Evaluating Environmental Side-Effects of Carbon Reduction

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Objective

- To evaluate carbon dioxide (CO_2)-reduction energy technologies considering environmental positive and negative side-effects;

1. Screening of several CO_2-reduction energy technologies based on life-cycle impact assessment (LCIA)

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2. Evaluation focusing on fuel cell vehicle (FCV) and bio-ethanol (EtOH):
   - Potentials of adverse side-effects
   - Insights for their mitigation

LCIA methodologies applied

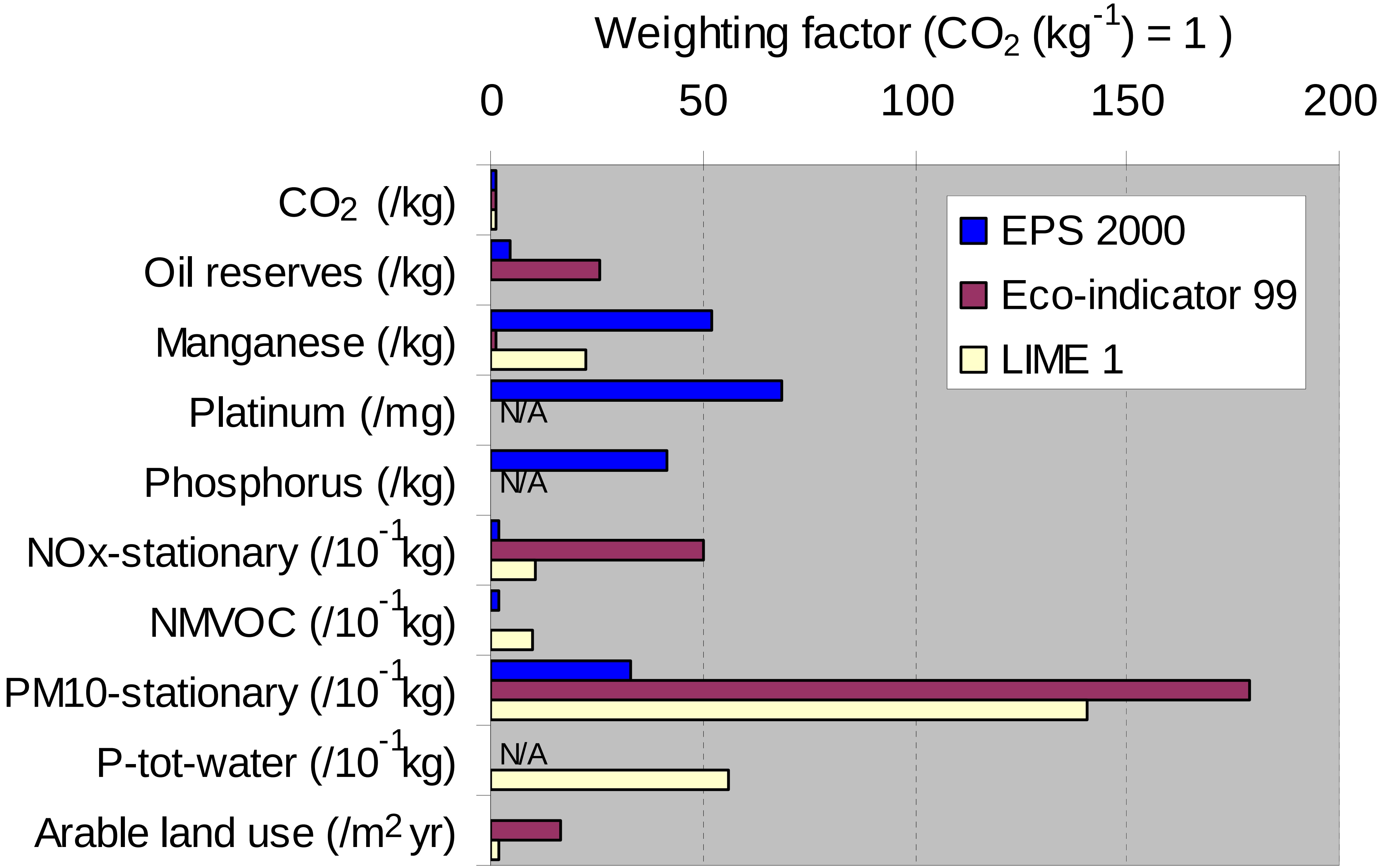
LCIA method	Target region	Weighting method	Ref.
EPS 2000	World	Damage cost via market value & CVM	[1]
Eco-indicator 99	Europe	Non-dimensional value via panel procedure	[2]
LIME 1	Japan	Damage cost via conjoint analysis	[3]

[1] Steen, B. (1999). A Systematic Approach to Environmental Priority Strategies in Product Development (EPS) Version 2000 - Models and Data of the Default Method, CPM report 1999:5, Chalmers University of Technology, Environmental Systems Analysis, Göteborg, Sweden.

[2] Goedkoop, M., Spriensma, R. (2001). The Eco-indicator 99: A damage oriented method for Life Cycle Impact Assessment – Methodology Report, 3rd edition, nr. 1999/36A, PRé Consultants BV, Amersfoort, The Netherlands.

[3] Itsubo, N., Inaba, A. (Eds.) (2005). Life-cycle Environmental Impact Assessment Method. Japan Environmental Management Association for Industry, Tokyo, Japan.

Weighting factors for environmental loads



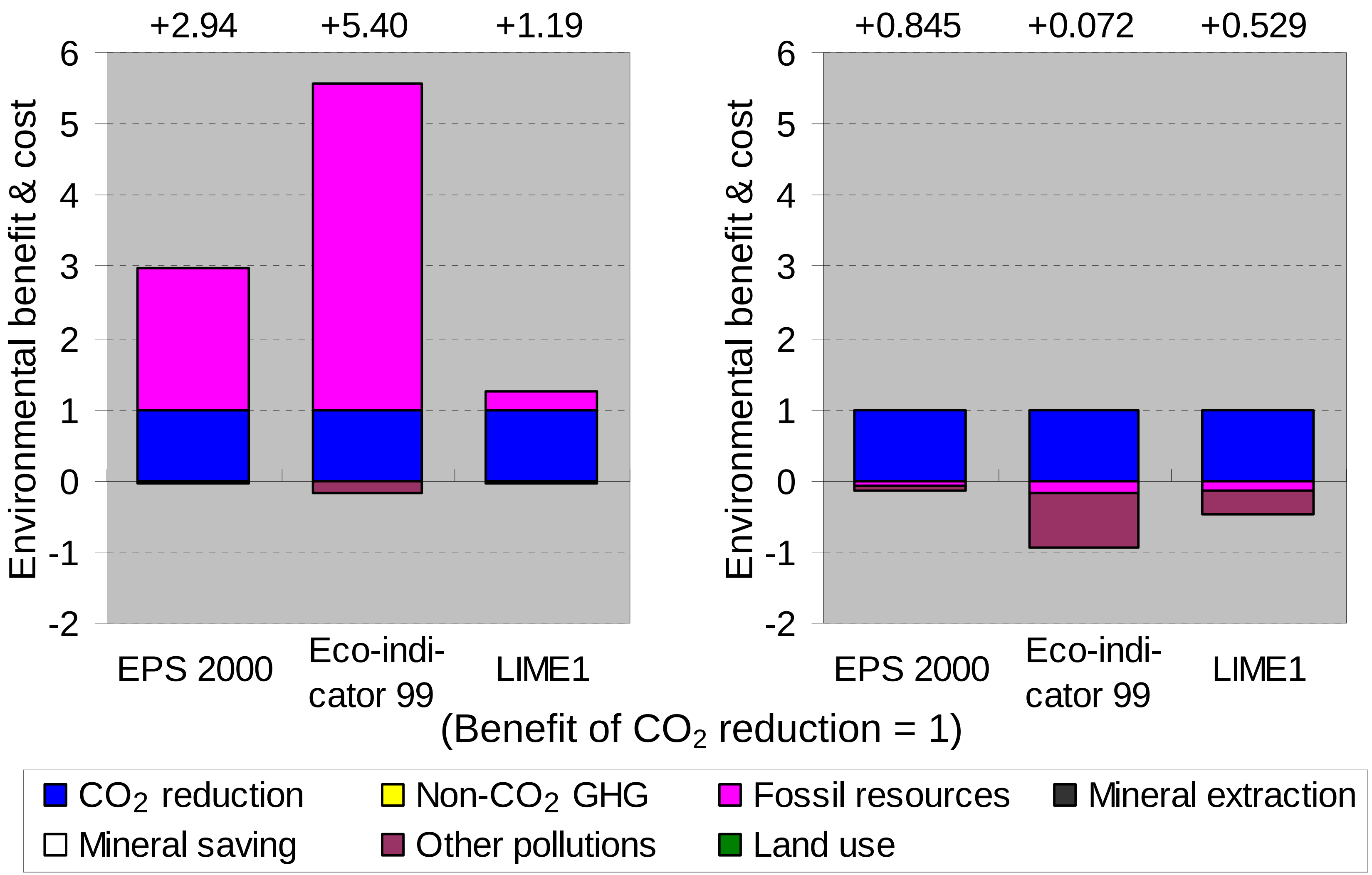
Basic evaluation

Evaluated technology	Ref. technology	Source
Photovoltaics (PV)	Japanese utility elec.	[1]
CO_2 capture from coal power plant	Coal power plant	[2]
Electric vehicle (EV)	Gasoline ICE vehicle	[3-5]
Fuel cell vehicle (FCV) fueled by H_2 from natural gas	Gasoline ICE vehicle	[5-7]
Bio-ethanol produced from maize	Gasoline	[8,9]

[1] Pehnt, M. (2006). Renewable Energy 31, 55–71; [2] Viebahn, P., et al. (2007). Int. J. Greenhouse Gas Control 1, 121-133; [3] Nansai, K., et al. (2002). Applied Energy 71, 111–125; [4] Central Research Institute of Electric Power Industry (2001). NEDO Contract Research Report; [5] Schade, W., et al. (2007). MATISSE Project Working Paper 15; [6] Saurat, M., and Bringezu, S. (2008). MATISSE Project Working Paper 20; [7] Colella, W.G., et al. (2005). Journal of Power Sources 150, 150-181; [8] Renouf, M.A., et al. (2008). Biomass and Bioenergy, doi:10.1016/j.biombioe.2008.02.012; [9] Righelato, R., and Spracklen, D.V. (2007). Science 317, 902.

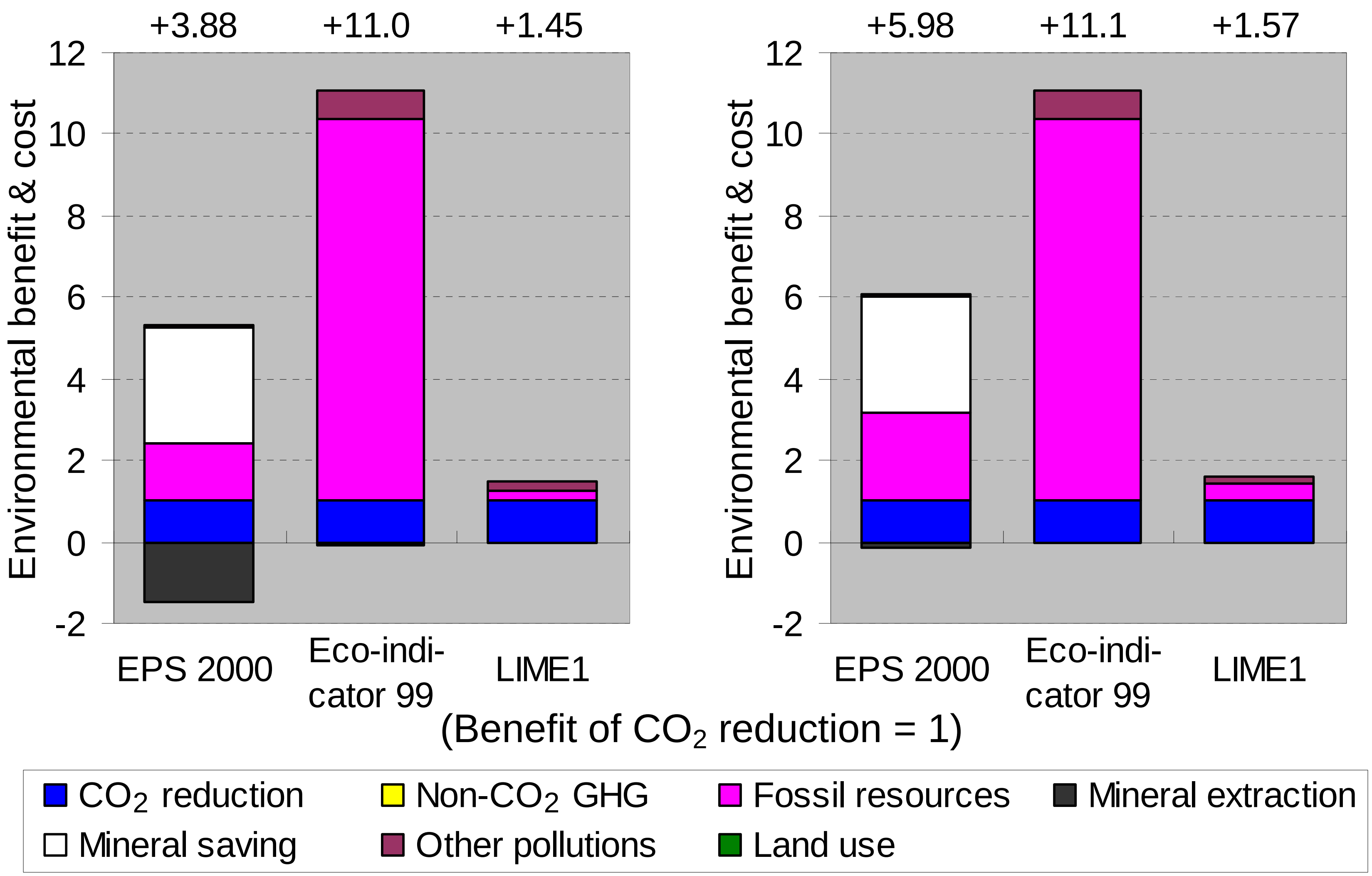
Basic evaluation result (1)

- PV (polyc. SOG-Si)
- CCS (pulverised coal)



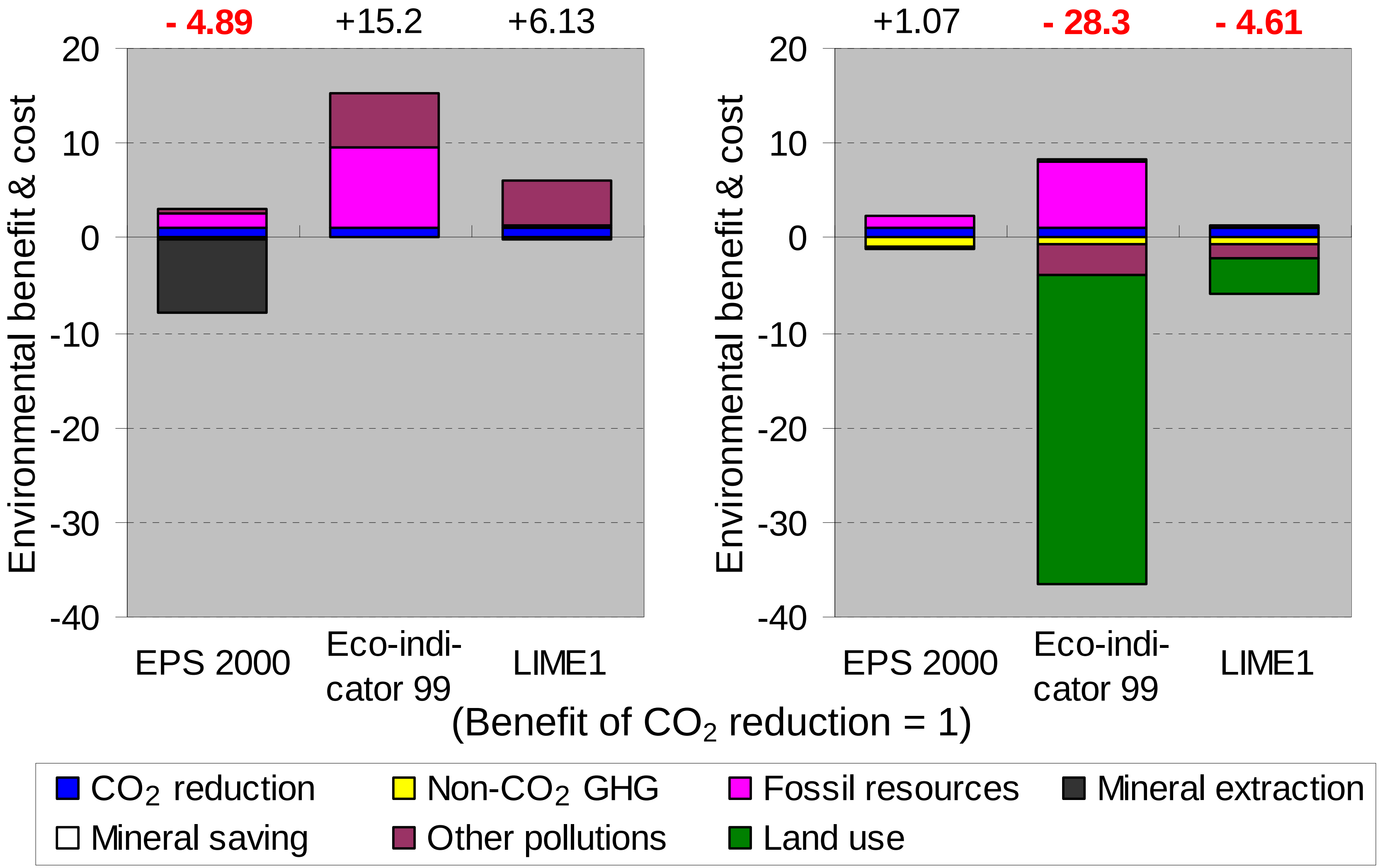
Basic evaluation result (2)

- EV ($LiNi_{0.8}Co_{0.1}Mn_{0.3}O_2$)
- EV ($LiMn_2O_4$)



Basic evaluation result (3)

- FCV (natural-gas H_2)
- Bio-EtOH (US maize)

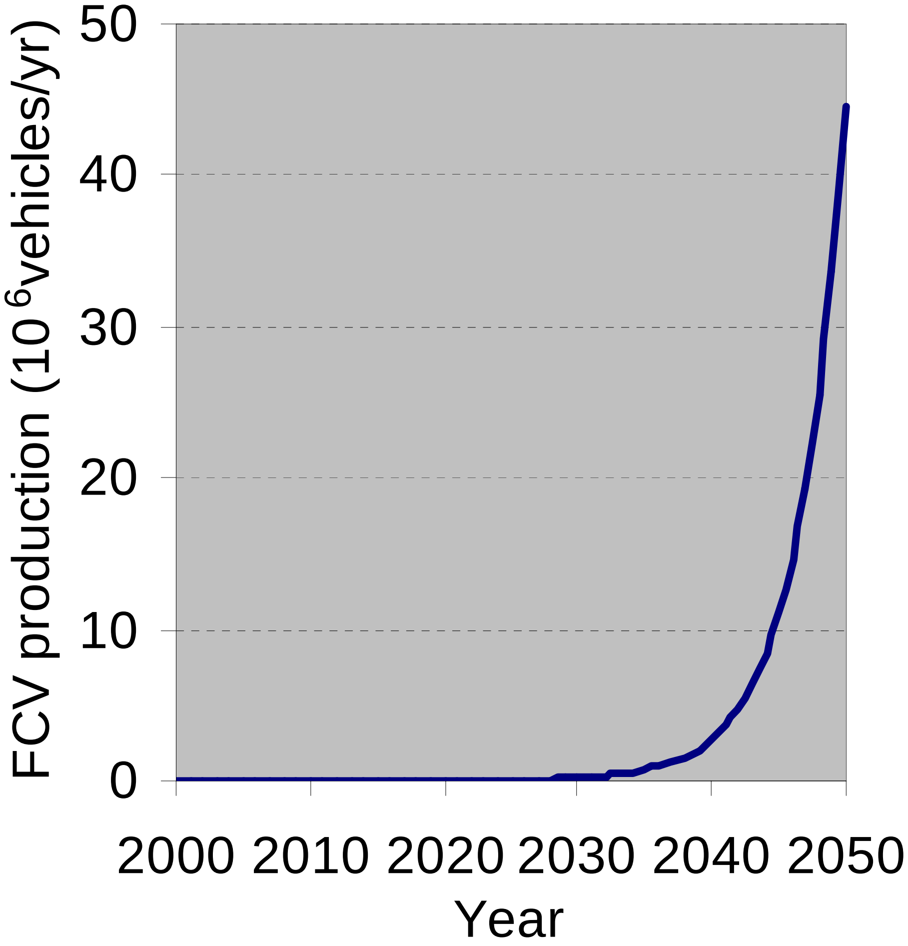


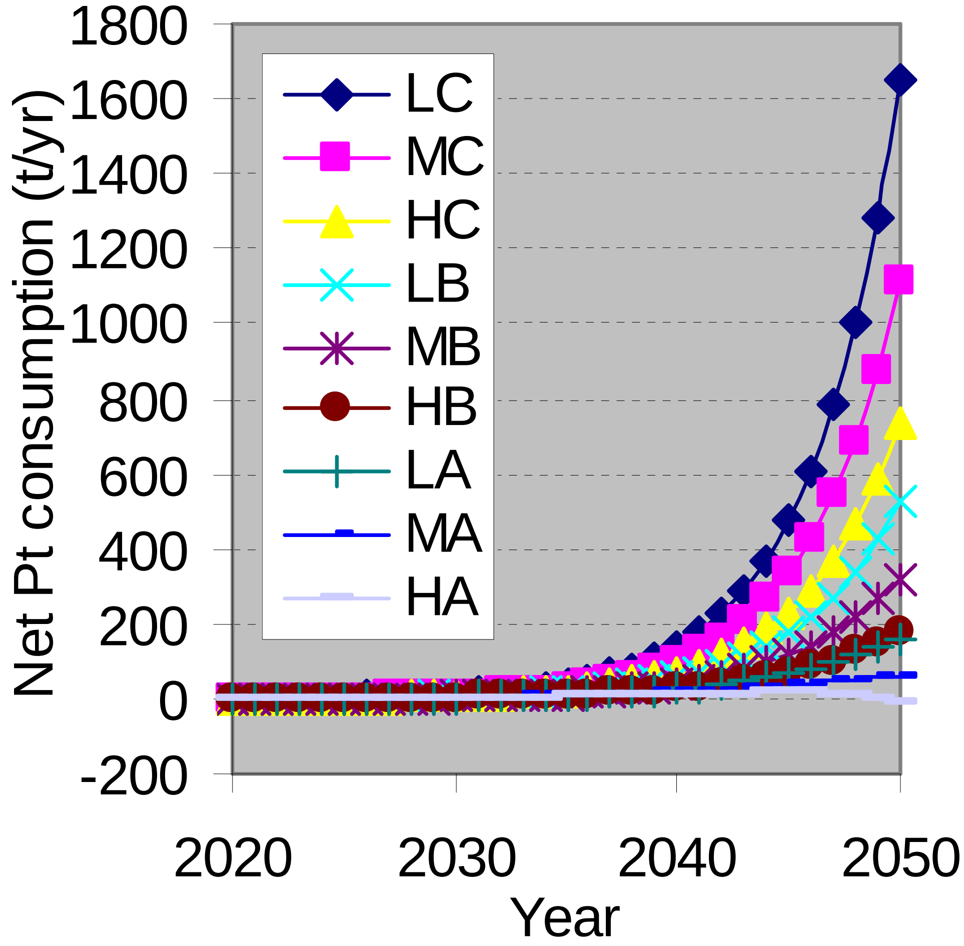
Evaluating fuel cell vehicle (FCV)

- Scenario-based evaluation for 50 yrs. (-2050)
  - FCV share: exponentially increase to 9% of all vehicles in the world [1]
  - Type of FCV: Polymer electrolyte membrane, H_2
  - Power output of FC: 90 kW (Ref.) or lower
  - Source of H_2: Natural gas (Ref.) or wind [2]
  - Difference in fuel economy between FCV and gasoline ICE [2]: same throughout the period
  - Platinum loading: FCV: decrease from 2 g/kW (2000) with production learning (9 cases) [3]; Gasoline ICE: 4.1 g/vehicle [4] (90kW equivalent; Euro 5) [5]

[1] IEA (2006). Energy Technology Perspectives 2006, OECD/IEA, Paris; [2] Colella, W.G., et al. (2005). Journal of Power Sources 150, 150-181; [3] Tsuchiya, H., Kobayashi, O. (2004). Int. J. Hydrogen Energy 29, 985-990; [4] Saurat, M., Bringezu, S. (2008). MATISSE Project Working Paper 21; [5] EC (2007) Regulation No. 715/2007;

FCV production and Pt consumption

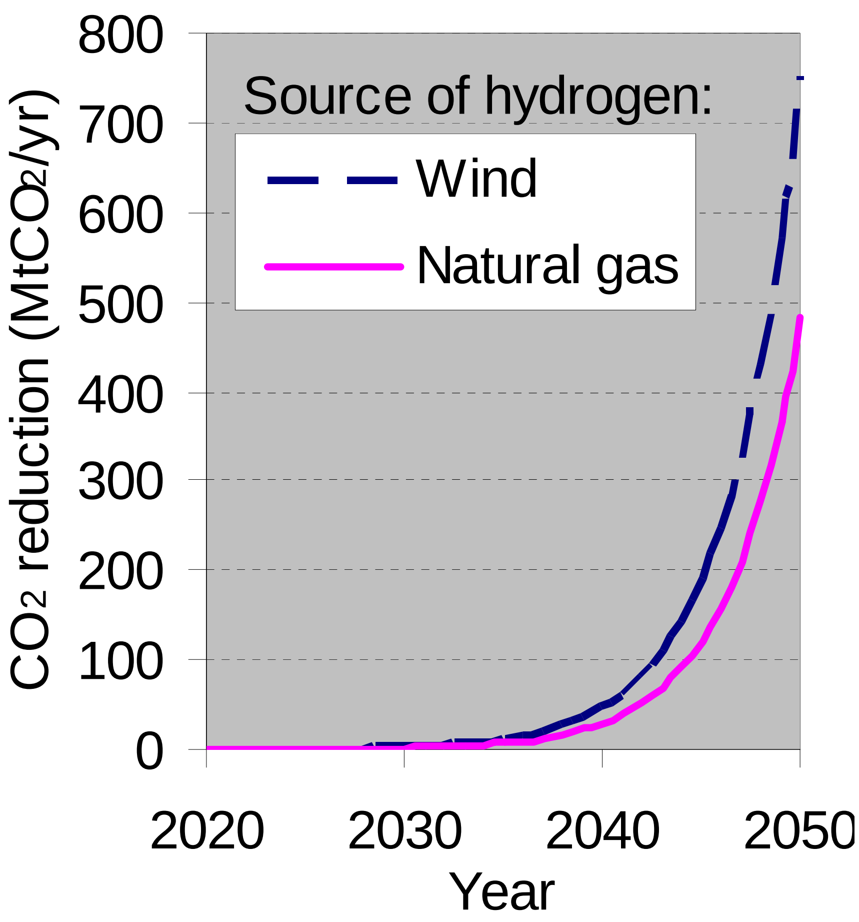


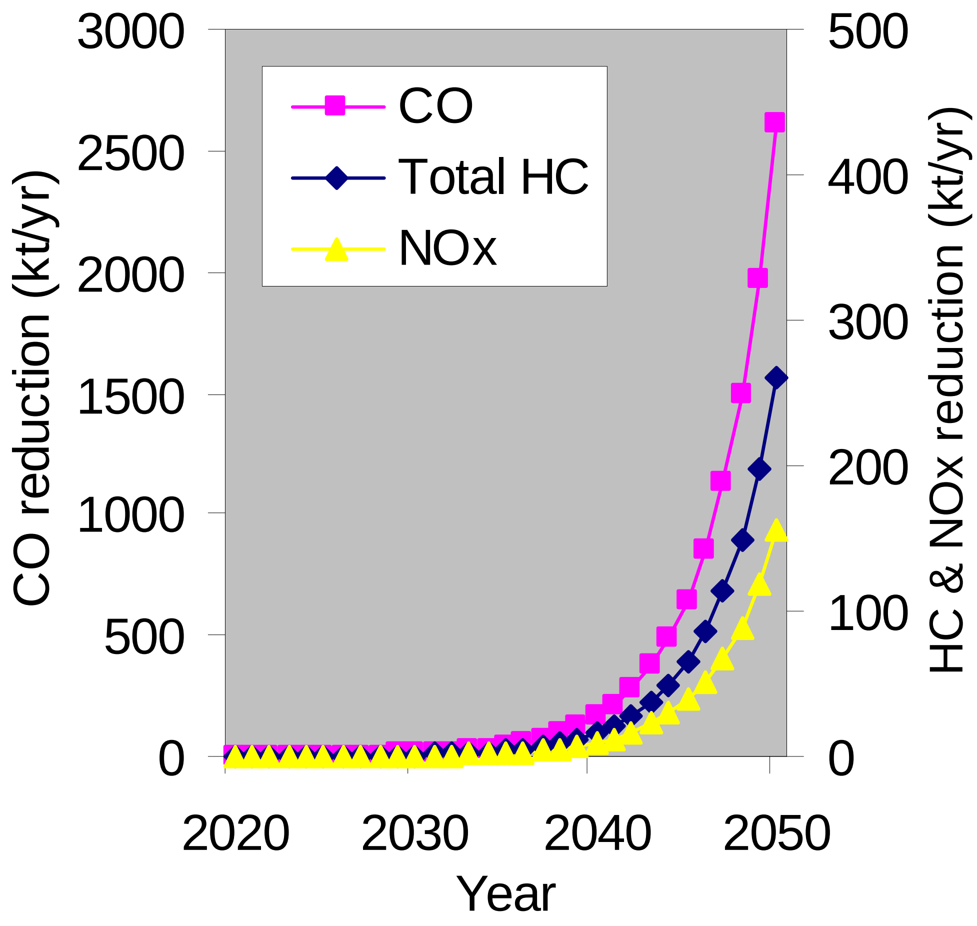


- Net Pt consumption = Gross Pt consumption for FCV production *minus* recycled Pt from end-of-use FCV *minus* reduced Pt consumption for substituting gasoline ICE vehicle production.

Emissions to the air

- CO_2 reduction
- Air pollutants reduction

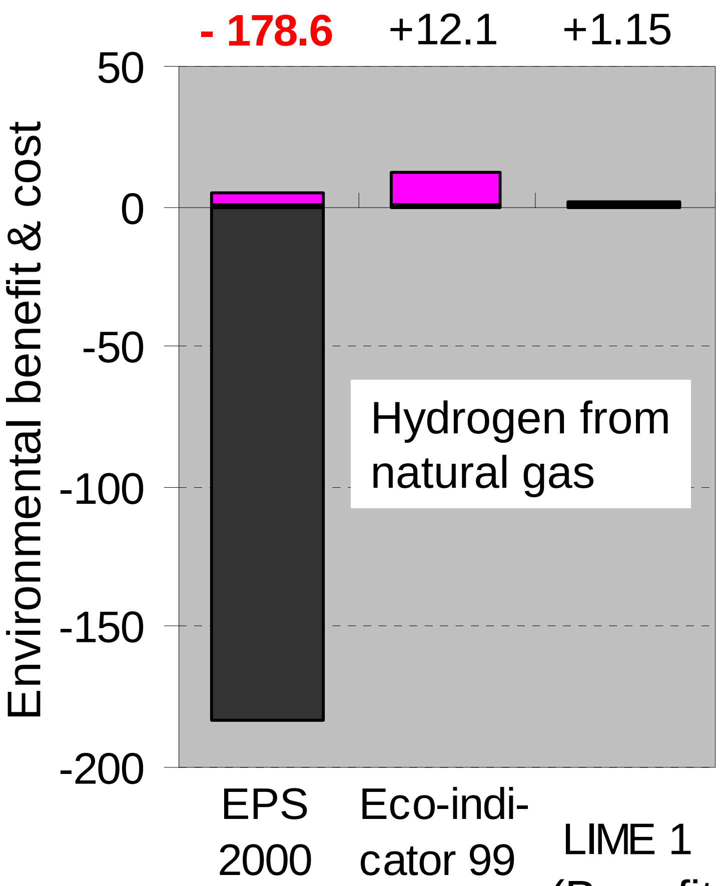




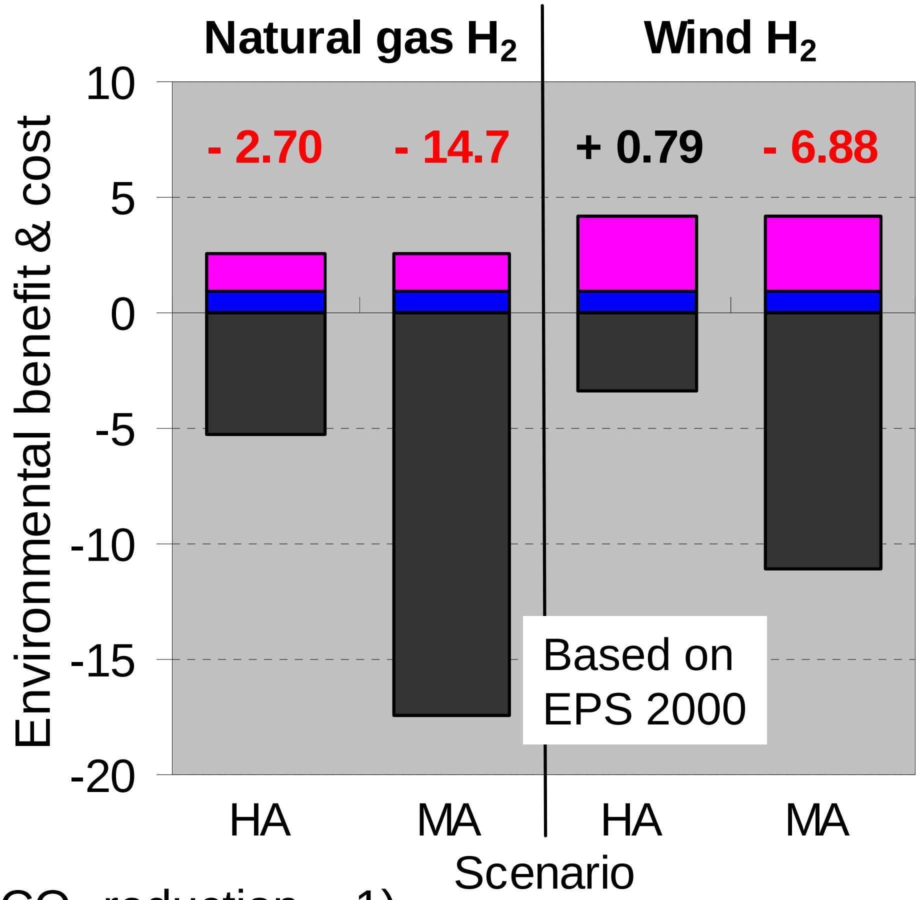
Evaluation of FCV based on LCIA

2000-2050 total

- LC case (pessimistic)



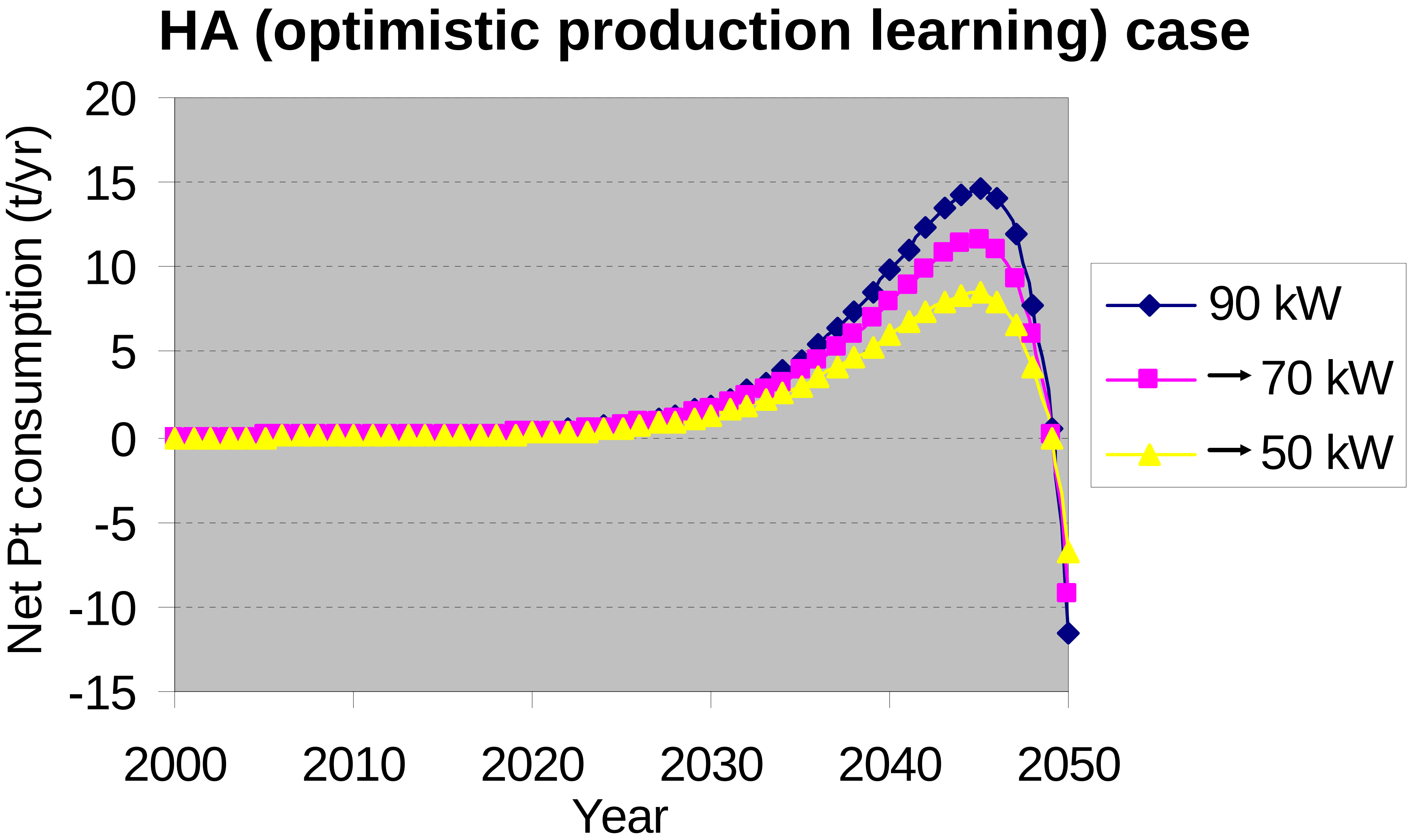
- HA and MA (optimistic)



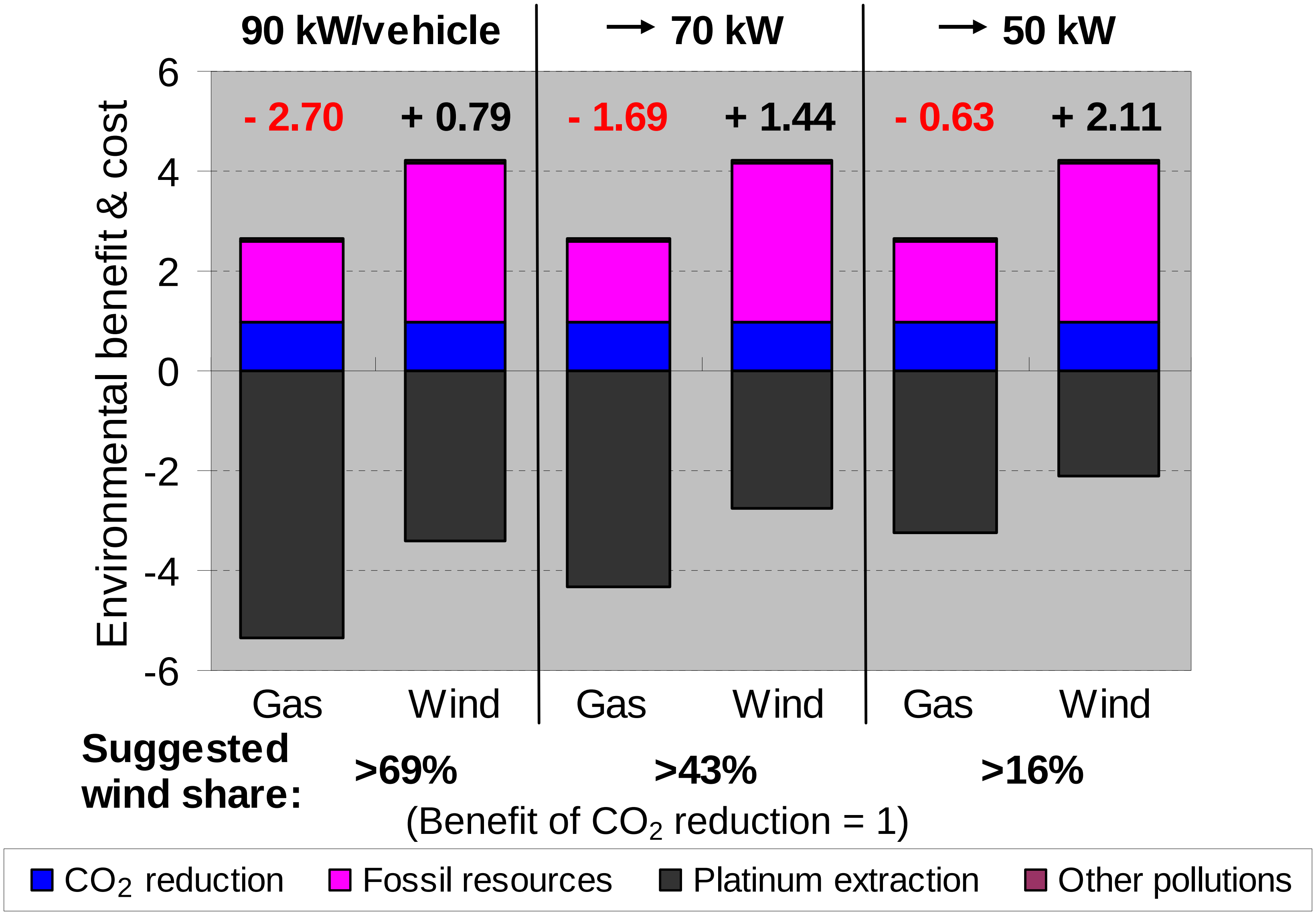
(Benefit of CO_2 reduction = 1)

■ CO_2 reduction ■ Fossil resources ■ Platinum extraction ■ Other pollutions

Pt saving by shifting to compact vehicle



Assessment of vehicle-size shift

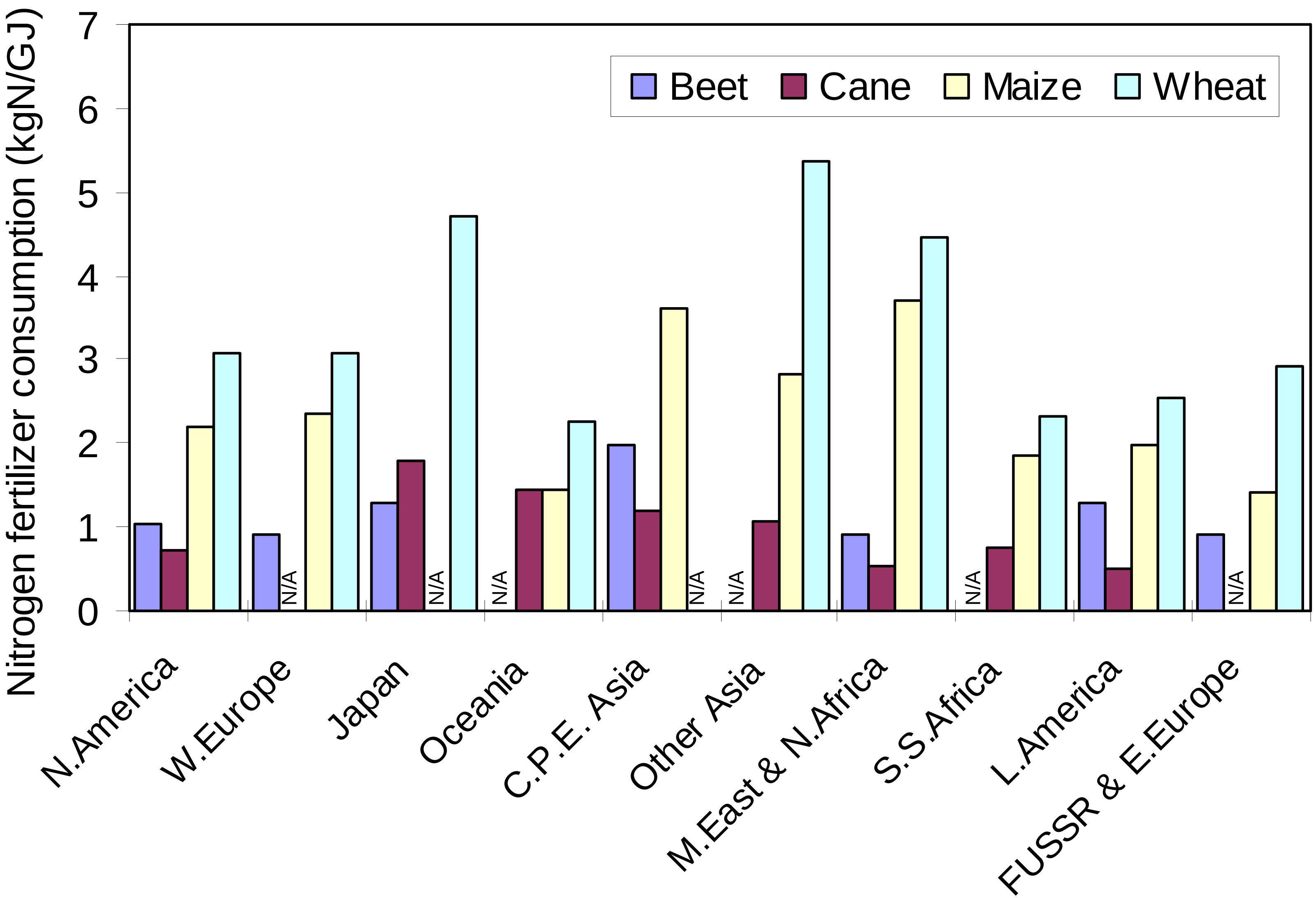


Evaluating Bio-Ethanol (EtOH)

- Data sources:
  - Crop (sugar beet, sugar cane, maize, wheat) yield and fertilizer use: compiled from FAOSTAT [1]
  - EtOH yield from crop: from [2]
  - Cultivation energy: from [3,4]
  - Emissions factors of N_2O, NH_3, NOx, N-tot, P-tot: lowest values among 6 studies [4,5]
  - Fertilizer production energy: from [6]
  - Pesticide use and run-off, co-products are not considered.

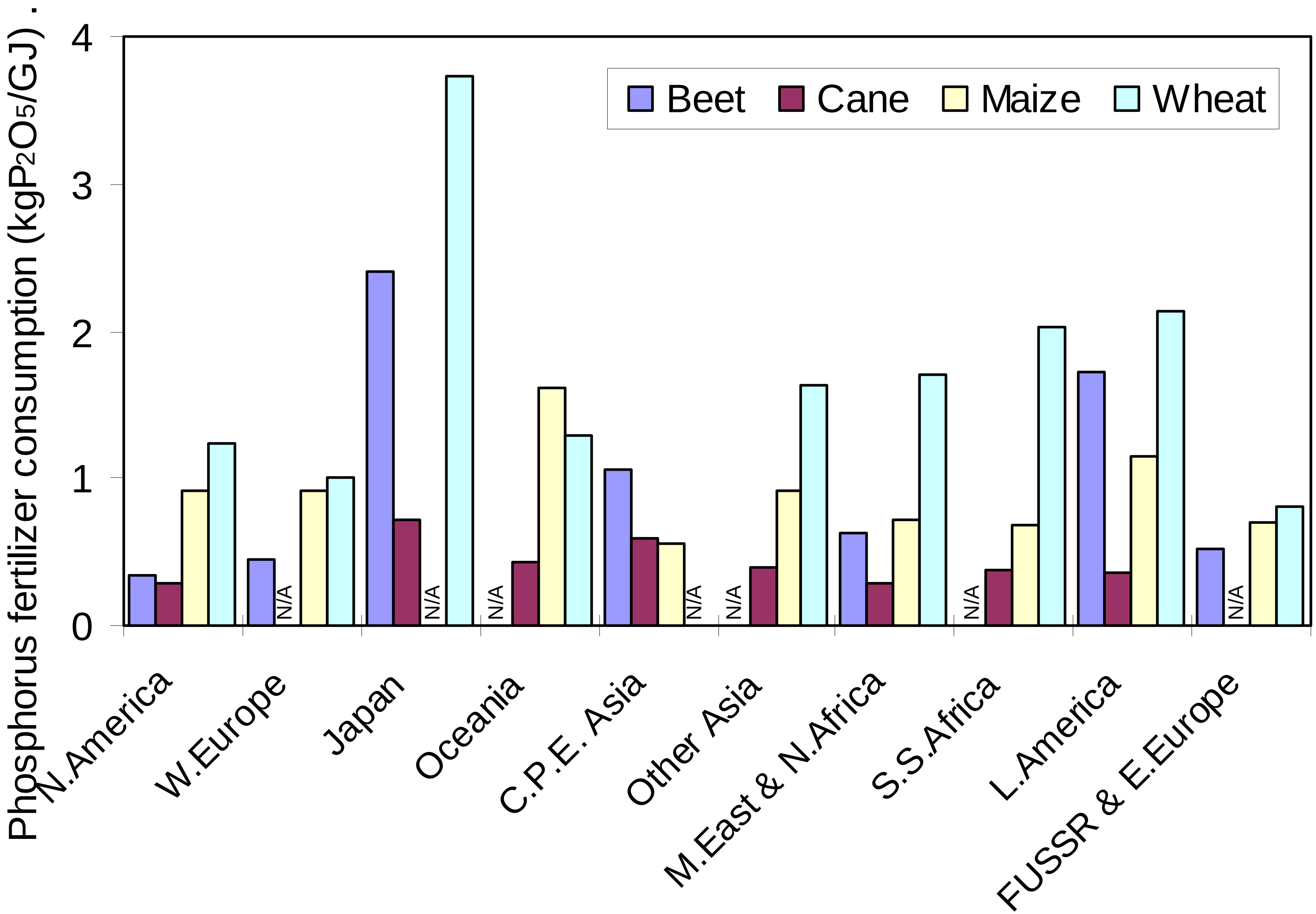
[1] http://faostat.fao.org/; [2] Righelato, R., Spracklen, D.V. (2007). Science 317, 902; [3] Punter, G., et al. (2004). LowCVP Report FWG-P-04-024; [4] Renouf, M.A., et al. (2008). Biomass and Bioenergy, doi:10.1016/j.biombioe.2008.02.012; [5] Jungbluth, N., et al. (2007). ESU-services Ltd. Report Del.: D 5.2.7; [6] Macedo, I.C., et al. (2008). Biomass and Bioenergy, doi:10.1016/j.biombioe.2007.12.006.

N fertilizer consumption for bio-EtOH



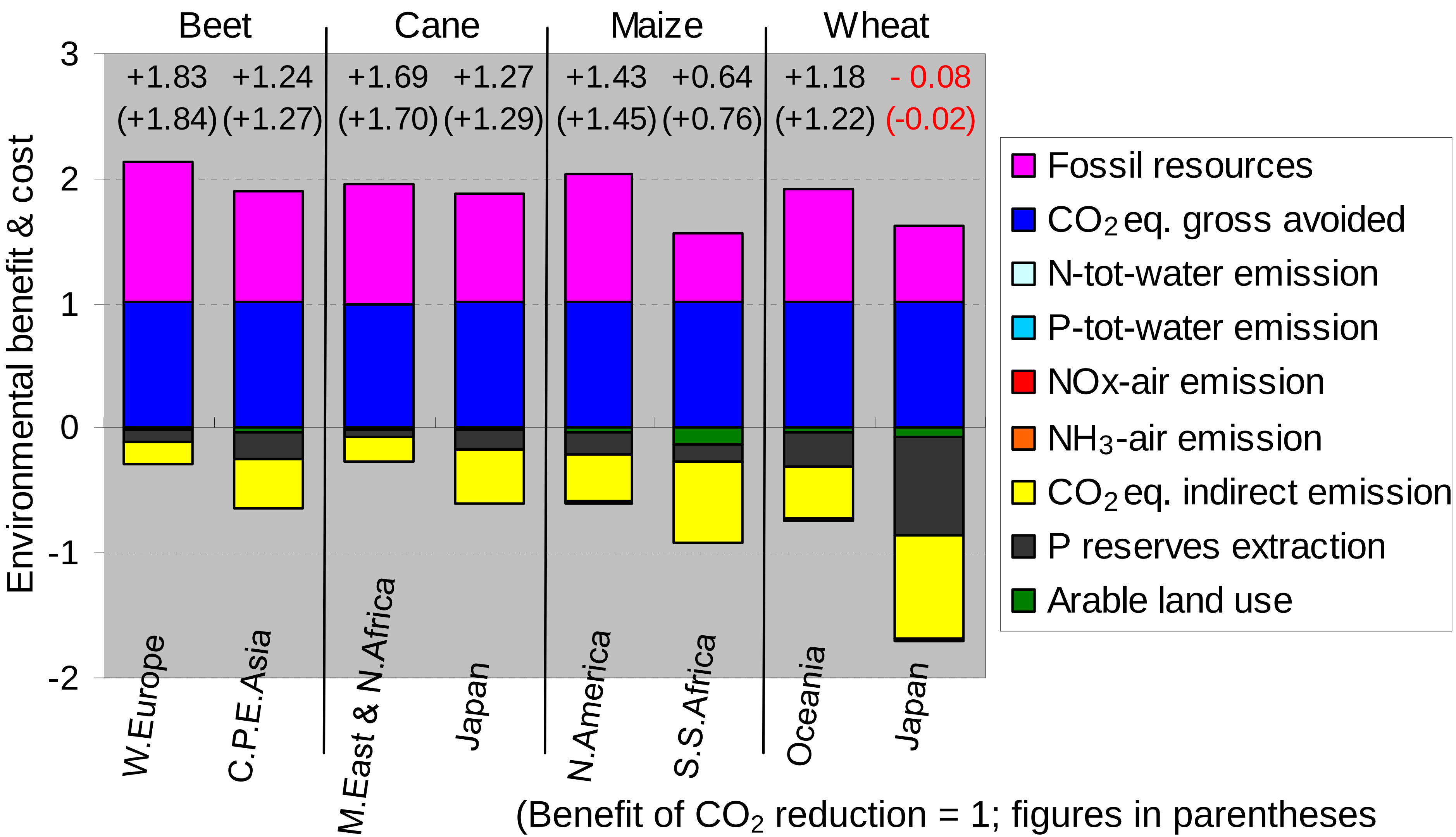
Estimated referring to FAOSTAT, Righelato, R., Spracklen, D.V. (2007).

P fertilizer consumption for bio-EtOH



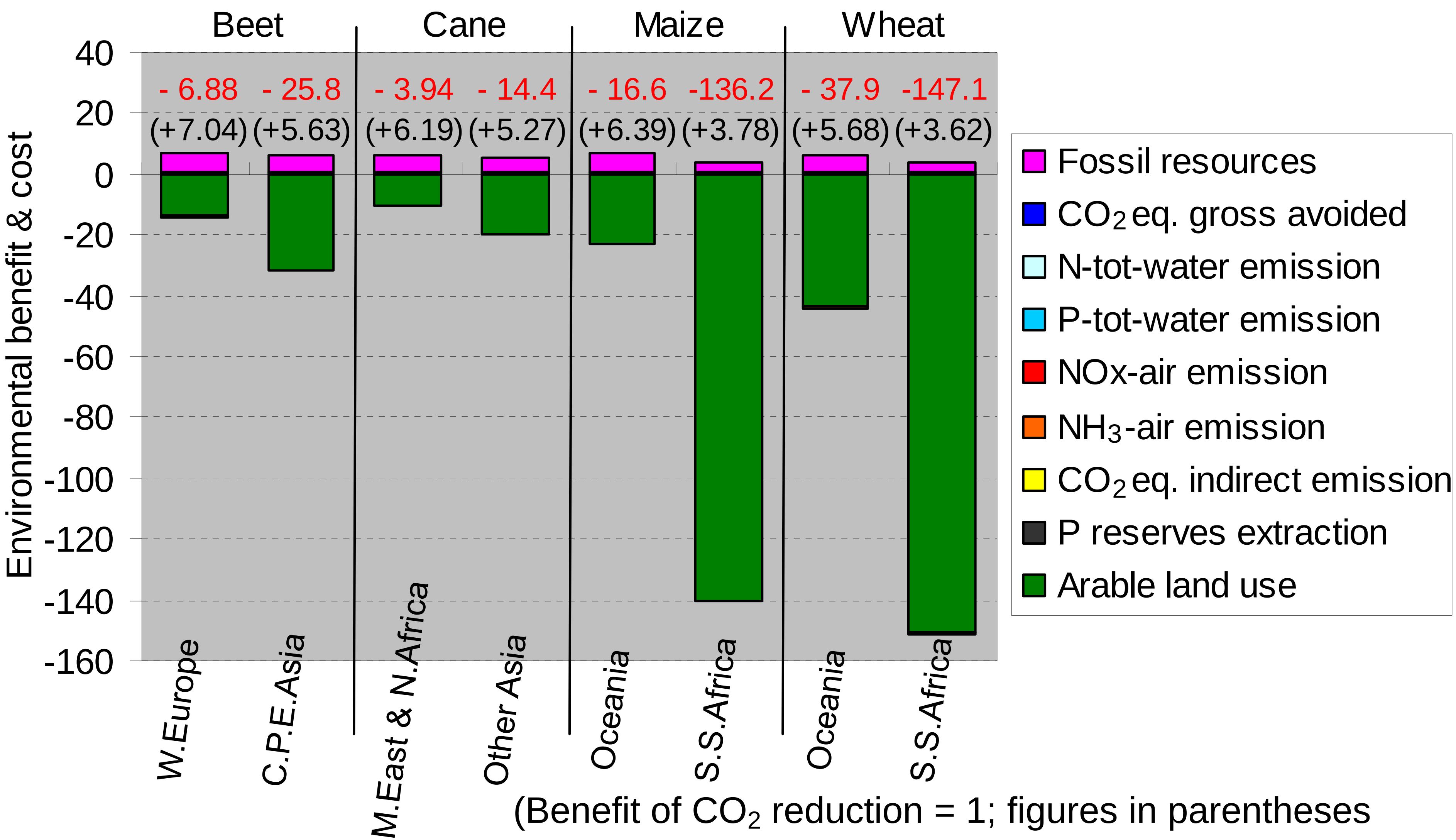
Estimated referring to FAOSTAT, Righelato, R., Spracklen, D.V. (2007).

Assessment based on EPS 2000



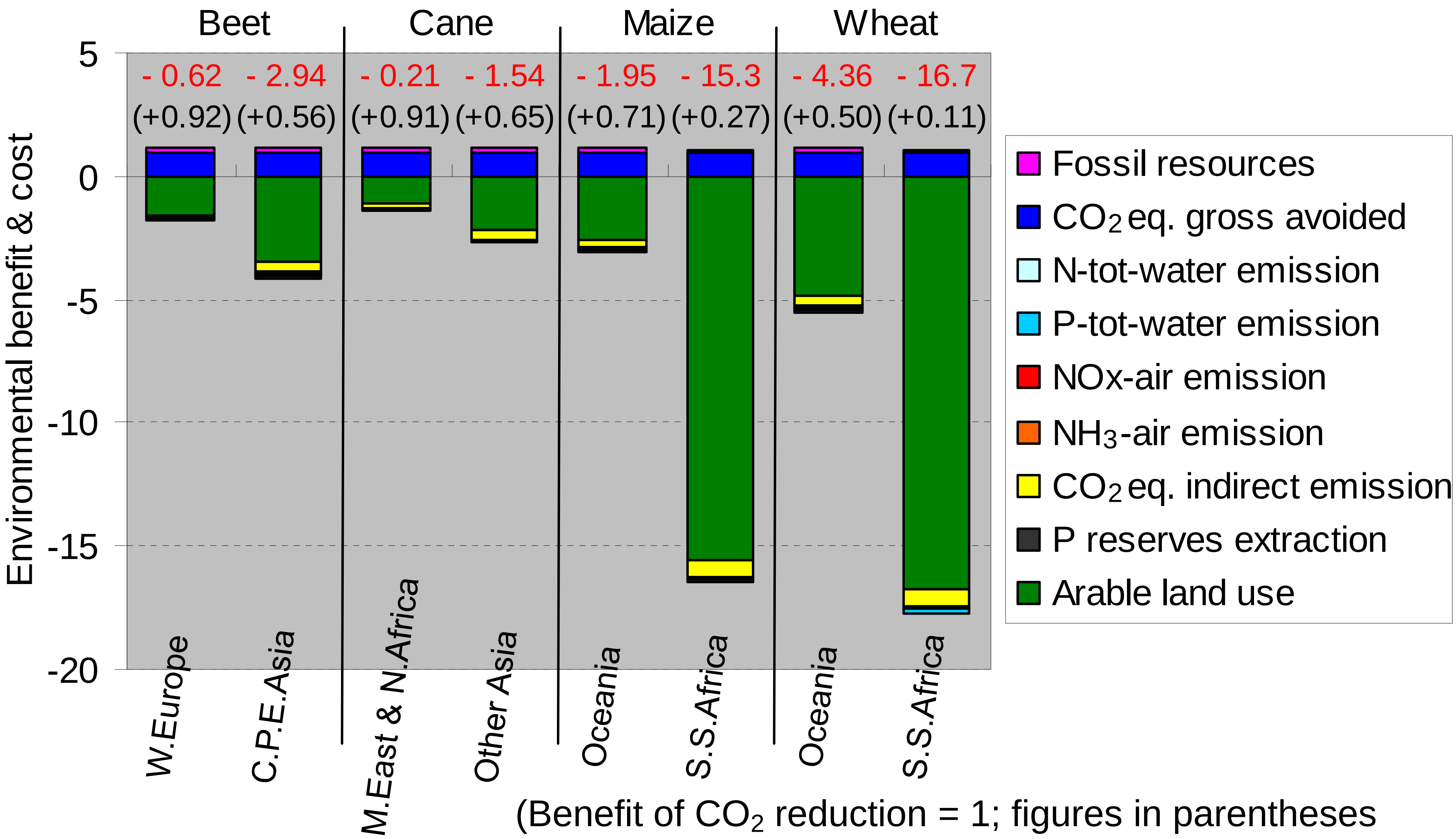
(Benefit of CO_2 reduction = 1; figures in parentheses consider no environmental cost concerning land-use.)

Assessment based on Eco-indicator 99



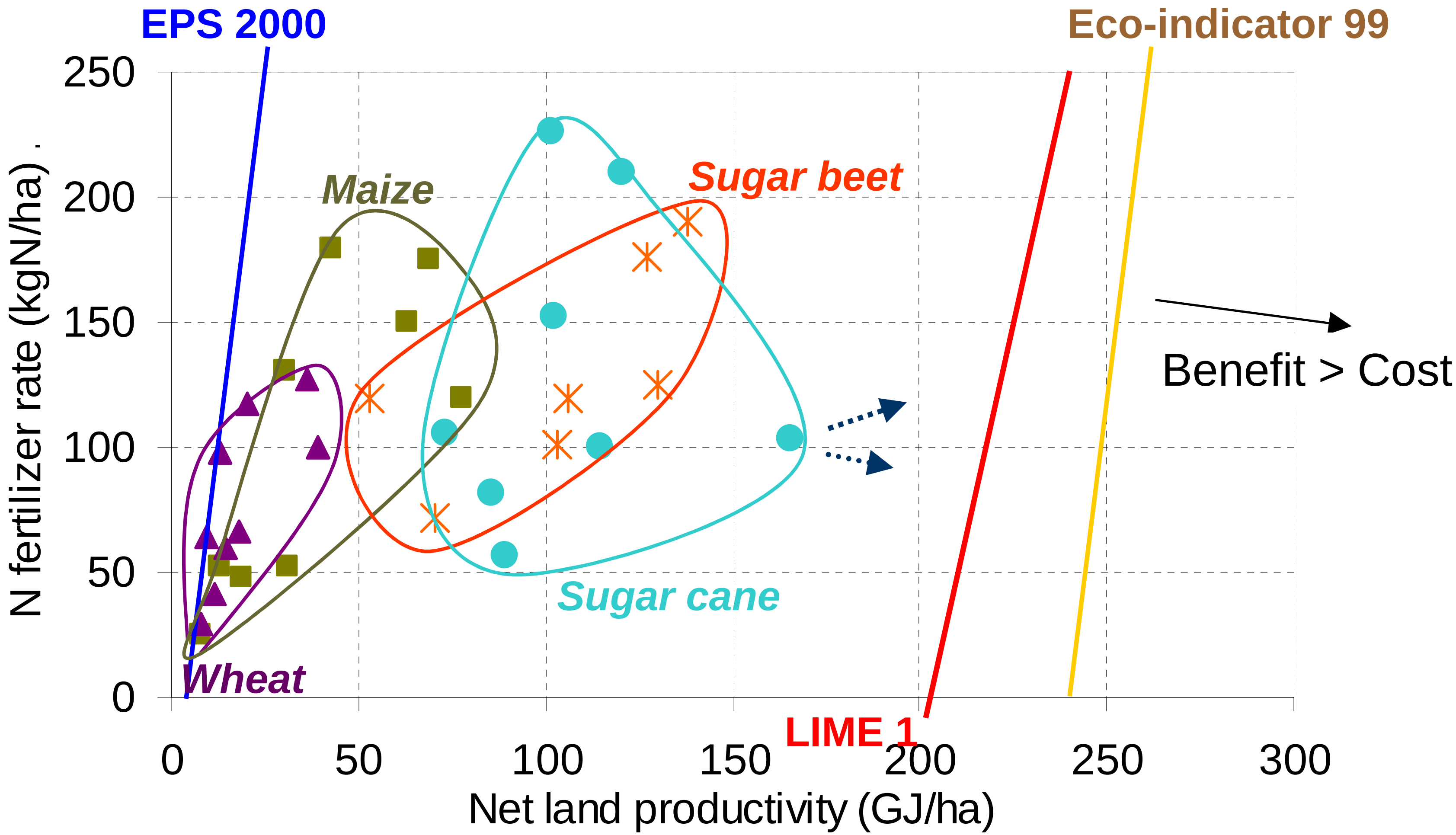
(Benefit of CO_2 reduction = 1; figures in parentheses consider no environmental cost concerning land-use.)

Assessment based on LIME 1



(Benefit of CO_2 reduction = 1; figures in parentheses consider no environmental cost concerning land-use.)

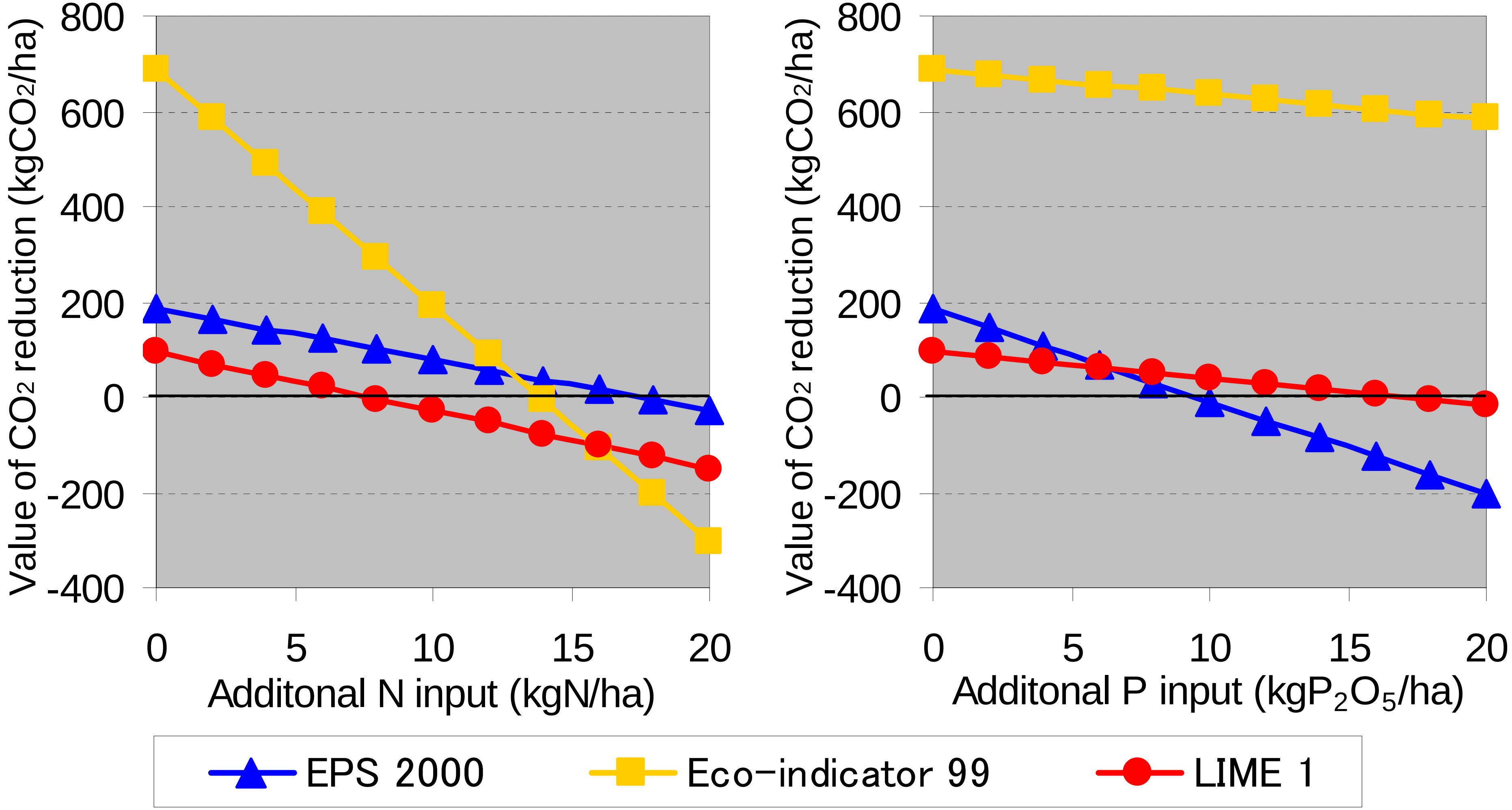
Environmental break-even chart



- Net land productivity = net energy production (produced EtOH *minus* direct energy use for cultivation) divided by land area.

Impact of 1 GJ/ha-yield increase

- By additional N fertilizer
- By additional P fertilizer



Final remarks

- Adverse environmental side-effects of FCV and bio-EtOH production may outweigh benefits, depending on an applied LCIA method.
- For FCV, proper shift of H_2 fuel source and shifting to compact vehicle are recommended to mitigate the concern.
- For bio-EtOH, adequate selection of crop & region, careful increase in crop yield by additional fertilizer use are suggested.

Thank you for your attention.