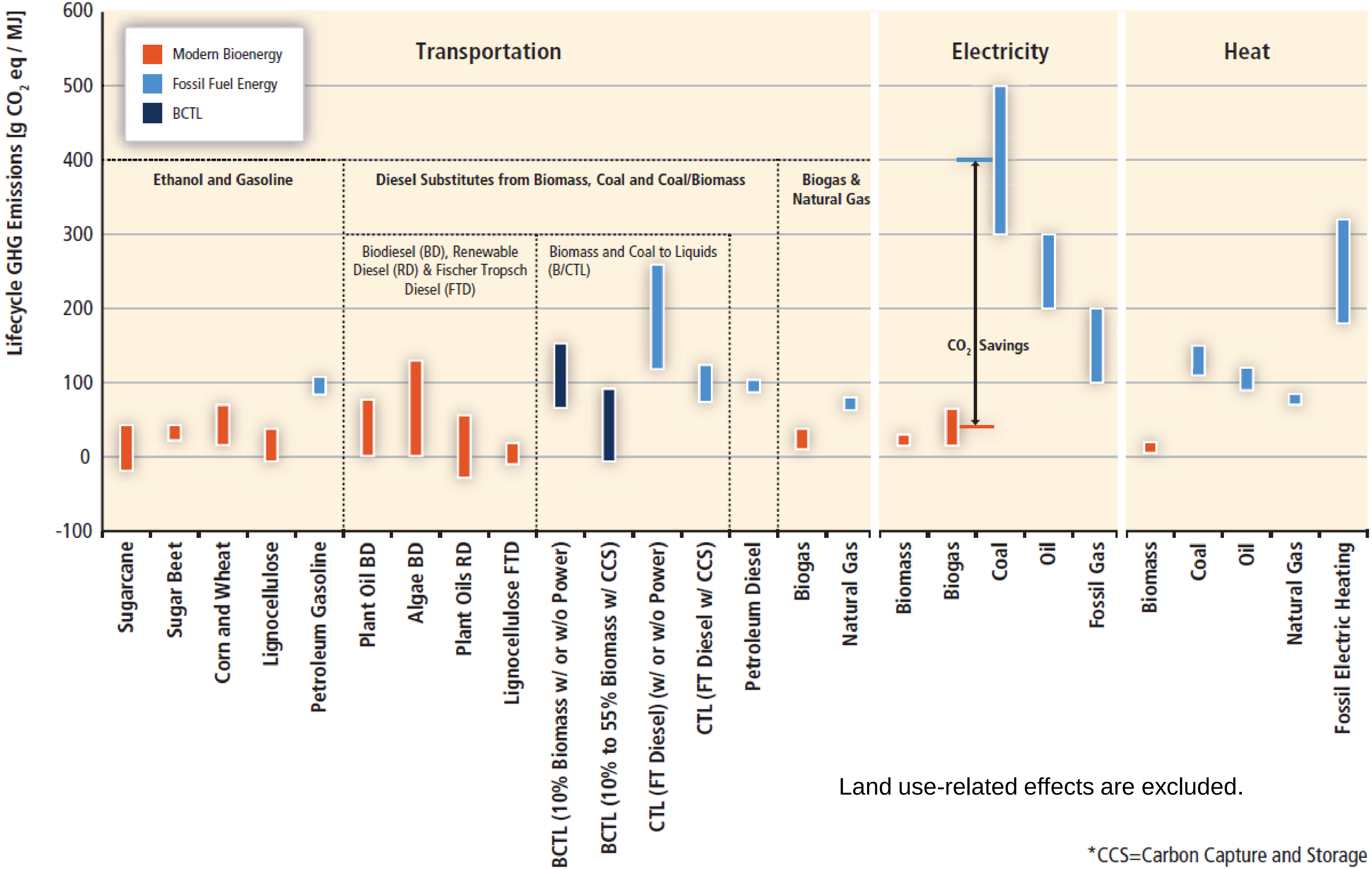
Calculated with SimaPro based on ecoinvent3

- Pumped storage hydro
  - Idem as CED
- PV
  - Manufacturing with electricity from coal
- Influence of the importation
  - 42% of impacts due to importation from Germany
- Correlation between CED and climate change
  - for fossil fuels
  - Assumptions? System boundaries?

Conclusions on wind power impacts

- CED is lower compared to most of the other energy systems
- Electricity production parameters are key
- Should be used to substitute fossil fuels!
- Single value to characterize environmental impacts of energy pathways is not relevant
  - Wide heterogeneity ➔ energy planning crucial
- Intermittency not taken into account
  - What if wind turbines require gas power plant as back-up? Or energy storage systems? Or…

Lifecycle GHG emissions - Overview



Land use-related effects are excluded.

*CCS=Carbon Capture and Storage

IPPC: Special Report ‘Renewable Energy Sources and Climate Change Mitigation’, 2012, p.259

Lifecycle GHG emissions – Electricity

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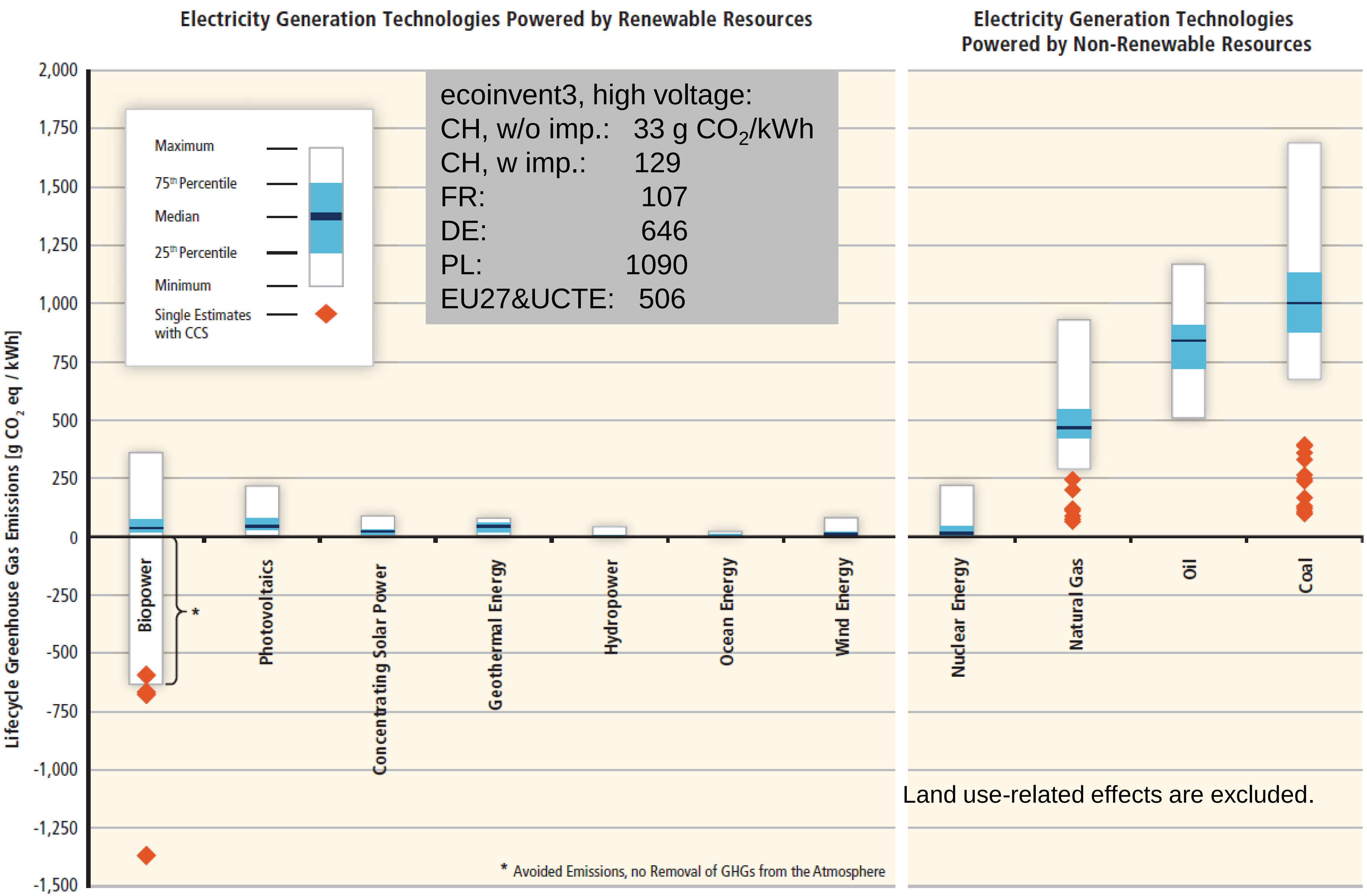
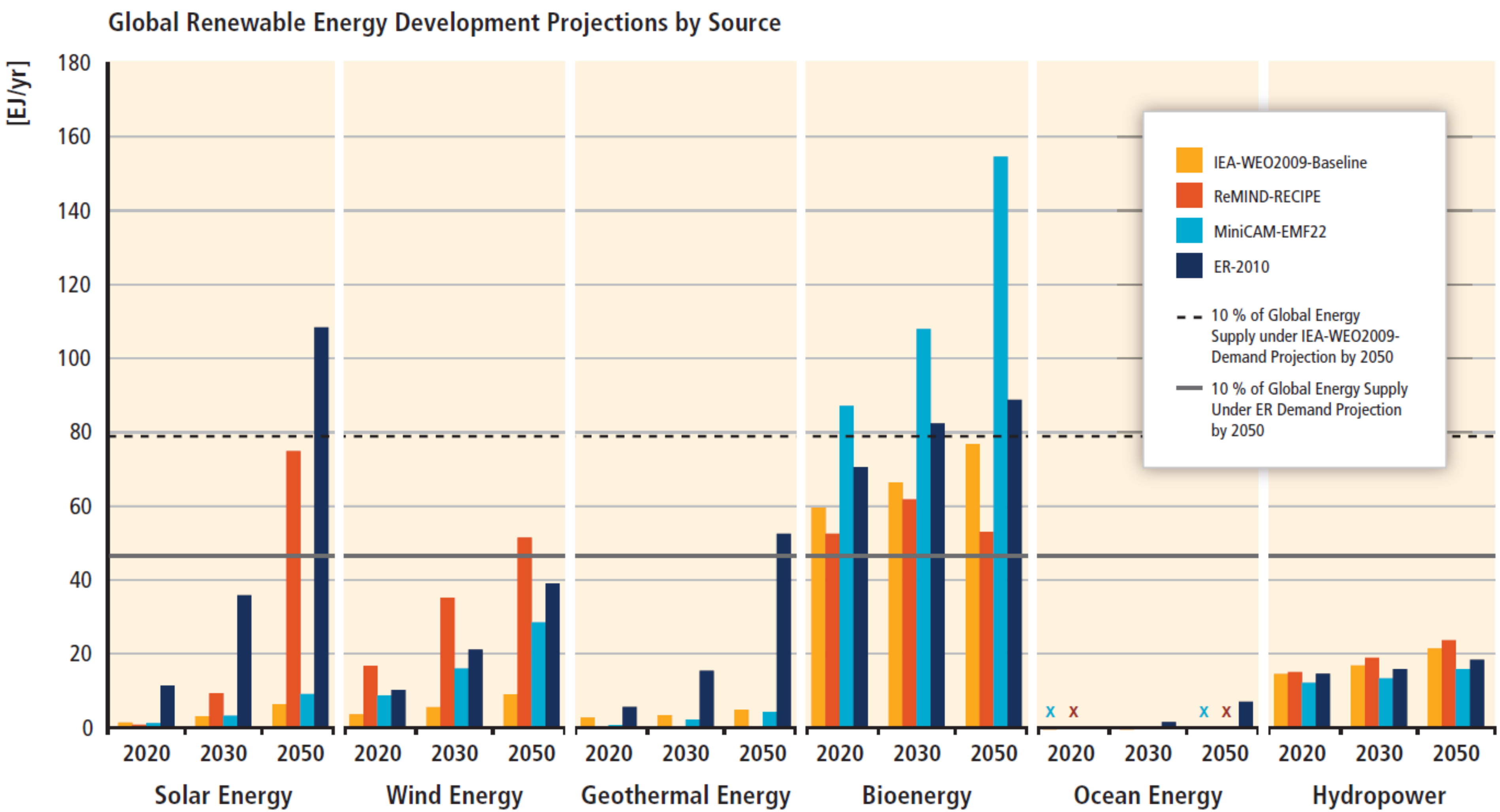


IPPC: Special Report ‘Renewable Energy Sources and Climate Change Mitigation’, 2012, p.732

Which ones to watch out for?



IPPC: Special Report 'Renewable Energy Sources and Climate Change Mitigation', 2012, p.138

Annual Global CO_2 savings

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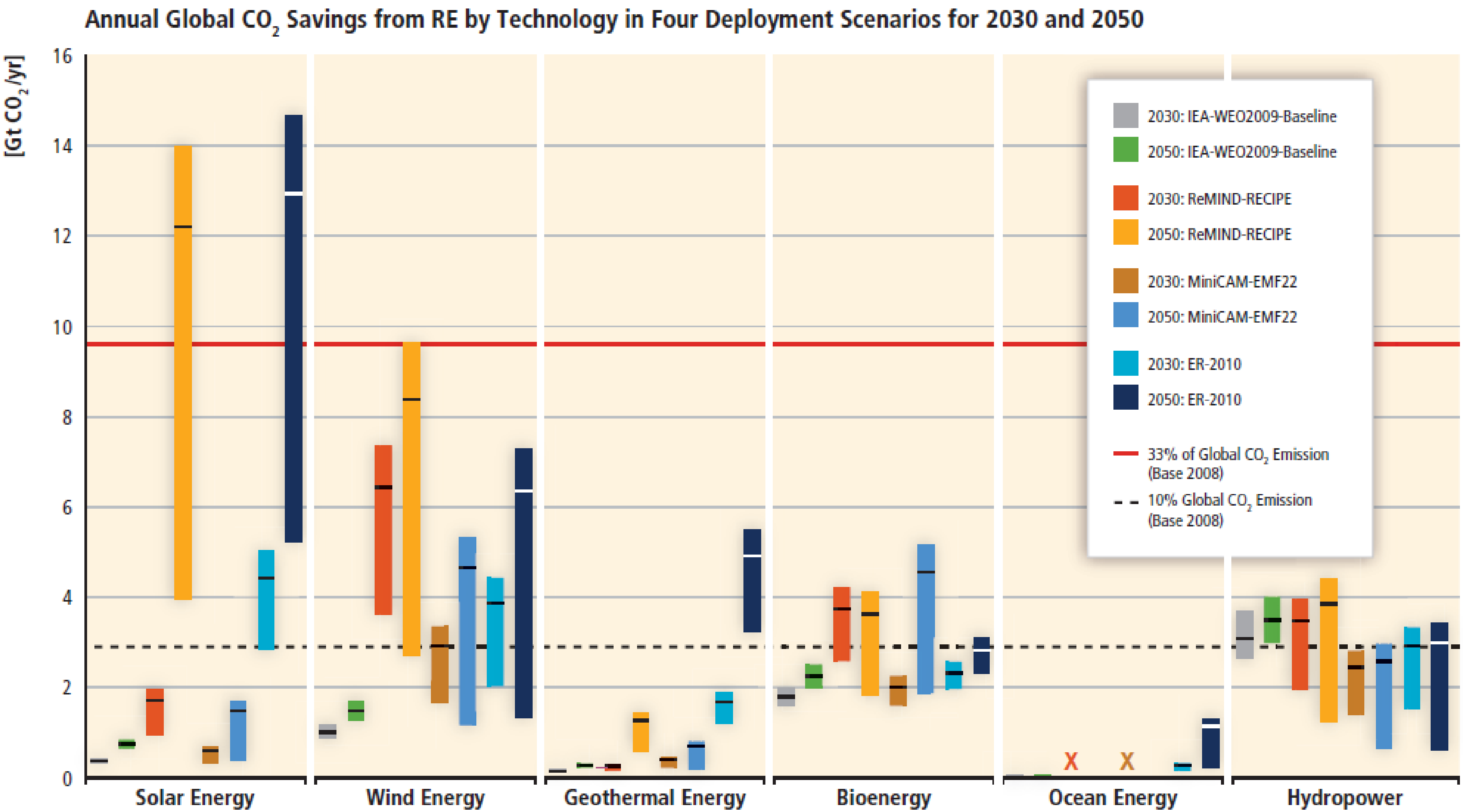

IPPC: Special Report 'Renewable Energy Sources and Climate Change Mitigation', 2012, p.829

Lifecycle GHG emissions – Electricity (2/2)

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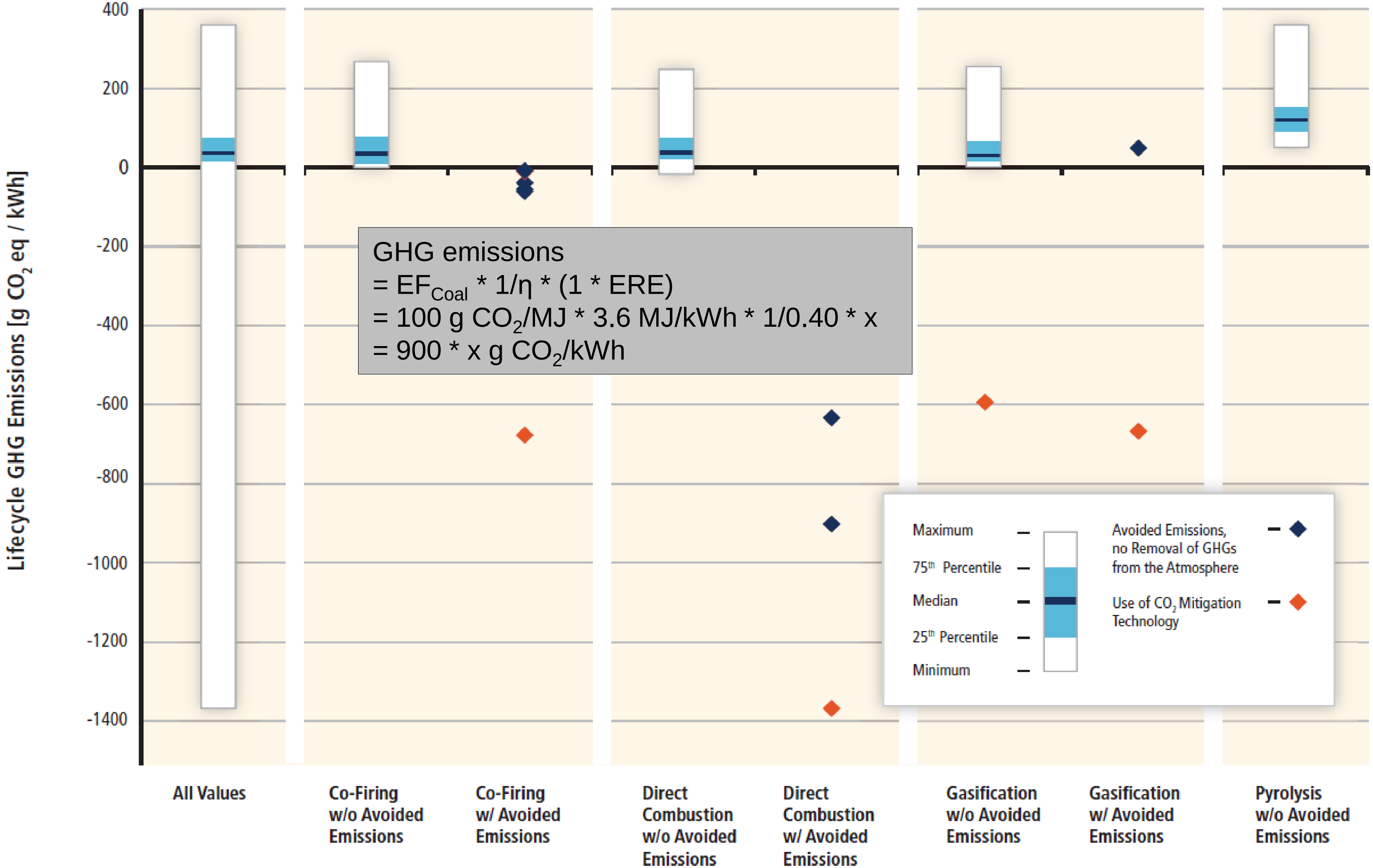


GHG emissions

$= EF_{Coal} * 1/\eta * (1 * ERE)$

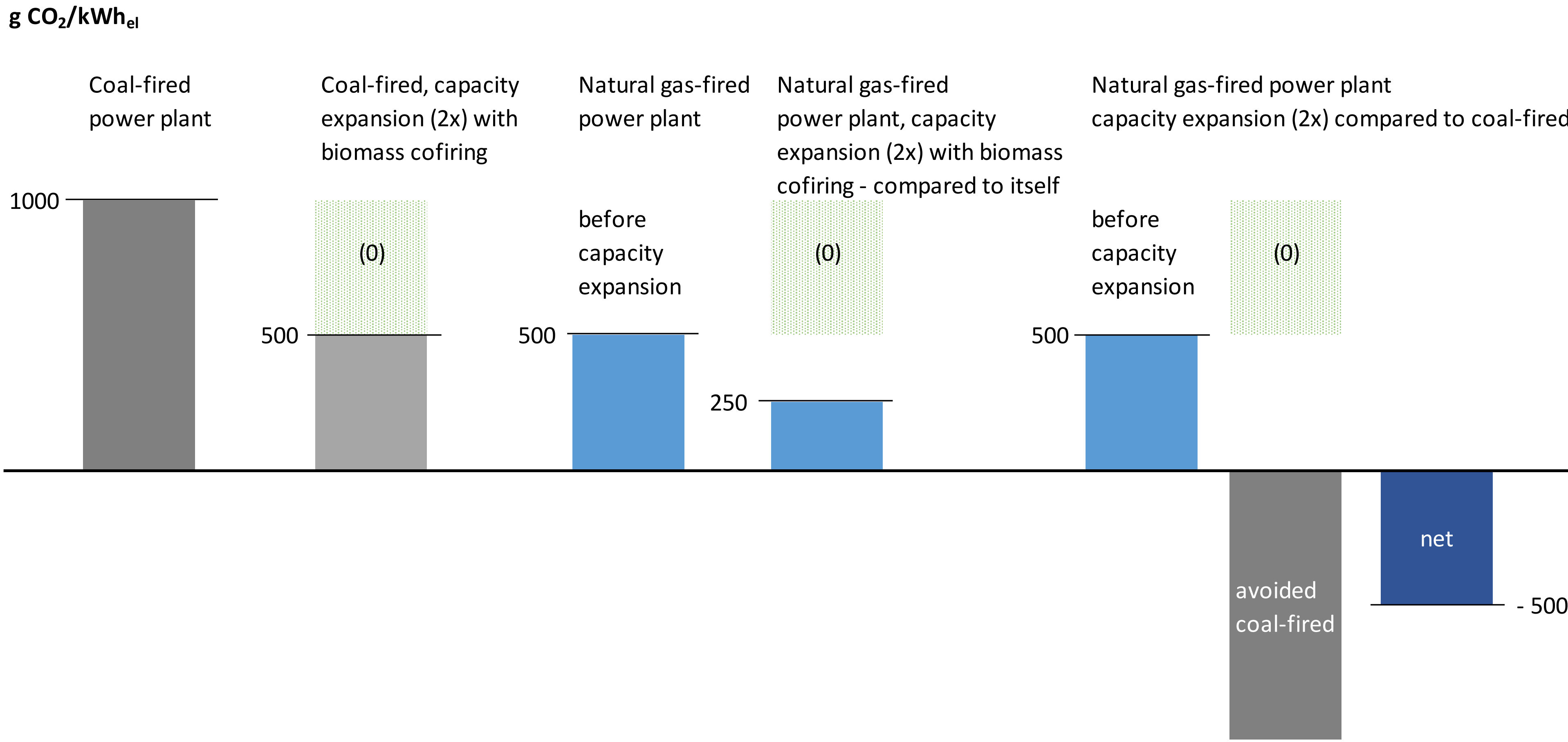
$= 100$ g CO_2/MJ * 3.6 MJ/kWh * 1/0.40 * x

$= 900 * x$ g CO_2/kWh

IPPC: Special Report 'Renewable Energy Sources and Climate Change Mitigation', 2012, p.260

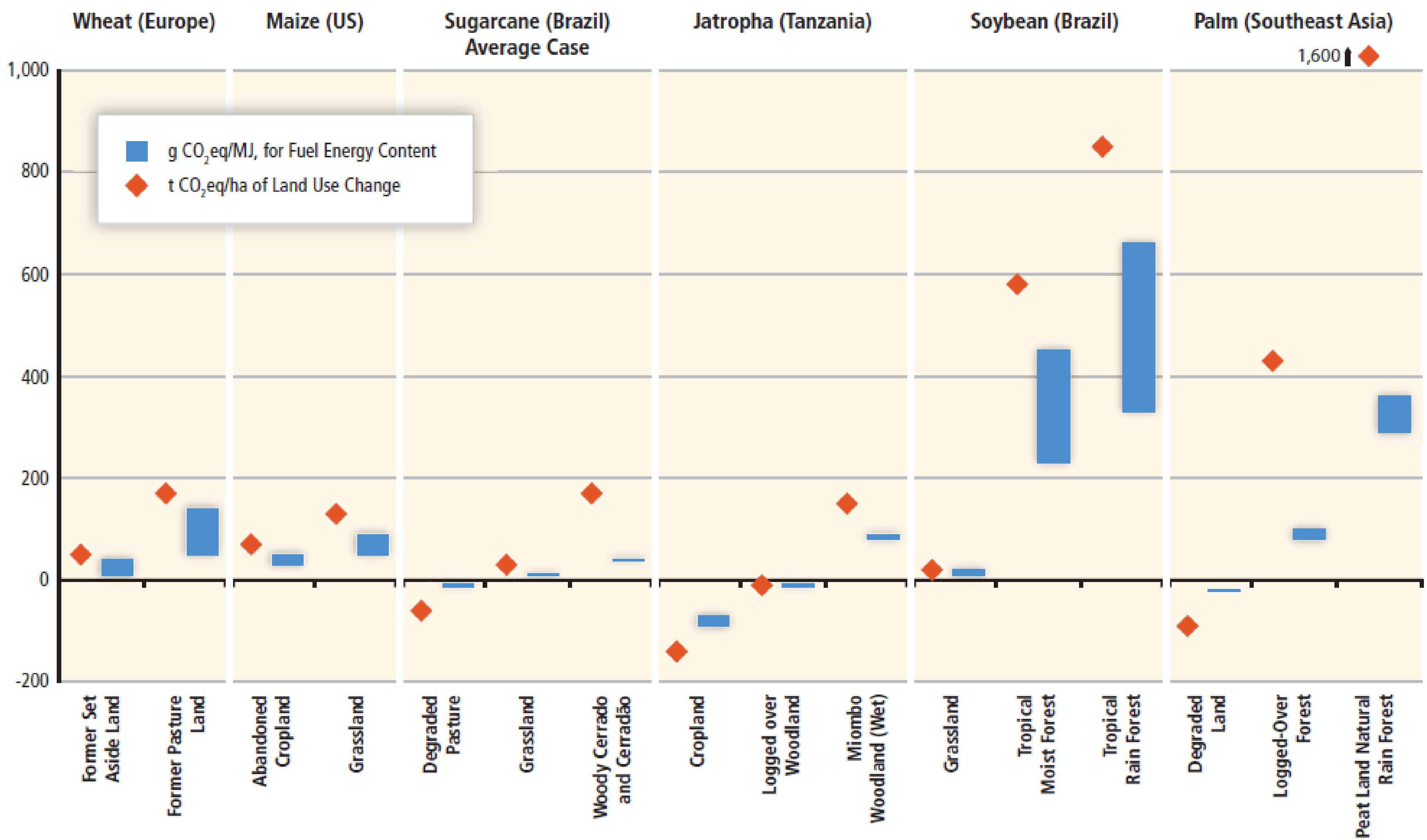
Partitioning versus System expansion

Attributional versus Consequential LCA



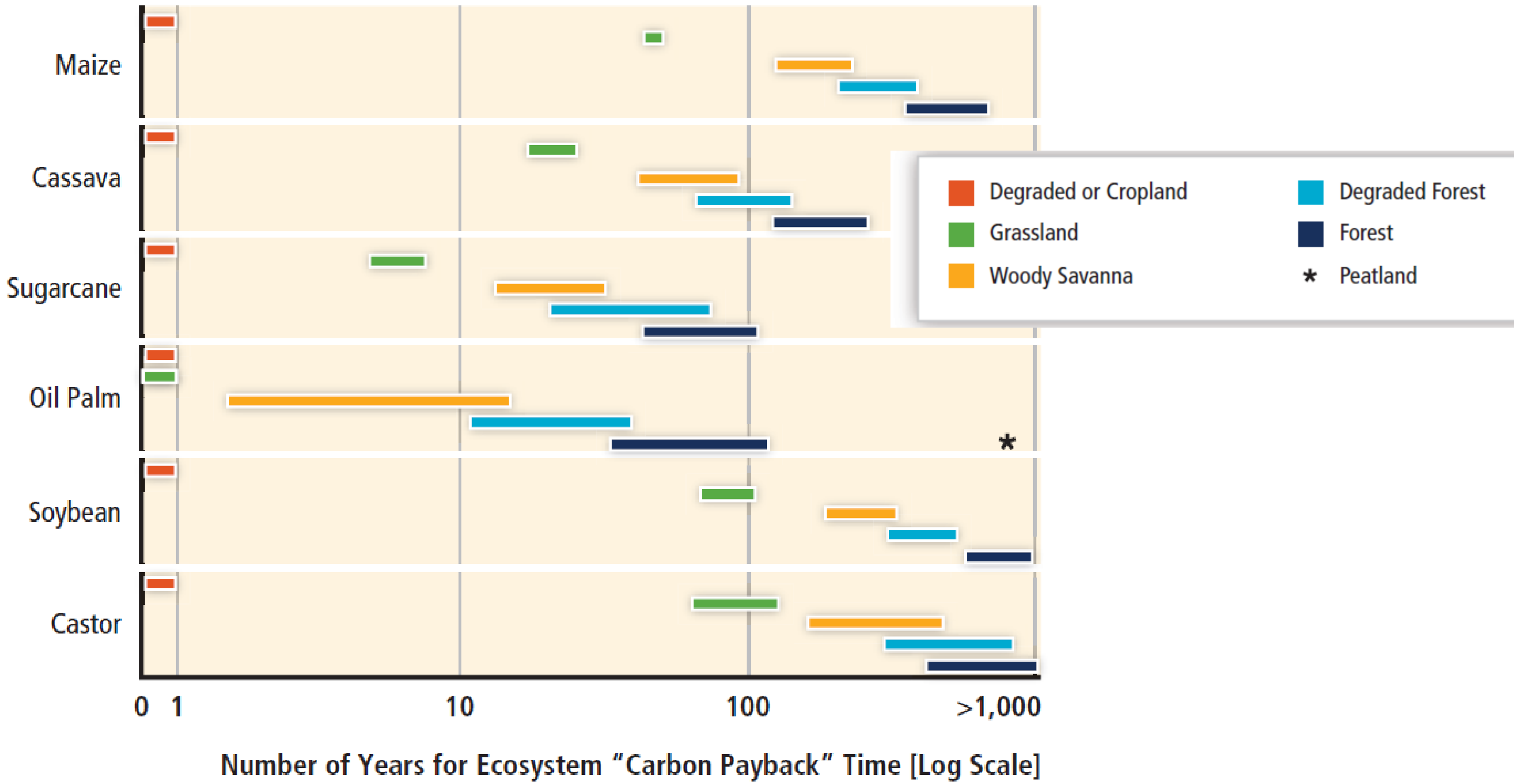
Lifecycle GHG emissions – Biofuels

Direct Land Use Change – GHG emissions



IPPC: Special Report ‘Renewable Energy Sources and Climate Change Mitigation’, 2012, p.736

Direct Land Use Change, (D)LUC - Carbon Payback time for biofuels



*: Palm oil establishments on tropical peat swamp forests

DLUC very small for degraded or cropland; and for '2nd generation feedstocks'.

IPPC: Special Report 'Renewable Energy Sources and Climate Change Mitigation', 2012, p.264

Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change

Timothy Searchinger,[1]* Ralph Heimlich,[2] R. A. Houghton,[3] Fengxia Dong,[4] Amani Elobeid,[4] Jacinto Fabiosa,[4] Simla Tokgoz,[4] Dermot Hayes,[4] Tun-Hsiang Yu[4]

Science, Vol. 319, 29 Feb. 2008

"By using a worldwide agricultural model to estimate emissions from land-use change, we found that [U.S.] corn-based ethanol, instead of producing a 20% savings, nearly doubles greenhouse emissions over 30 years and increases greenhouse gases for 167 years."

Indirect Land Use Change (ILUC), 1/4

Example: Biodiesel (rapseed oil/RME)

- Rapeseed replaces other crop
- other crop continues to be needed (food?) and therefore continues to be produced
- is cultivated elsewhere → cascade…
- …ultimately use of formerly un-used land with potentially large release of carbon
- (falls under consequential modelling)

Indirect Land Use Change (ILUC), 2/4

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iLUC: Values Used in Scenario Analysis (1440 runs)

Parameter/ Scenario	Description	Values
YPE	Yield Price elasticity	0.05 to 0.3
PAEL	Cropland pasture elasticity	0.1 to 0.6 U. S. 0.1 to 0.2 Brazil
ETL2	Land transformation elasticity that distributes available cropland between crops	Baseline, 80%, 90%, 110% and 120% of baseline
ETL1	Land transformation elasticity that governs land conversion between forest, cropland, and pasture land	Baseline, 80%, 90%, 110% and 120% of baseline
ETA	Elasticity of crop yields with respect to area expansion	Baseline, 80%, and 120% of baseline

Notes: Armington for trade pattern did not significantly cange results

California Env. Protection Agency, Air Resources Board, 2014
http://www.arb.ca.gov/fuels/lcfs/lcfs_meetings/iluc_presentation_031014.pdf

<u>Indirect</u> Land Use Change (ILUC), 3/4

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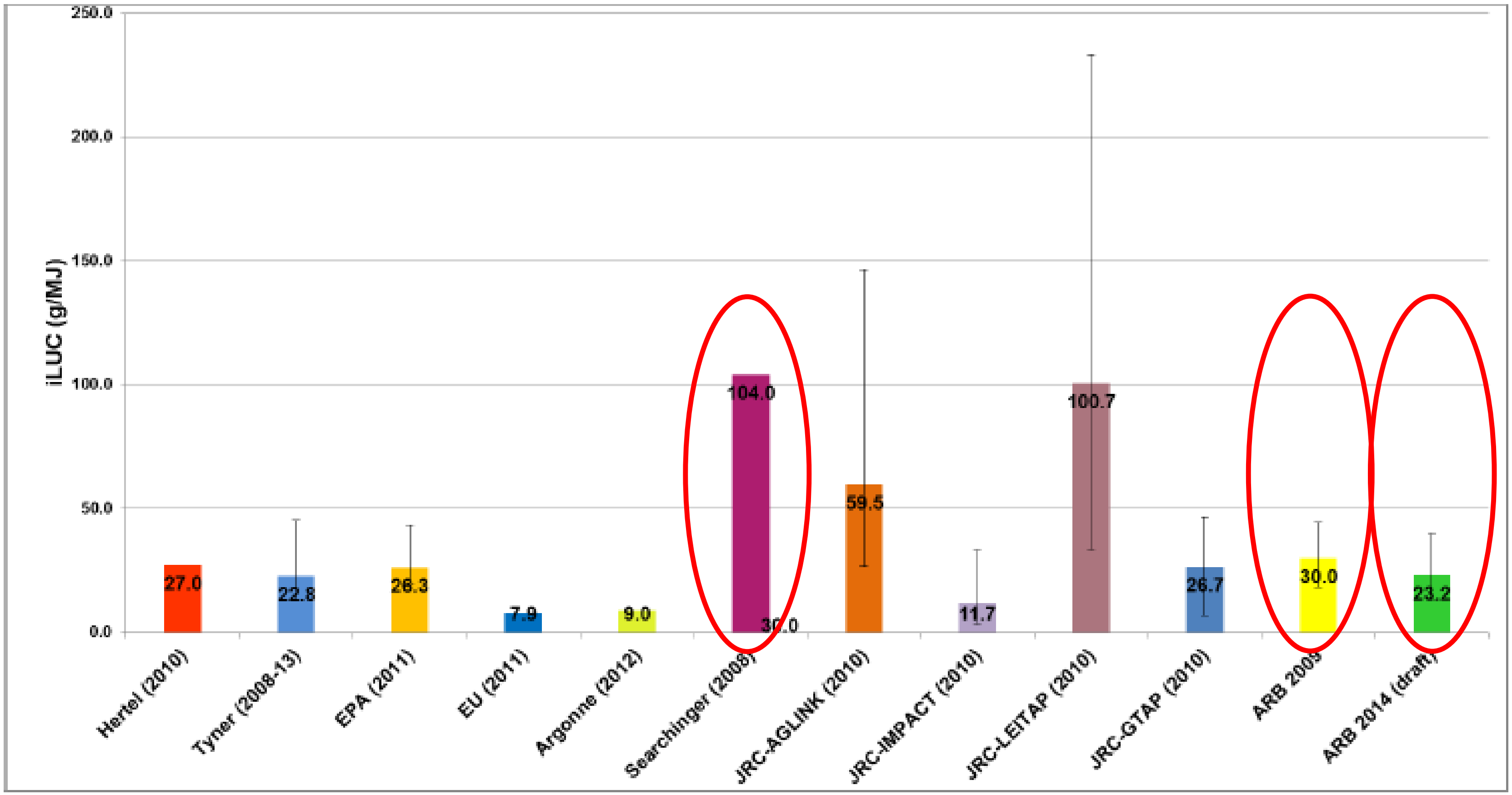
iLUC: Comparison of Results for Corn Ethanol



http://www.arb.ca.gov/fuels/lcfs/lcfs_meetings/iluc_presentation_031014.pdf

Indirect Land Use Change (ILUC), 4/4

- ILUC acc. to Californian Air Resources Board (ARB), preliminary results *)

Biofuel	2009 (g/MJ)	2014 Ave. (g/MJ)	Range (g/MJ)
Corn Ethanol	**30.0**	23.2	13.1 – 40.0
Sugarcane Ethanol	**46.0**	26.5	13.5 – 44.1
Soy Biodiesel	**62.0**	30.2	17.6 – 52.1
Canola Biodiesel	n/a	41.6	24.8 – 70.2
Sorghum Ethanol	n/a	17.5*	10.9 – 28.4*

- Assuming for corn ethanol 35% GHG emission reduction (Eur. Dir.):

74 kg CO_2 eq./GJ petrol · 35% = 26 g CO_2 eq./MJ

*) http://www.arb.ca.gov/fuels/lcfs/lcfs_meetings/iluc_presentation_031014.pdf

CO_2 from LUC (Land Use Change)

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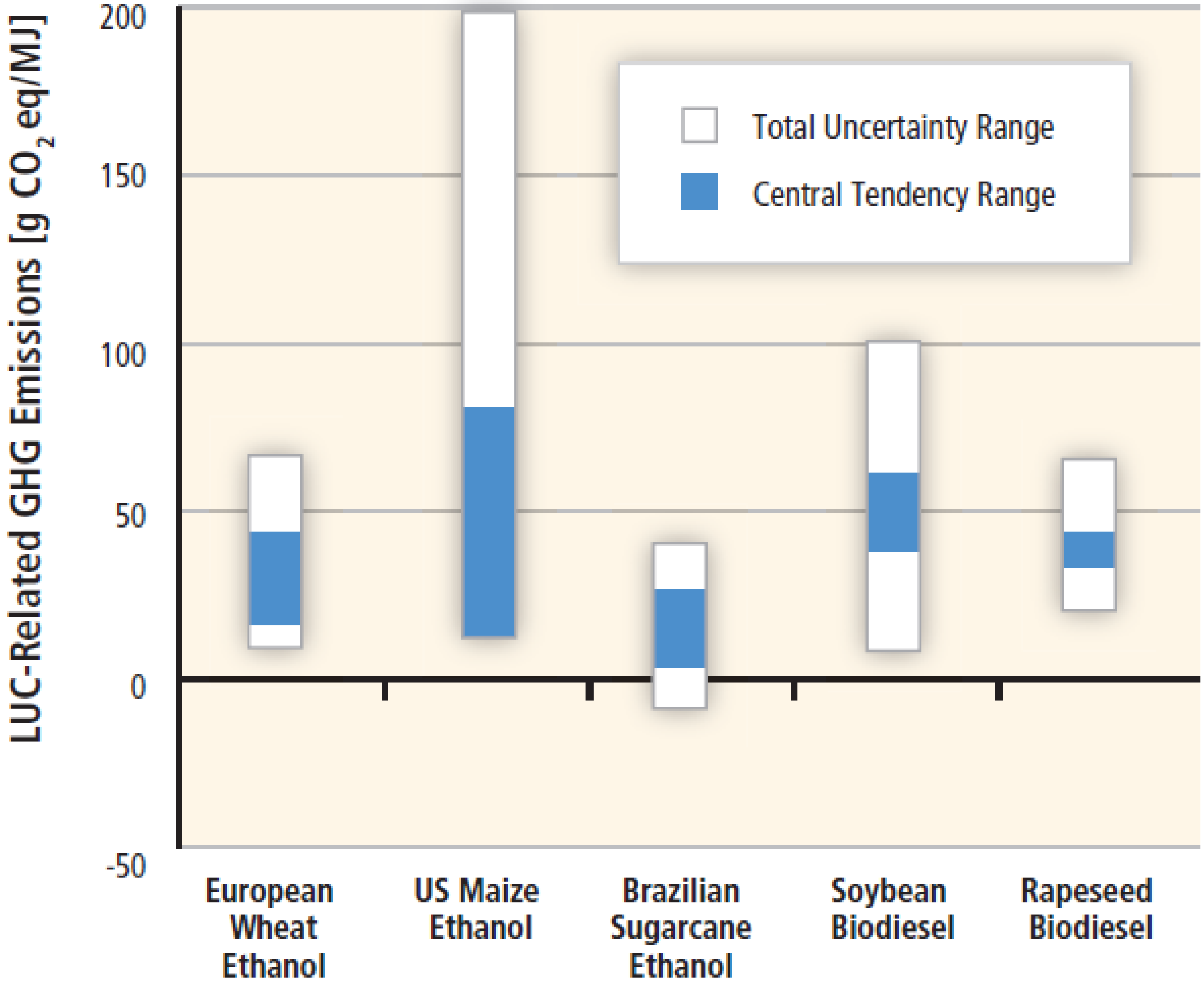

IPPC: Special Report 'Renewable Energy Sources and Climate Change Mitigation', 2012, p.736

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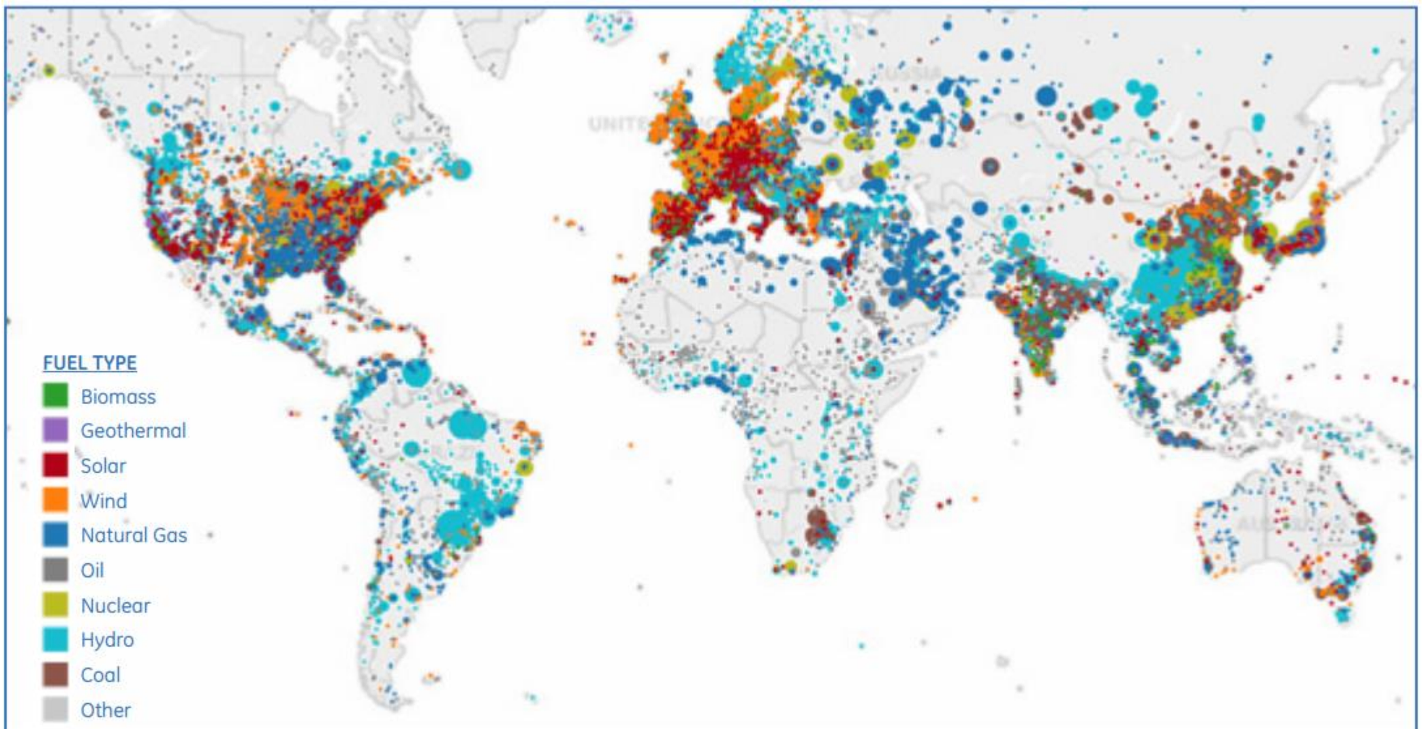
Hydro-electricity and LCA - Context

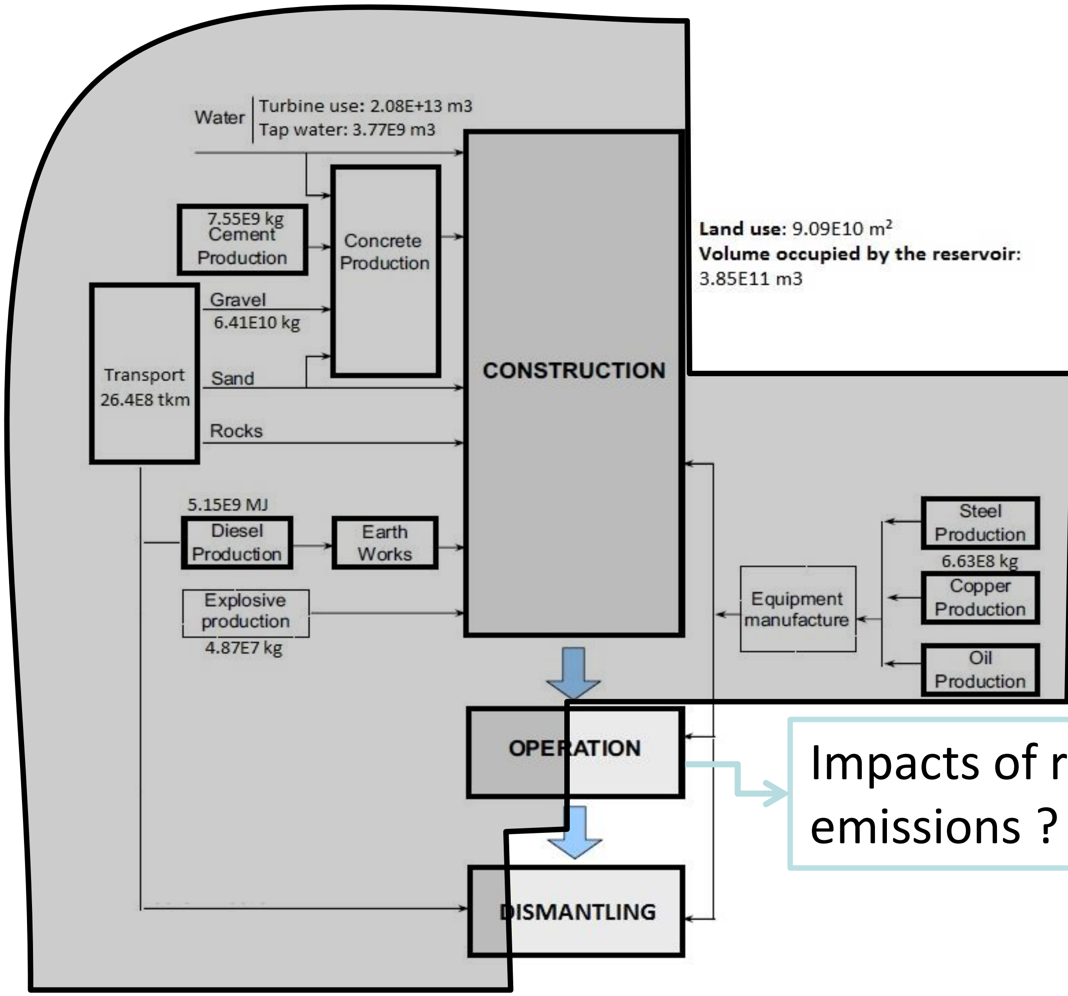
- Direct approach → CO_2 free electricity
  - Hydropower is strongly promoted all over the world to reduce GHG
  - Many developments in tropical regions



Source: Power plant data source Platts UDI Database, June 2012
Note: Circle size represents installed capacity (MW).

Hydro-electricity and LCA - Assumptions

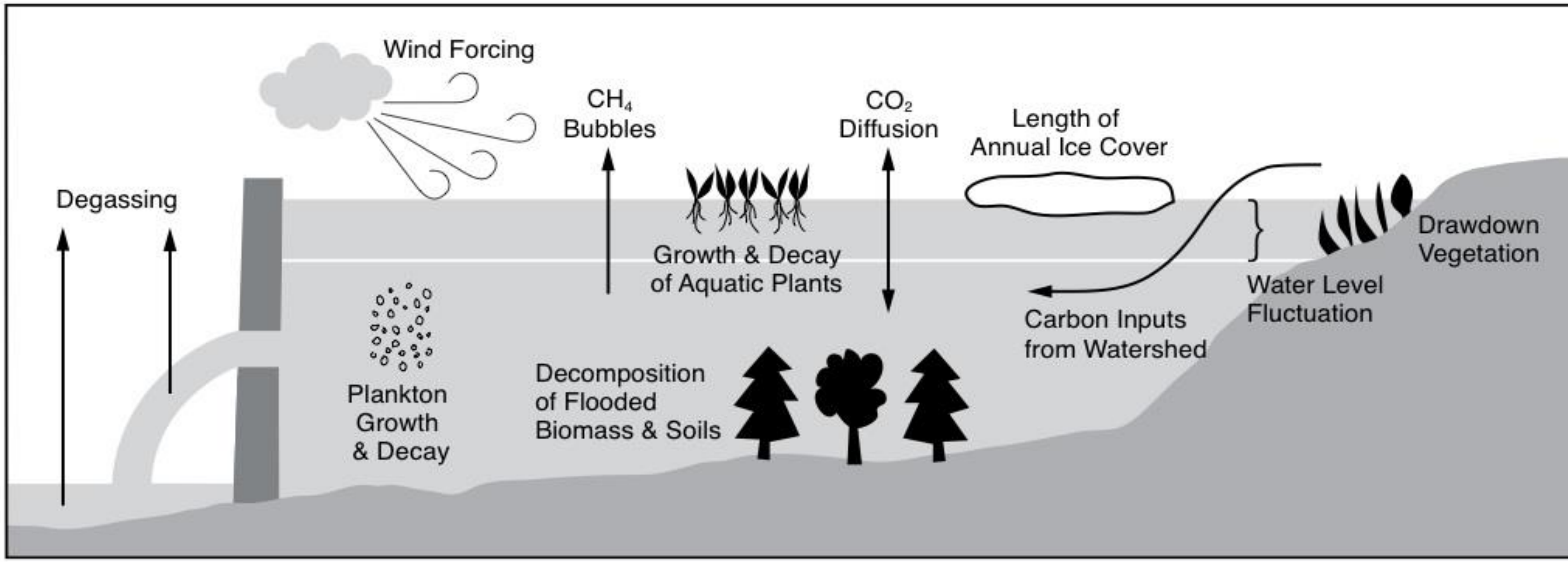
- Life cycle perspective

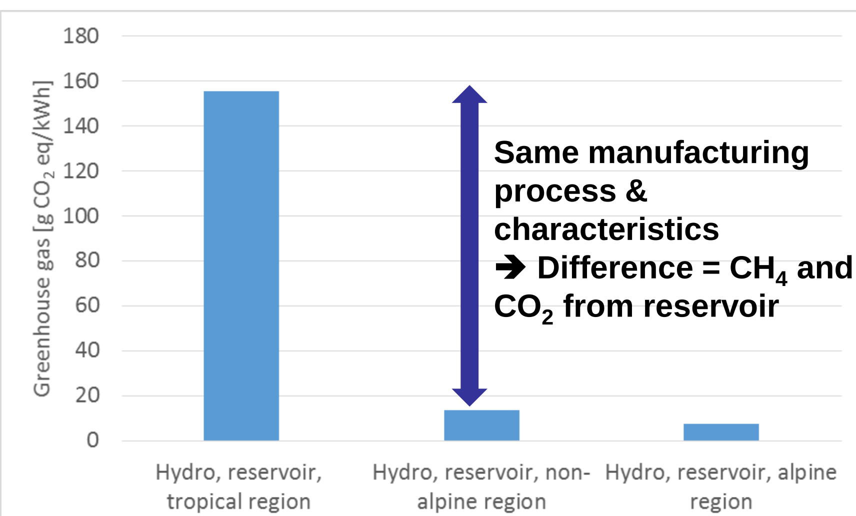


- Manufacturing → impacts driven by infrastructure and concrete
- Reservoir → impacts dependant on location
- Decommissioning → only the power plant (LT = 80 y)

Impacts of reservoir induced emissions ?

Hydro-electricity – LCA results





Calculated with SimaPro based on ecoinvent3

- Climate change impacts ➔ x10
  - Reservoir surface emissions (upstream)
  - Degassing and oxidization emissions (downstream)

  ➔ *Emissions modelling is complex*

Impact of methane on global warming

UNIVERSITÉ DE GENÈVE

IPCC 5th Assessment Report, WG1, 2013, p.713

- "The inclusion of indirect effects and feedbacks in metric values has been inconsistent in the IPCC reports."
- "While the Absolute Global Warming Potential for the reference gas CO_2 included climate–carbon feedbacks, this is not the case for the non-CO_2 gas in the numerator of GWP"
- "Though uncertainties in the carbon cycle are substantial, it is likely that including the climate–carbon feedback for non-CO_2 gases as well as for CO_2 provides a better estimate of the metric value than including it only for CO_2."

	Lifetime (years)		GWP_{20}	GWP_{100}
CH_4[b]	12.4[a] *)	No cc fb	84	28
		With cc fb	86	34

IPCC 4th AR: 25
IPCC 3rd AR: 21

*) For fossil methane, add one unit for GWP20 and 2 units for GWP100.

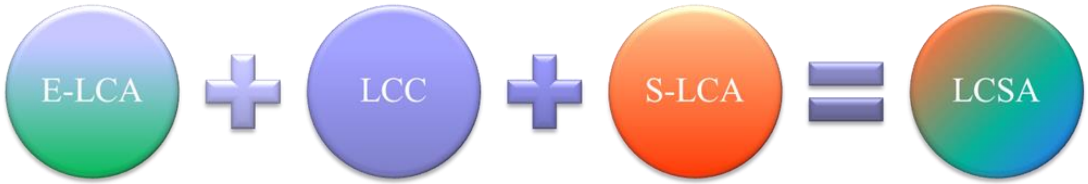
Conclusions - LCA and beyond

- LCA objectives
  - Overview of environmental impacts
  - Use: Avoid any « fausses bonnes idées »
    → Use by policy makers for development of energy
    → Use by technology developers for targeted improvements

- LCA findings for renewable energy systems
  - Important opportunities for reducing NREU and GHG (for bio: risk of LUC-related GHG)
  - Drawbacks for other impact categories
  - Decreased environmental impacts by innovative technology

- LCA methodology must be improved:
  - Grey energy of climate change impacts are not the only relevant indicators ➔ Water footprint, ionizing radiation, etc.
  - Spatialization, consequential LCA, etc.
  - Interpretation

- **Life Cycle Sustainability Assessment**



Source: Source: UNEP (2012) Social Life Cycle Assessment and Life Cycle Sustainability Assessment