“Life Cycle Assessments of Wind Energy and Other Renewables”…

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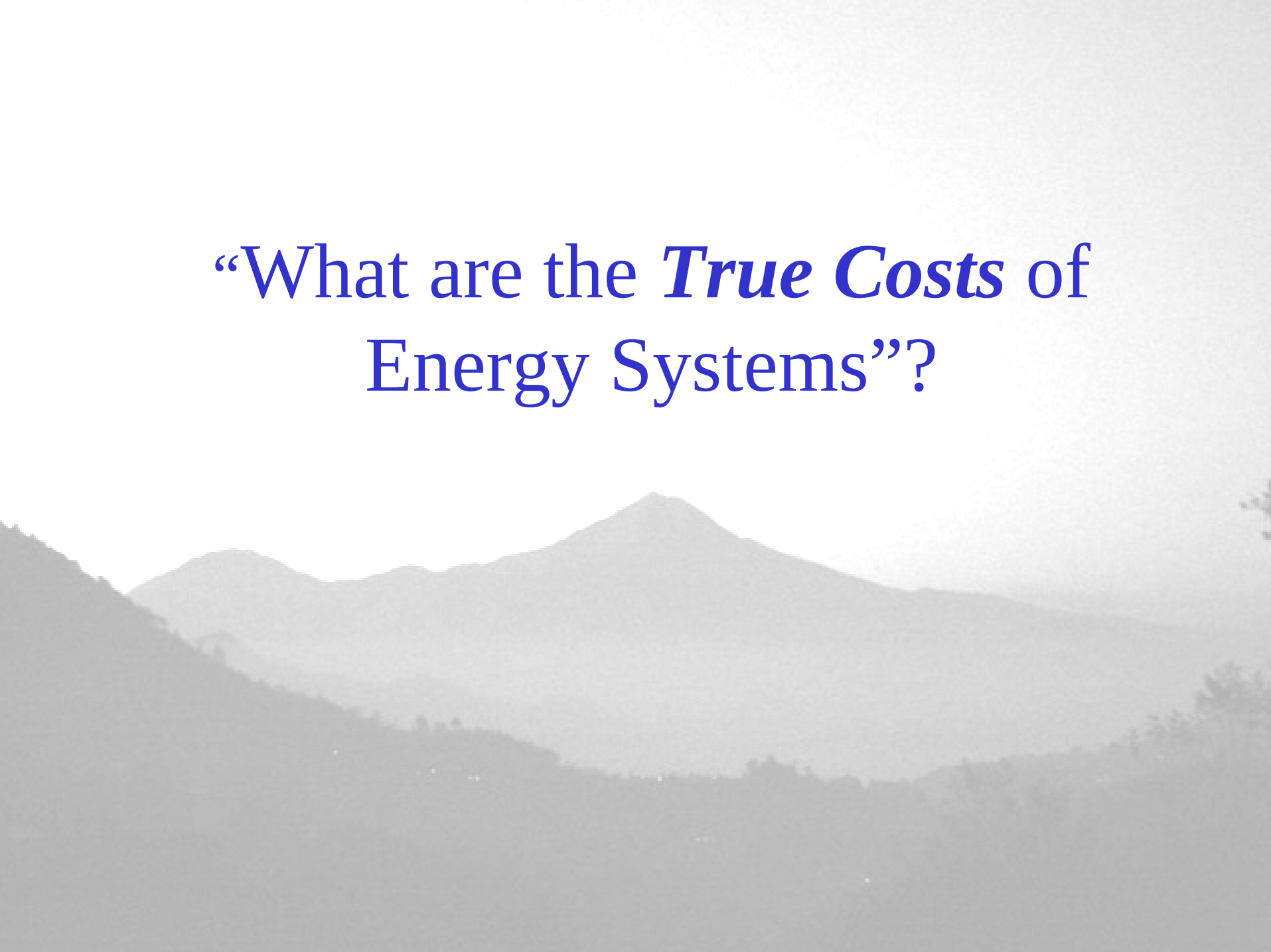
Motivating Questions

- Which is better (from an environmental point of view): Wind or Photovoltaics?
- Why? How so?
- Big (utility-scale) wind vs. small (local) wind
- What are priorities for improving either?
- How much better is wind than coal?


“What are the ***True Costs*** of
Energy Systems”?

Impacts to Include:

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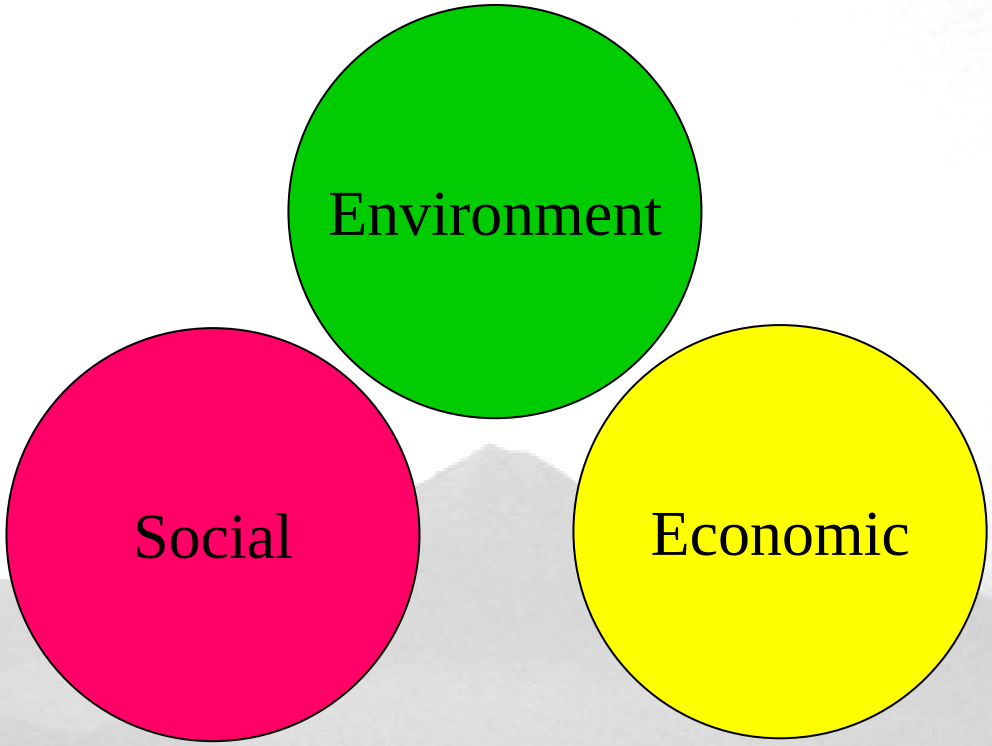
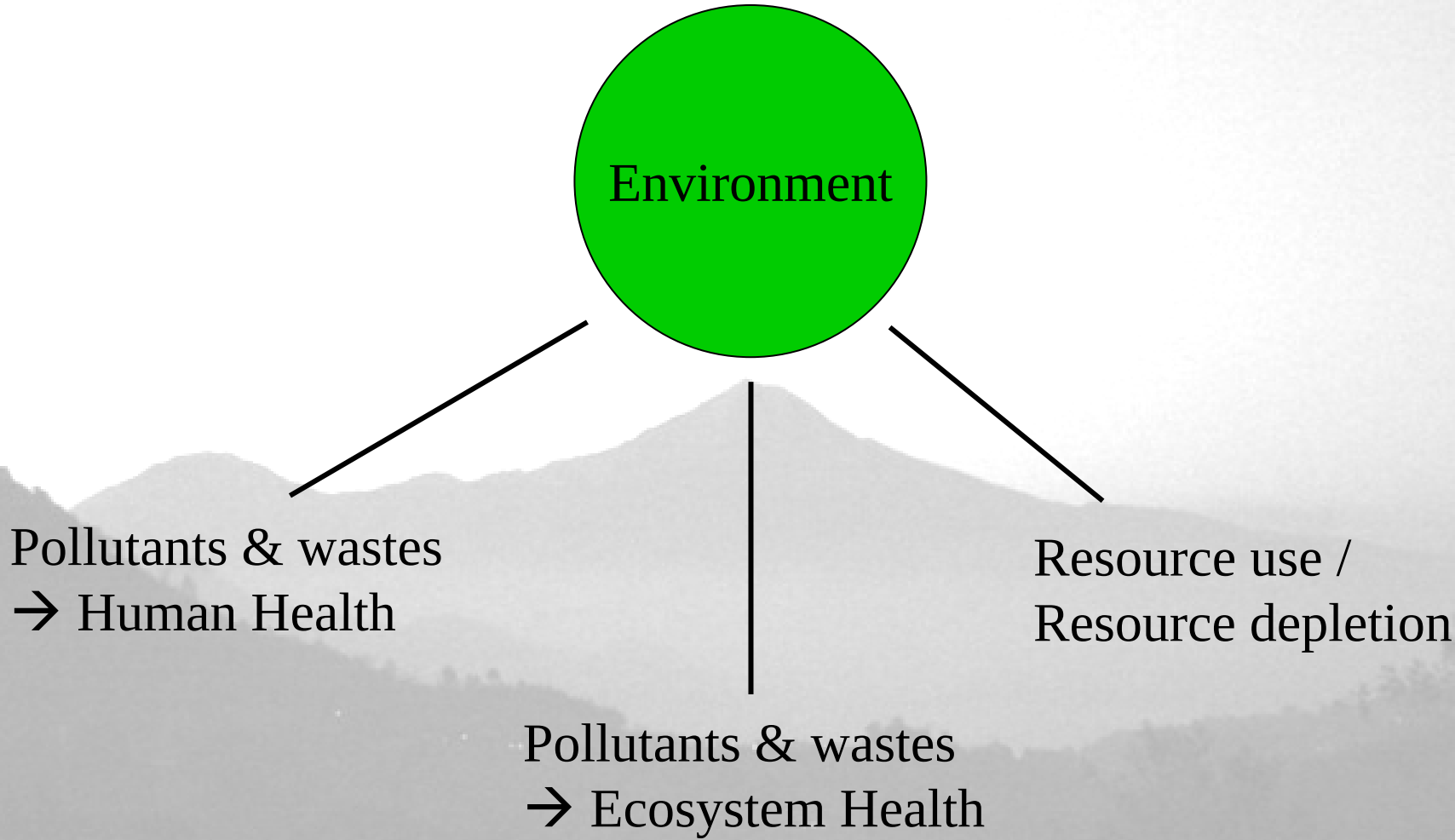

Environment
Social
Economic


Environment
Pollutants & wastes
→ Human Health
Pollutants & wastes
→ Ecosystem Health
Resource use /
Resource depletion

Pollutants & wastes
→ Human Health

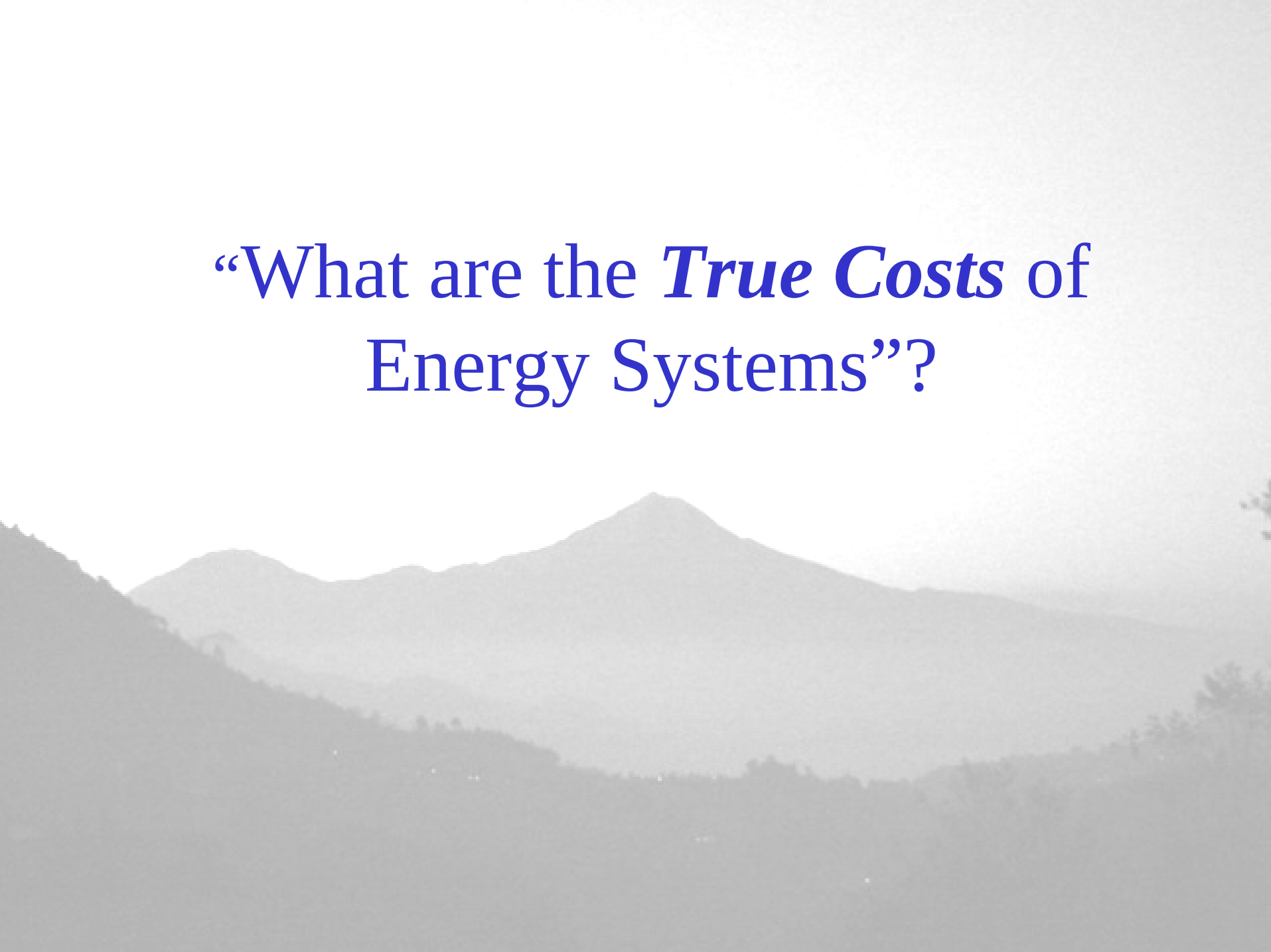
•Respiratory Organics
•Carcinogens
•Particulates
•Climate Change
•Radiation
•Ozone Layer depletion

Pollutants & wastes
→ Ecosystem Health

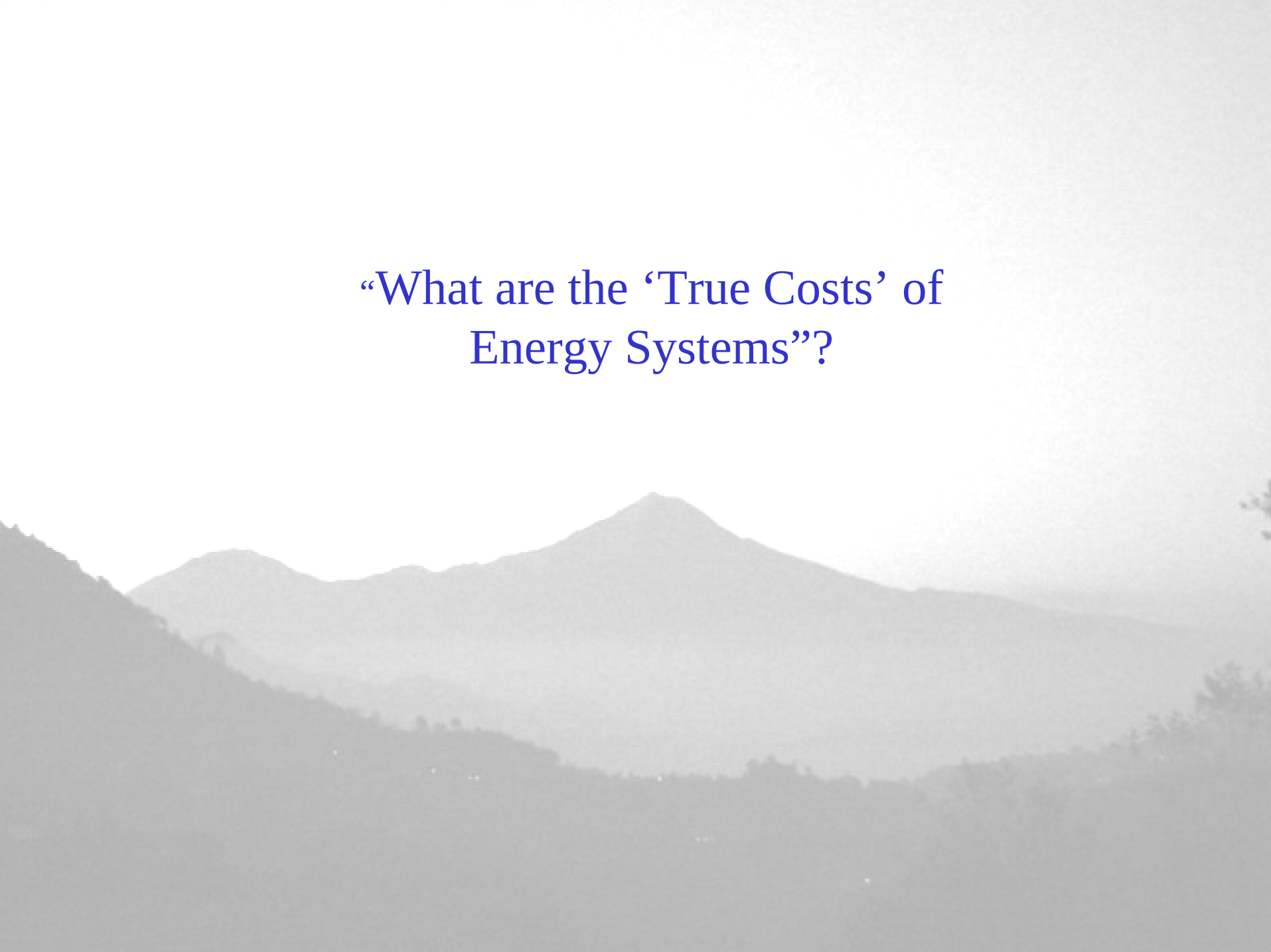
•Eco-toxicity
•Acidification
•Eutrophication
•Land use

Resource use /
Resource depletion

•Mineral resources
•Fossil fuels


“What are the ***True Costs*** of
Energy Systems”?

- Value of a human life:
-


“What are the ‘True Costs’ of
Energy Systems”?

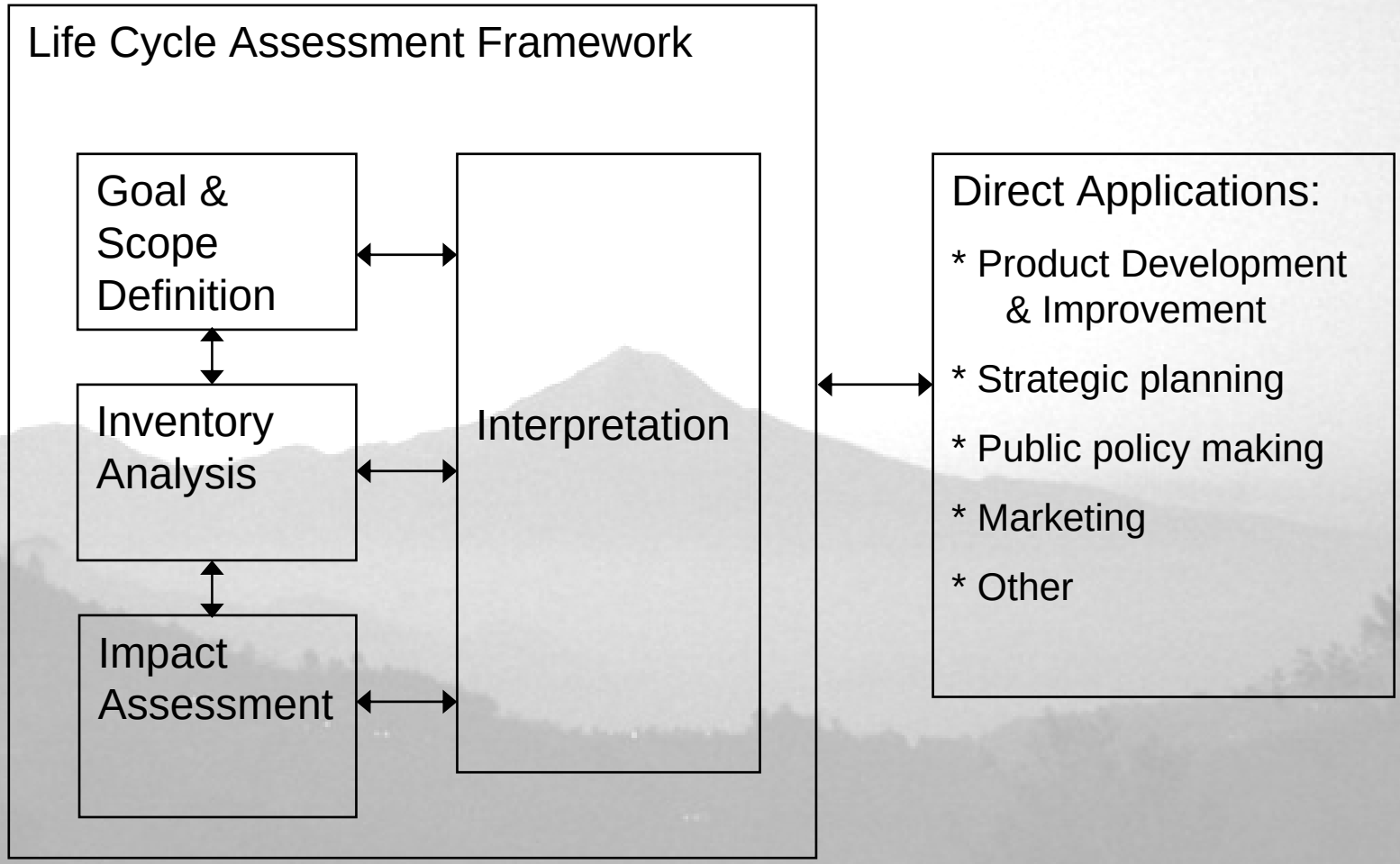
Outline

- Method 1: Life Cycle Assessment
- Method 2: Risk / Damage Assessment
- LCA+RA Example: Weatherization
- LCA Examples:
  - Wind Energy
  - Photovoltaic Electricity
  - Coal vs. wind

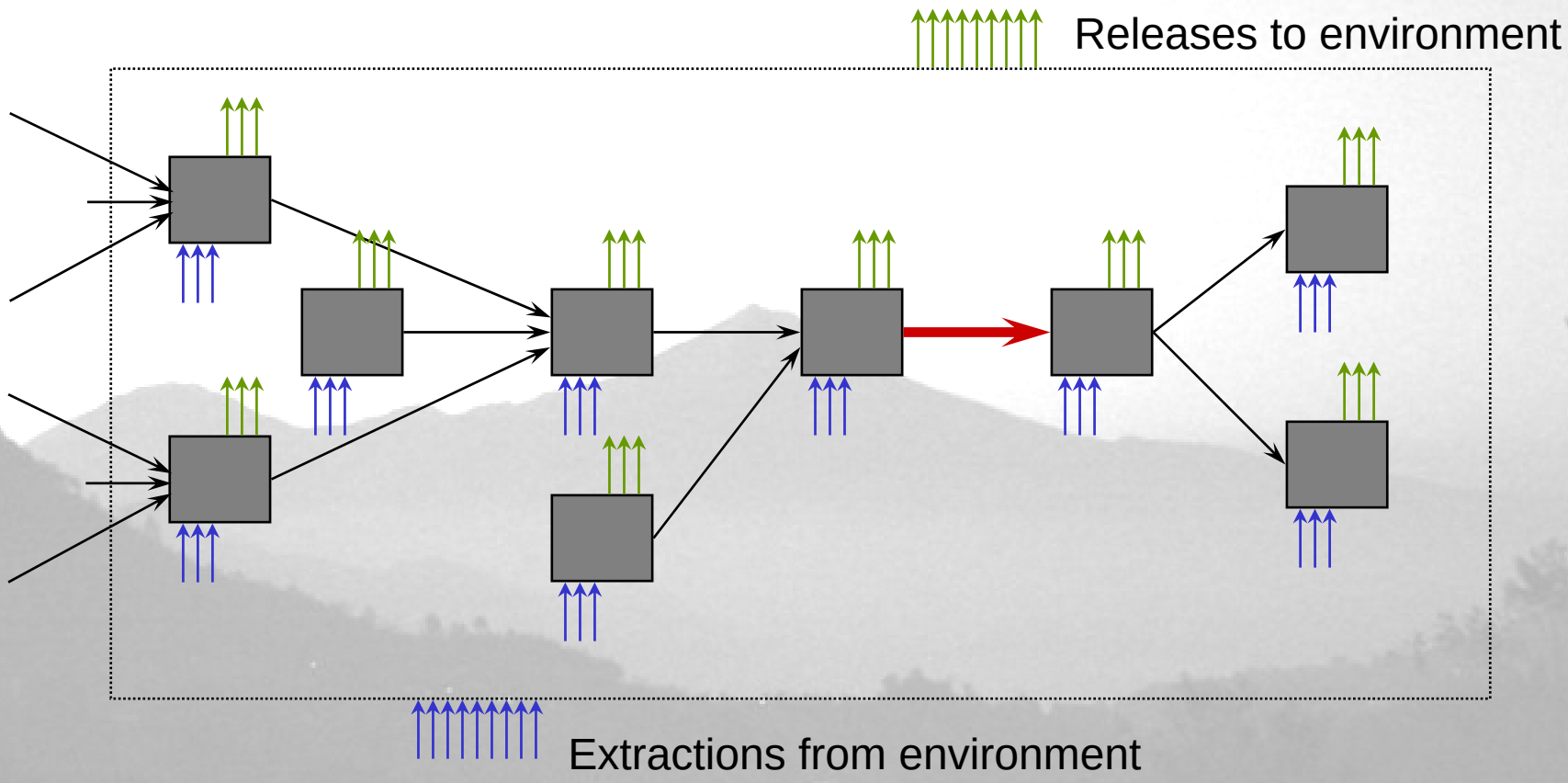
Method 1: Life Cycle Assessment

- Product life cycles, and their total system-wide impacts
  - Environment
  - (Economic and Social)
- “Cradle to Grave”
- Quantitative
- Data-intensive
- Standardized (ISO)
- Becoming Global

LCA Defined
ISO 14040 (‘97)



Life Cycle Inventory Analysis



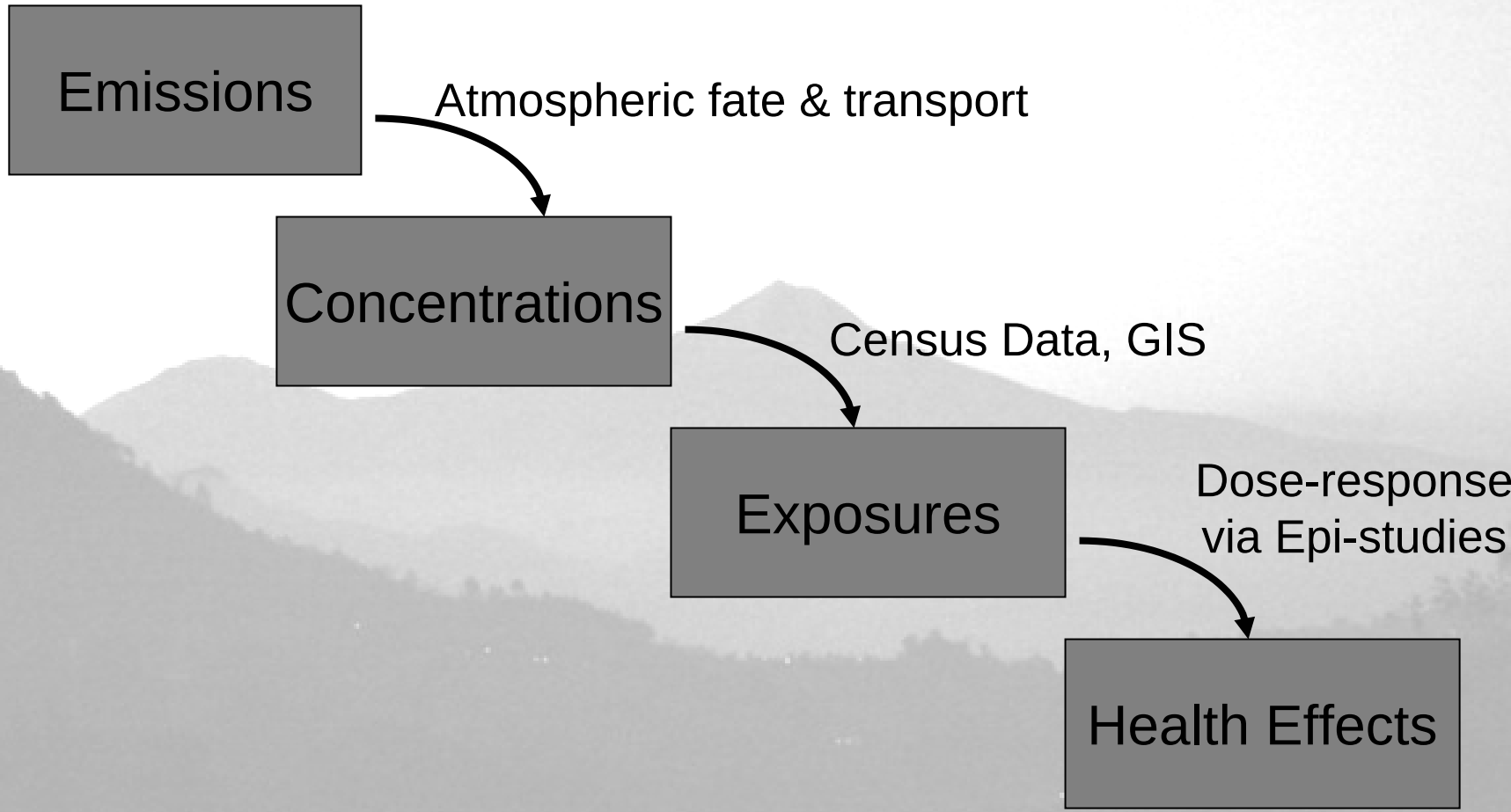
Life Cycle Impact Assessment

- “What do all these flows mean?”
- Prototype: Global Warming Potentials
- Other Common Impact Categories
  - Ozone Depletion
  - Acidification
  - Eutrophication
  - Smog Formation
  - Human Toxicity / Health
  - Eco Toxicity

Risk Analysis

- Risk Assessment
- Risk Characterization
- Risk Communication
- Risk Management
- Policy Relating to Risk

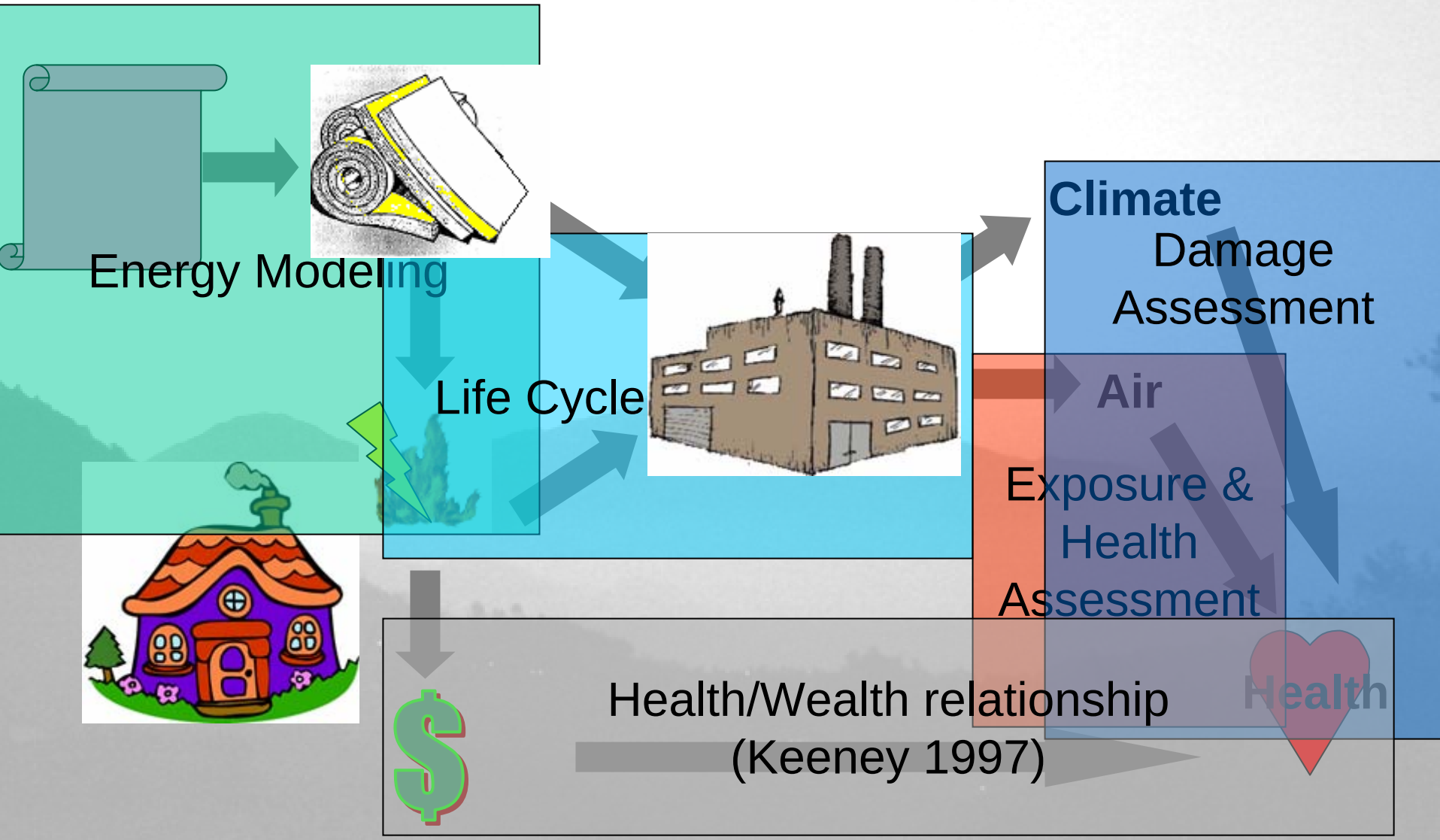
Exposure & Health Assessment:



Aggregating Health Impacts

- DALY = Disability-Adjusted Life-Year
- Mortality → life-years lost
- Morbidity → years lived at lower quality
- Way to combine mortality & morbidity impacts into a single measure of *effective life-years lost*
- World Health Organization

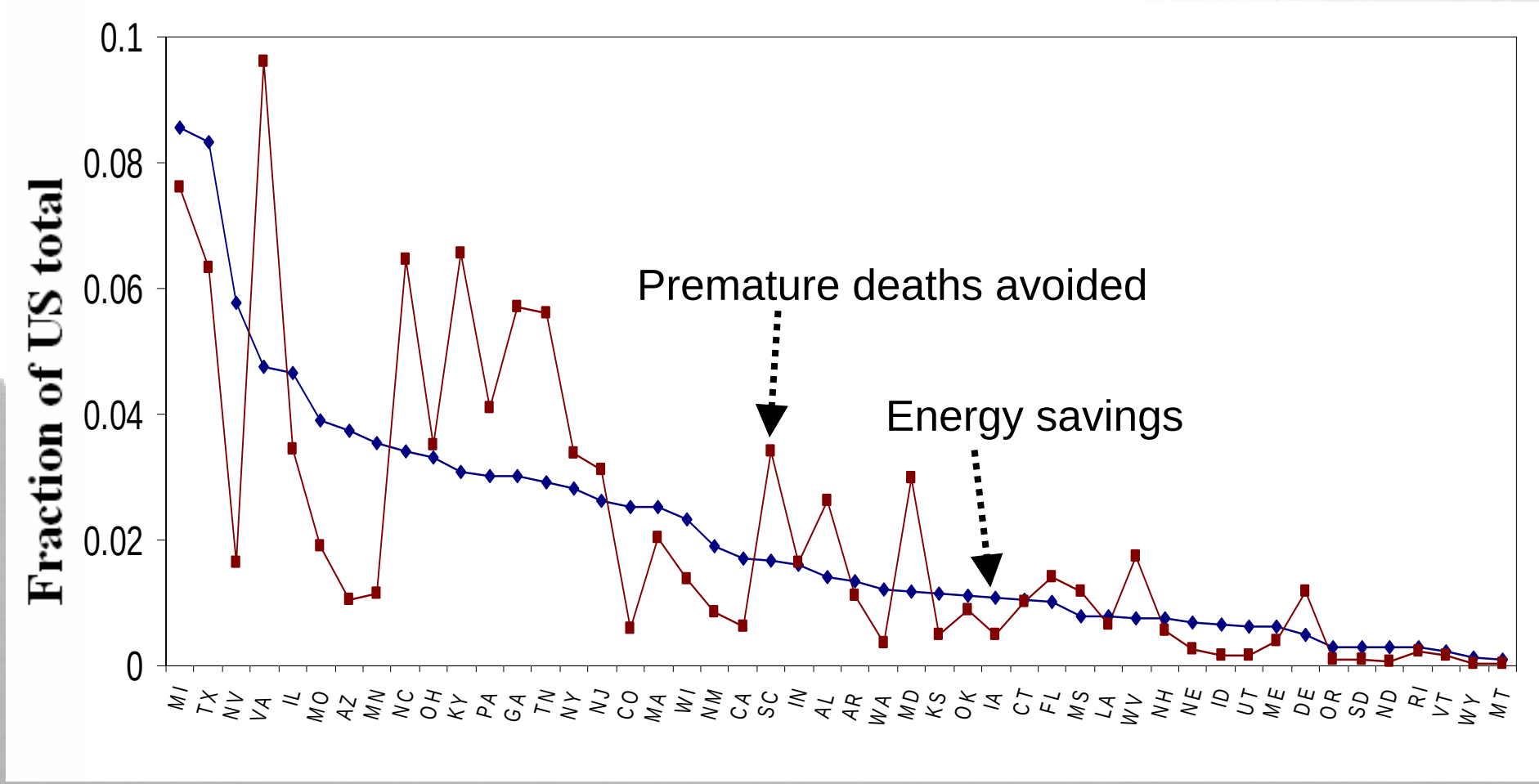
Wx Example: Methods Summary



Wx Scenarios

- New and existing homes meet IECC2000 by increasing insulation
- Loan program for financing the upfront cost of insulation
  - 2.5% interest rate
  - 20 years maximum loan term
  - Loan payments=energy savings until paid in full
  - 2% annual participation rate for existing homes
  - 58% of new SFH; 81% of existing homes will participate

End-use energy savings and health outcomes by State



Source: Nishioka et al. 2002.

10-year horizon: All new SF homes from 1999 standard practice to IECC 2000.

Results for PM Pathway

- Health benefits of 1 year of energy savings for 1 year's housing cohort:
  - 7 fewer fatalities
  - 200 fewer asthma attacks
  - 3000 fewer restricted activity days

70 DALYs

- Health benefits of 50-year measure life, for 1 year's housing cohort:
  - 350 fewer fatalities
  - 10K fewer asthma attacks
  - 150K fewer restricted activity days

3500 DALYs

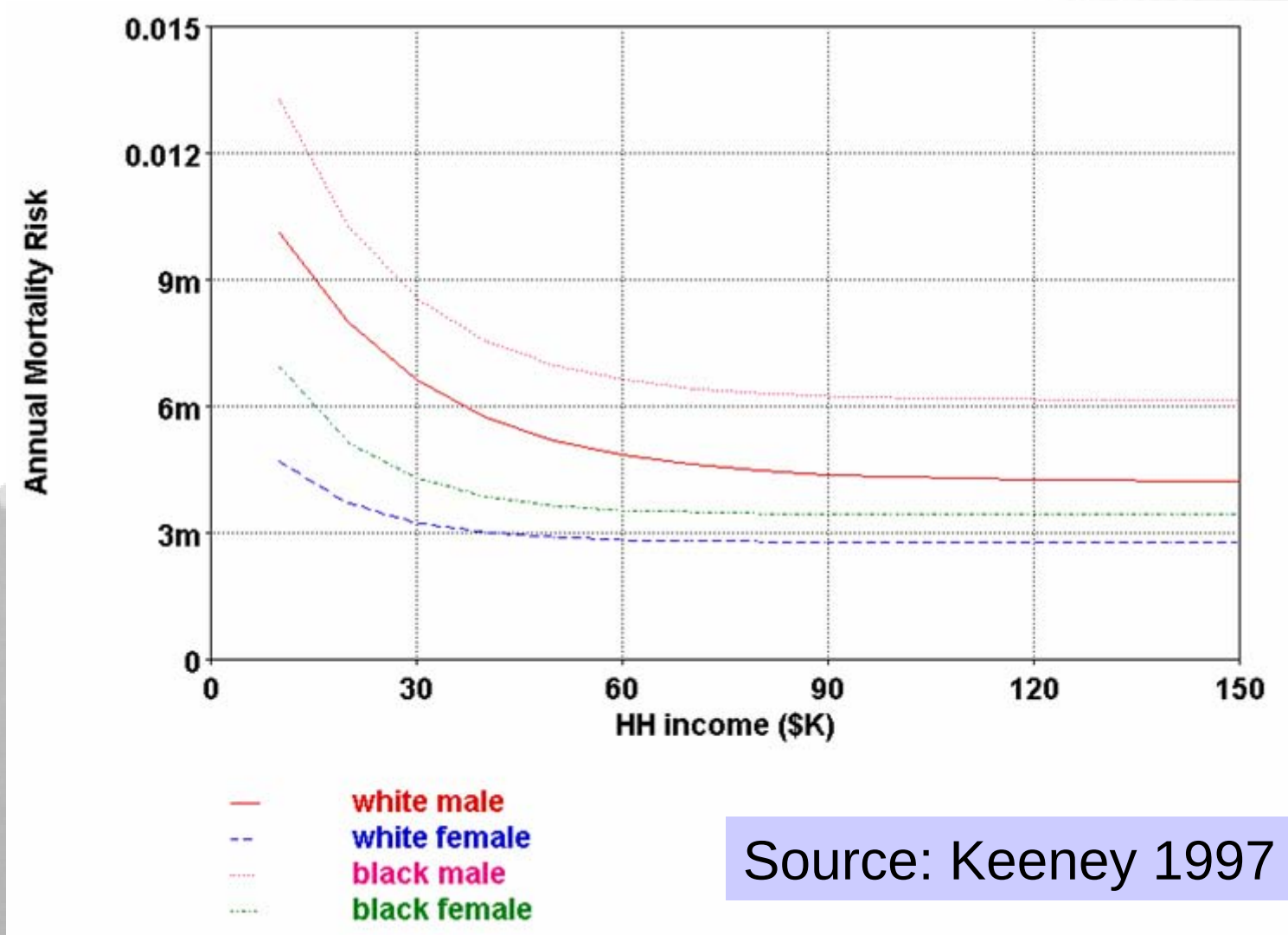
Results for GHG Pathway

- Tol (1999): FUND model
- Climate-related pathways considered:
  - Heat and cold-related illnesses & deaths
  - Vector-borne diseases (e.g., malaria)
  - Infectious diseases due to sea-level rise via population displacement, infrastructure
  - Psychological disorders via sea-level rise

Results for GHG Pathway

- Health benefits of 1 year of energy savings for 1 year's housing cohort:
  - 20 fewer fatalities
  - 400 fewer DALYs
- Health benefits of 50-year measure life, for 1 year's housing cohort:
  - 1000 fewer fatalities
  - 20K fewer DALYs

Results via Financial Savings

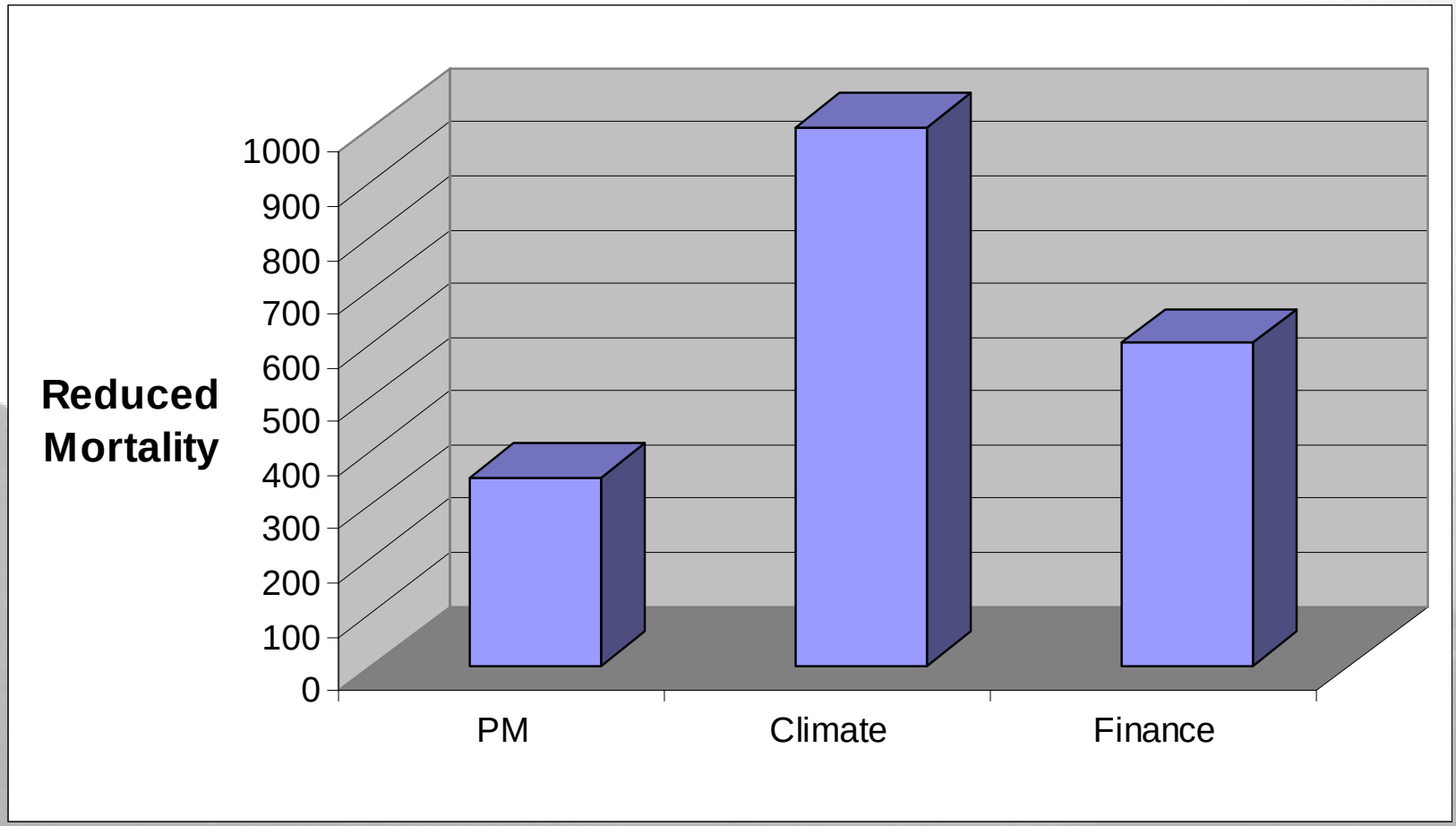


Source: Keeney 1997

Results via Financial Savings

- Conservative assumption:
  - Net zero annual economic impact until cost of insulation measures paid for by energy savings, with 2.5% interest rate
- Health benefits of 50-year measure life, for 1 year's housing cohort:
  - 600 fewer fatalities
  - 7K fewer DALYs

Summary: Reduced Mortality via Single-Year Cohort



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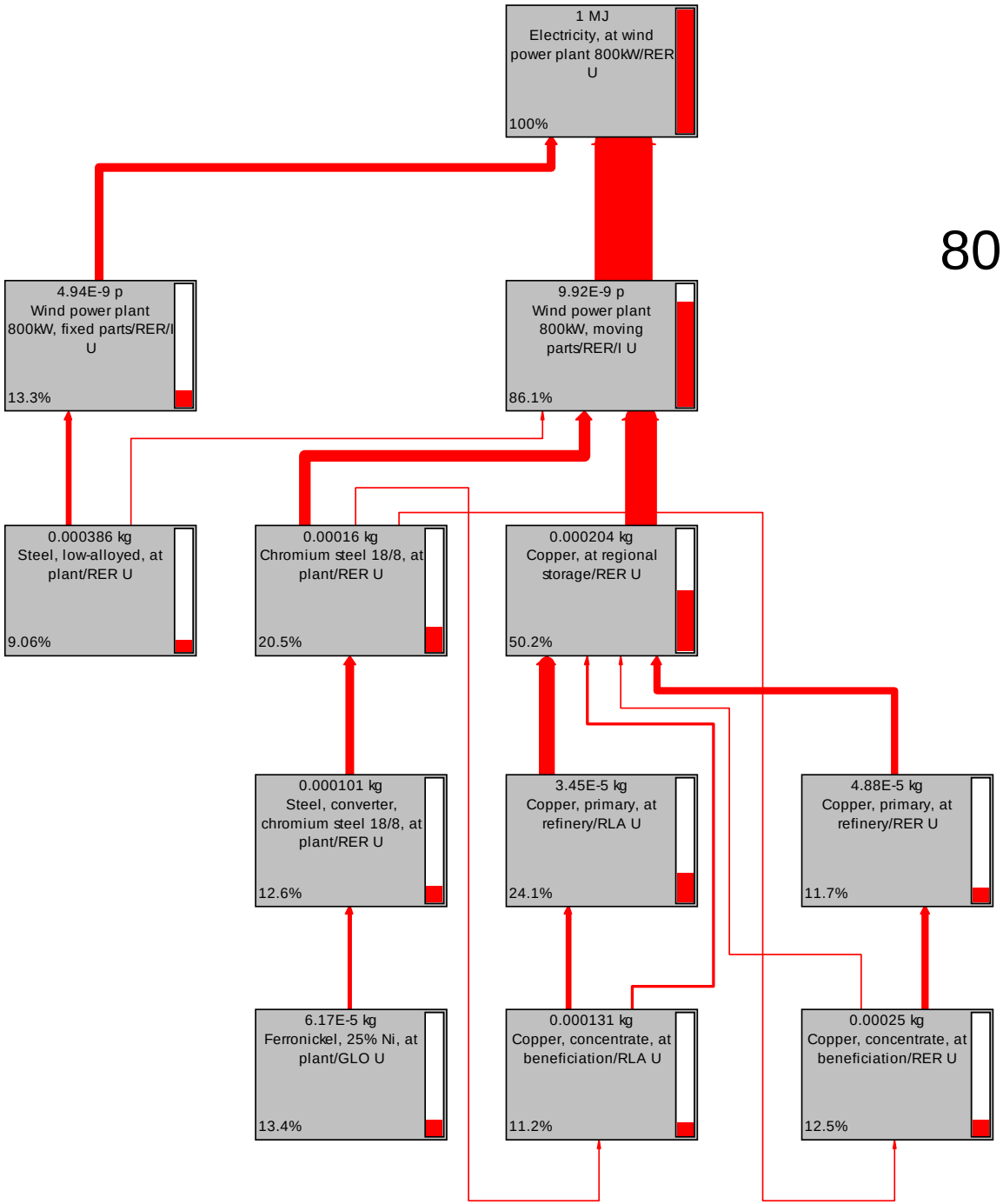
Scope: 800 kW Utility Wind

- Construction and operation of wind power with necessary change of gear oil
- Capacity factor: 20%
- Gear oil changed every second year
- Fixed parts lifetime: 40 years
- Moving parts lifetime: 20 years
- Efficiency: 25%
- Wind conditions: Average European

800 kW Utility Wind



800 kW Utility Wind: Inputs to Turbine Production

View energy process 'Wind power plant 800kW, moving parts/CH/I U'

Documentation | Input/output | System description

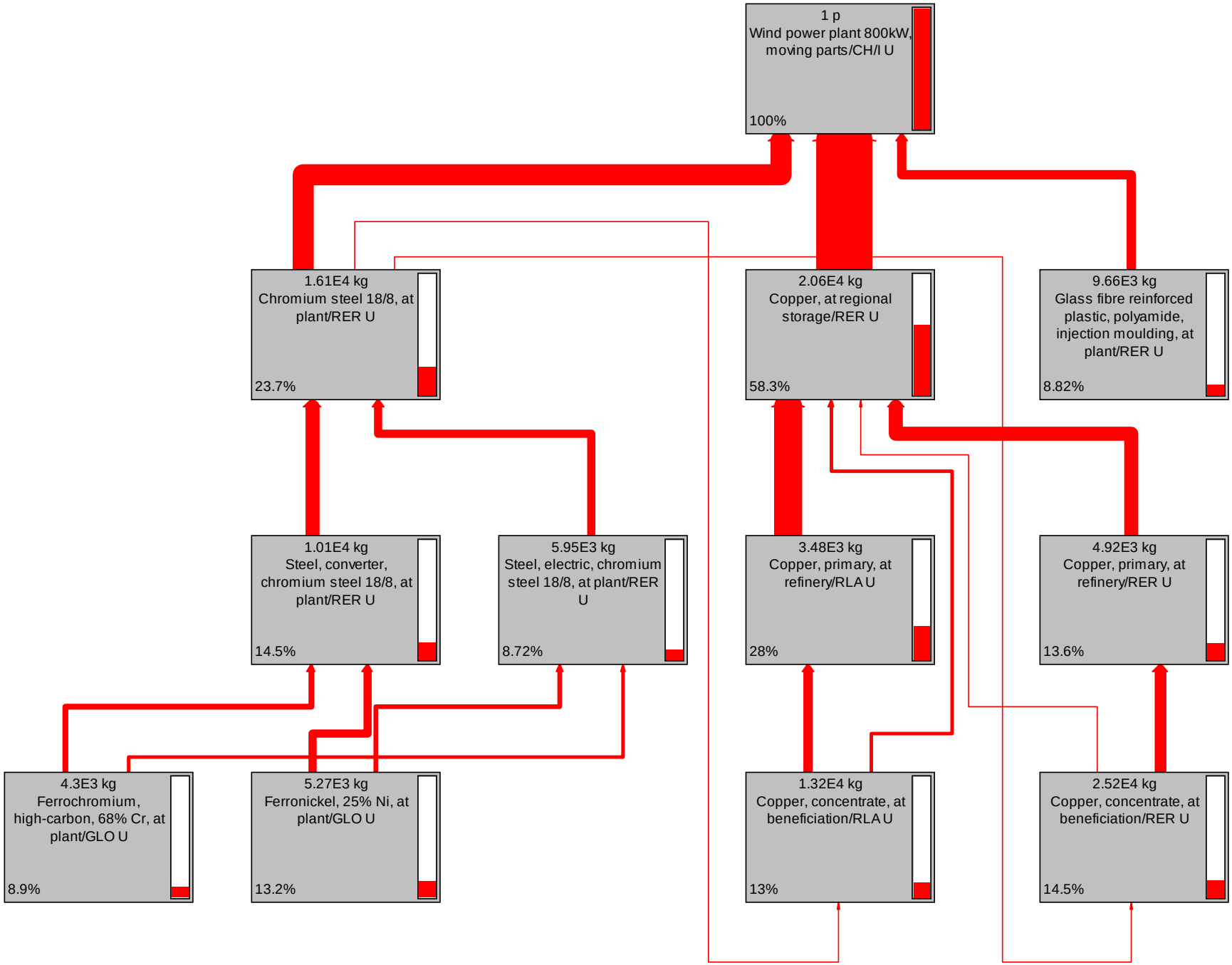
Known inputs from technosphere (materials/fuels)

Name	Amount	Unit
Lubricating oil, at plant/RER U	58.8	kg
Electricity, medium voltage, production UCTE, at grid/UCT	1.75E4	kWh
Electricity, medium voltage, at grid/CH U	10	kWh
Aluminium, primary, at plant/RER U	207	kg
Cast iron, at plant/RER U	6.48E3	kg
Chromium steel 18/8, at plant/RER U	1.45E4	kg
Copper, at regional storage/RER U	1.98E4	kg
Lead, at regional storage/RER U	0.5	kg
Steel, low-alloyed, at plant/RER U	3.75E3	kg
Tin, at regional storage/RER U	0.5	kg
Section bar rolling, steel/RER U	1.02E4	kg
Sheet rolling, aluminium/RER U	207	kg
Sheet rolling, chromium steel/RER U	1.44E4	kg
Wire drawing, copper/RER U	1.96E4	kg
Glass fibre reinforced plastic, polyamide, injection mouldin	9.66E3	kg
Polyethylene, HDPE, granulate, at plant/RER U	4.41E3	kg
Polypropylene, granulate, at plant/RER U	400	kg
Polyvinylchloride, bulk polymerised, at plant/RER U	3.17E3	kg
Synthetic rubber, at plant/RER U	100	kg
Transport, lorry 28t/CH U	3.35E3	tkm
Transport, freight, rail/CH U	3.07E4	tkm

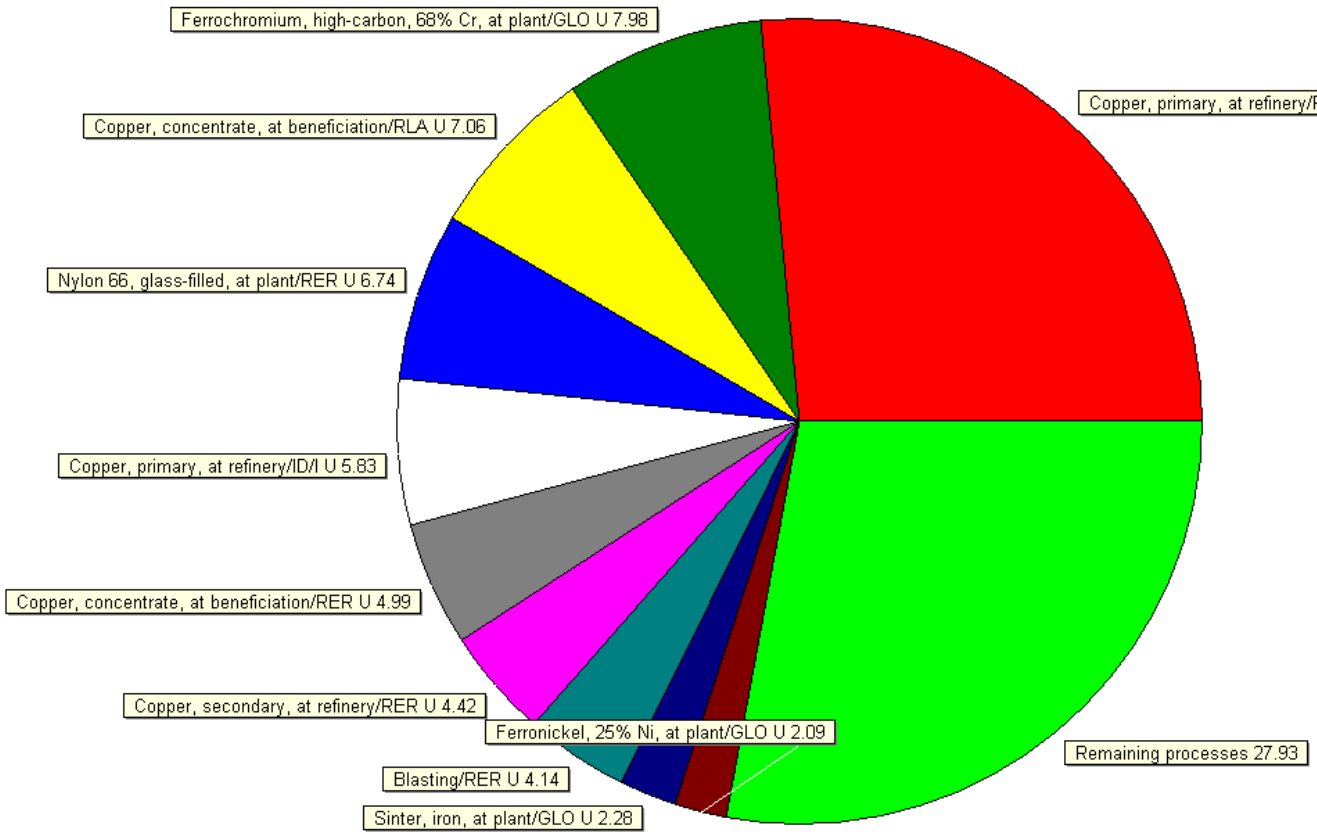
Scope: 800 kW Turbine Model

- Rotor, nacelle, electric parts, and their disposal
- Energy for assembling/fabrication and transport
- Connection to the grid

- *… Total of 1561 unit processes in system, plus loops*


1 p
Wind power plant 800kW, moving parts/CH/I U
100%
1.61E4 kg
Chromium steel 18/8, at plant/RER U
23.7%
2.06E4 kg
Copper, at regional storage/RER U
58.3%
9.66E3 kg
Glass fibre reinforced plastic, polyamide, injection moulding, at plant/RER U
8.82%
1.01E4 kg
Steel, converter, chromium steel 18/8, at plant/RER U
14.5%
5.95E3 kg
Steel, electric, chromium steel 18/8, at plant/RER U
8.72%
3.48E3 kg
Copper, primary, at refinery/RLA U
28%
4.92E3 kg
Copper, primary, at refinery/RER U
13.6%
4.3E3 kg
Ferrochromium, high-carbon, 68% Cr, at plant/GLO U
8.9%
5.27E3 kg
Ferronickel, 25% Ni, at plant/GLO U
13.2%
1.32E4 kg
Copper, concentrate, at beneficiation/RLA U
13%
2.52E4 kg
Copper, concentrate, at beneficiation/RER U
14.5%

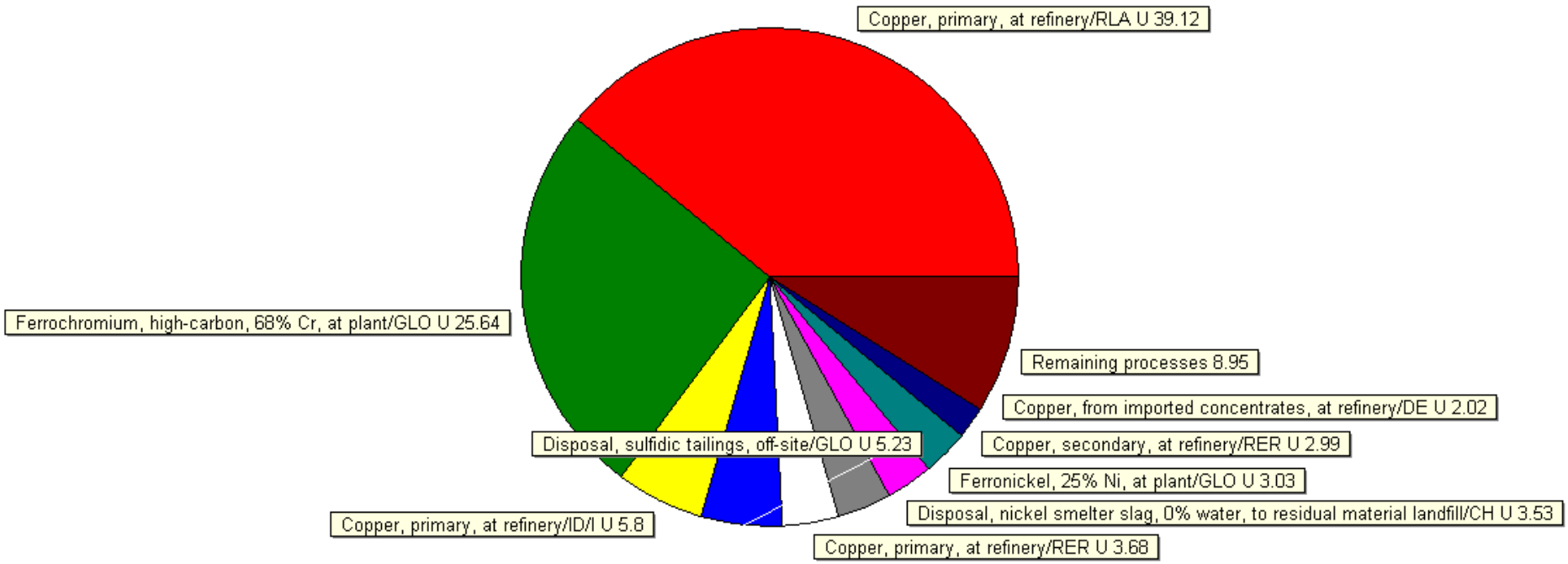
800 kW Utility Wind Turbine Production Supply Chain: Process contributions to total Human Health Impacts



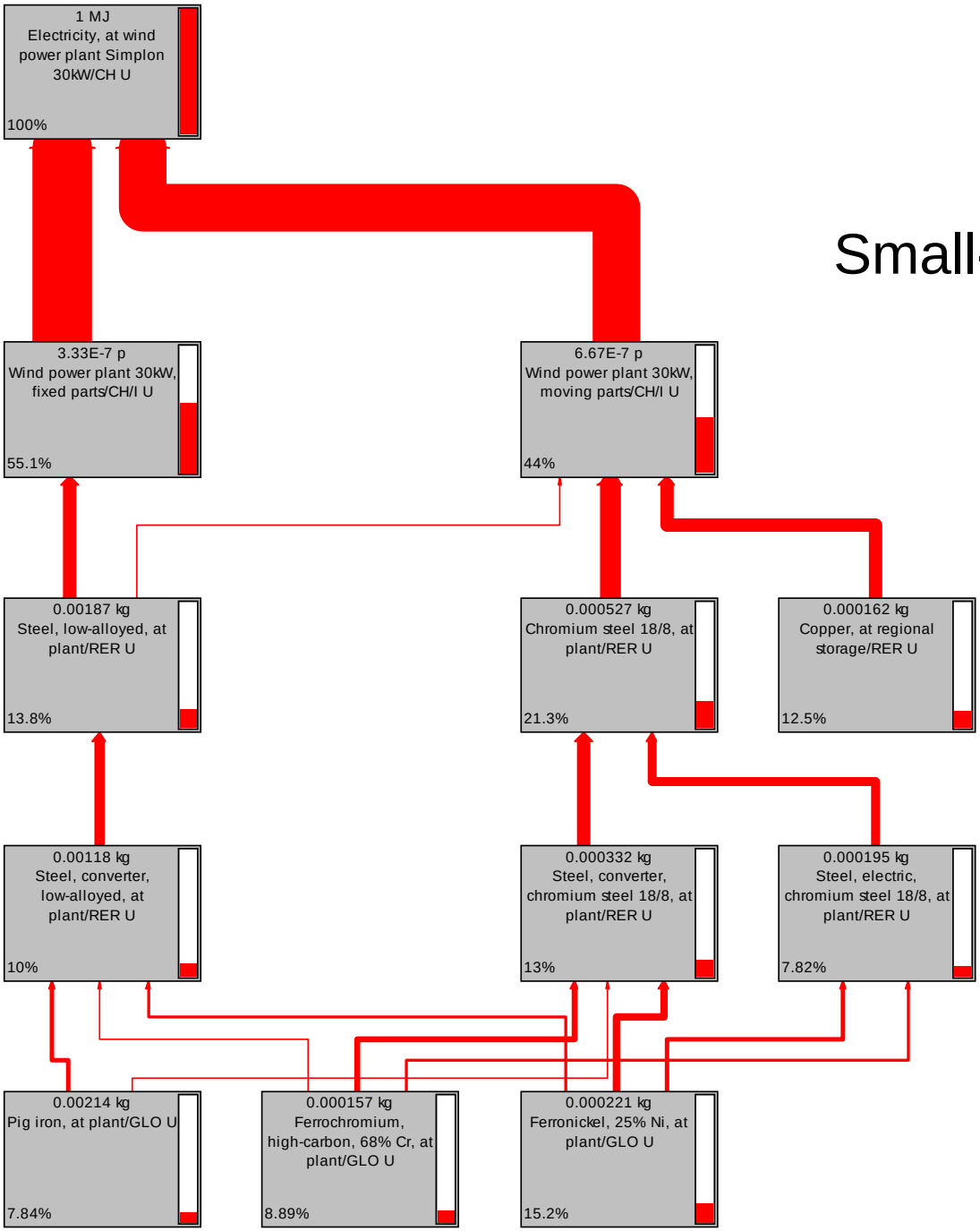
Copper, primary, at refinery/RLA U

Analyzing 1 p energy 'Wind power plant 800kW, moving parts/CH/I U'; Method: Eco-indicator 99 (H) V2.1 / Europe EI 99 H/H / damage assessment

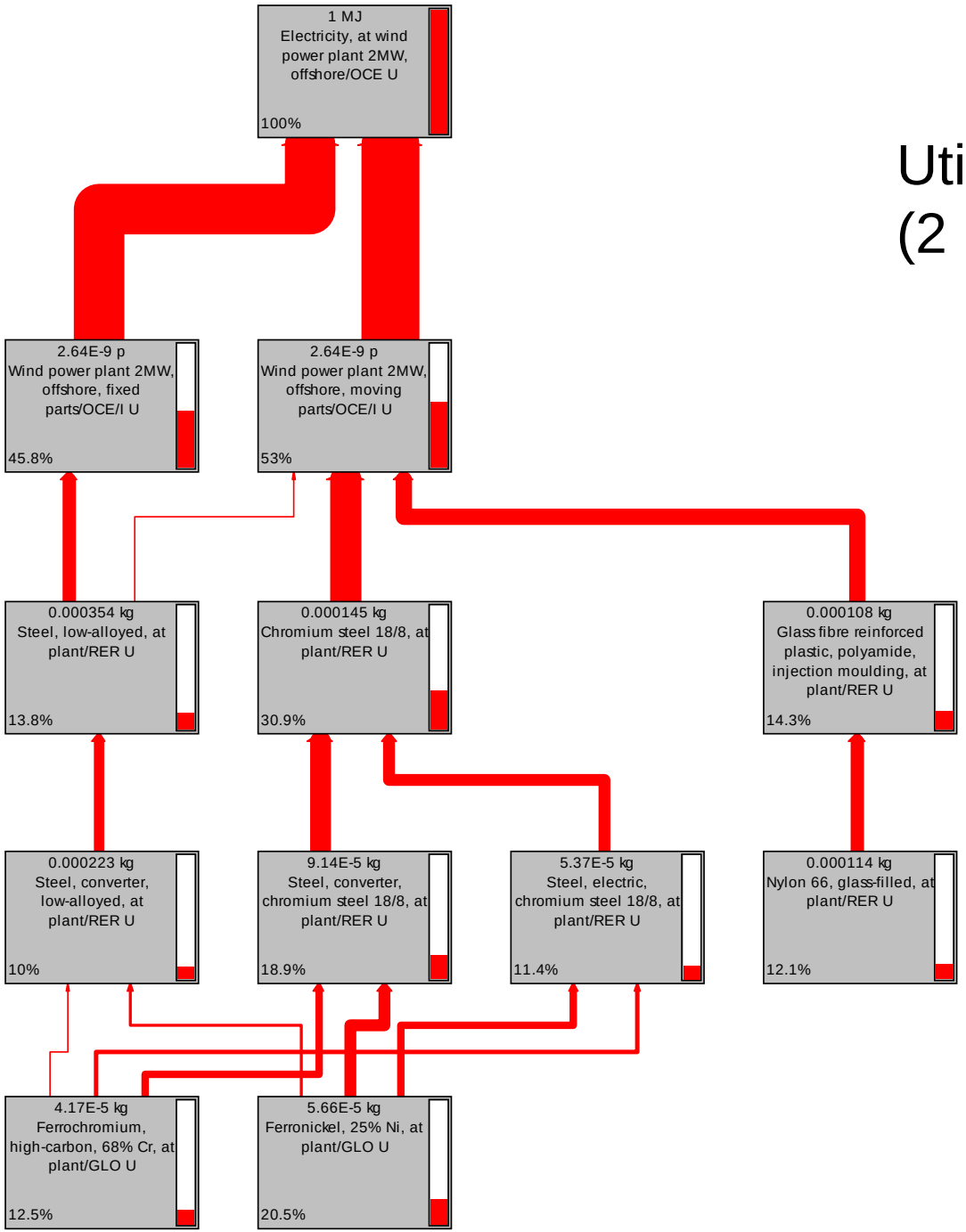
800 kW Utility Wind Turbine Production Supply Chain: Process contributions to total Ecosystem Impacts

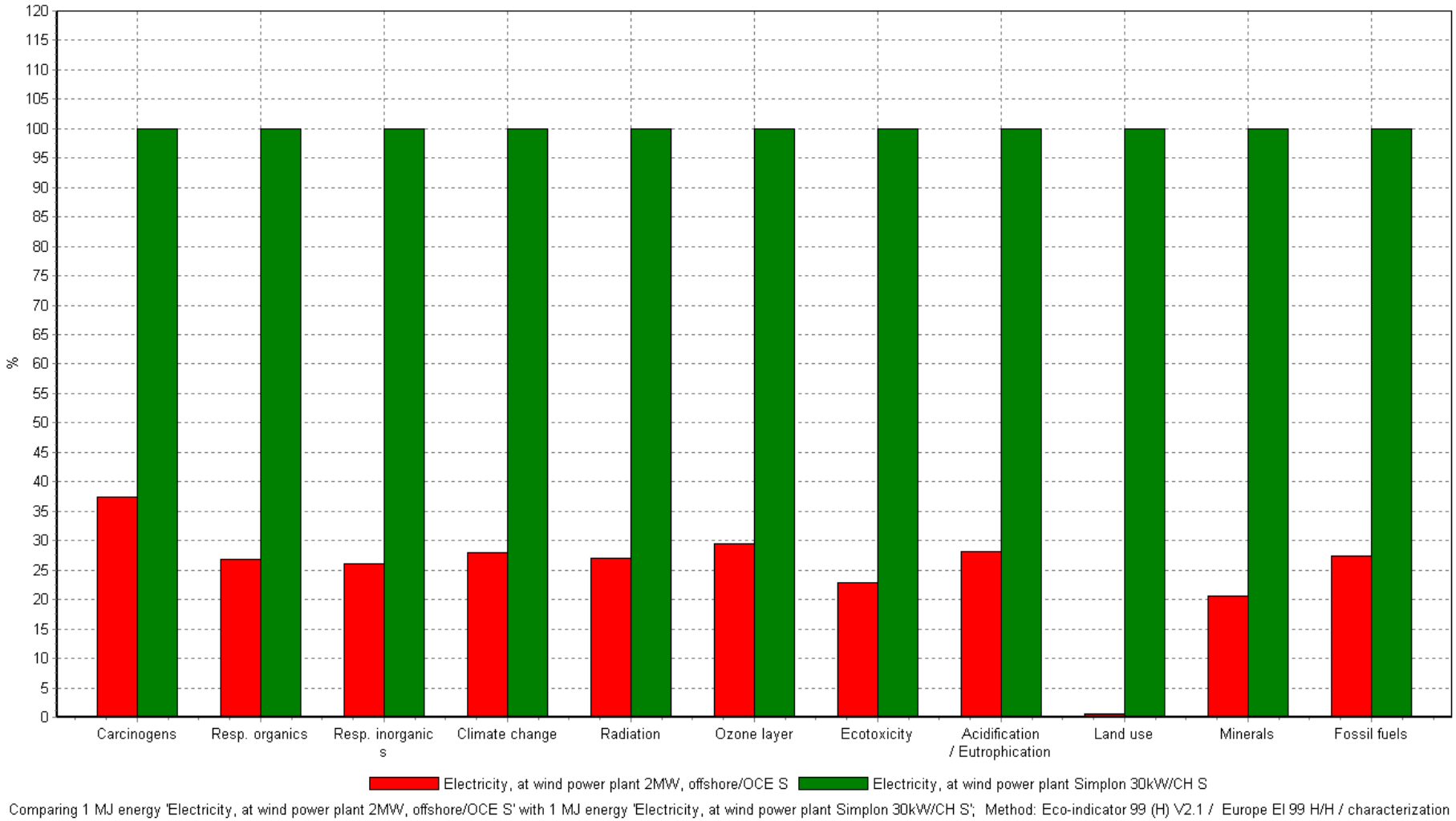


Small-Scale Wind

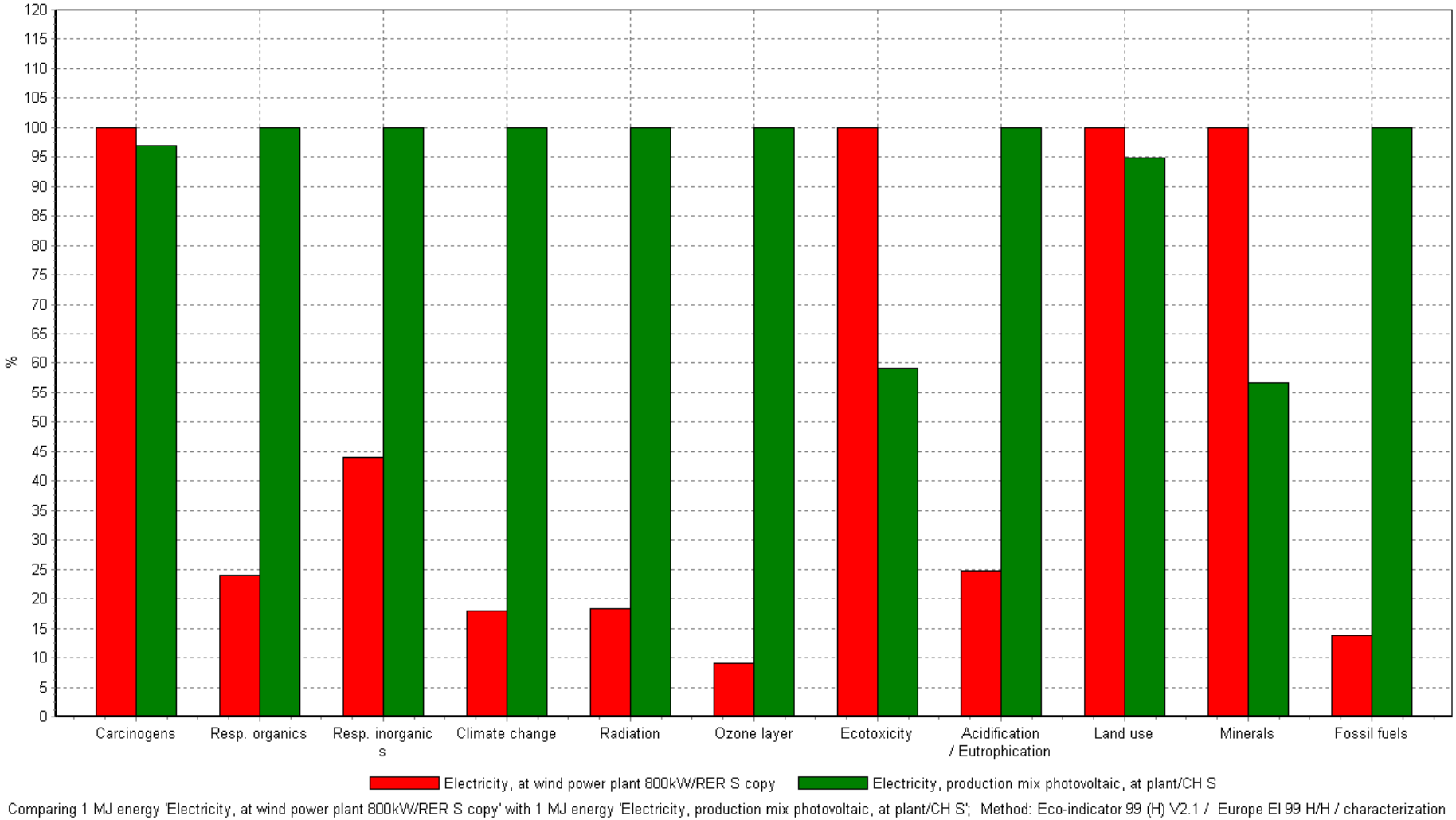


Utility-scale wind (2 MW, offshore)

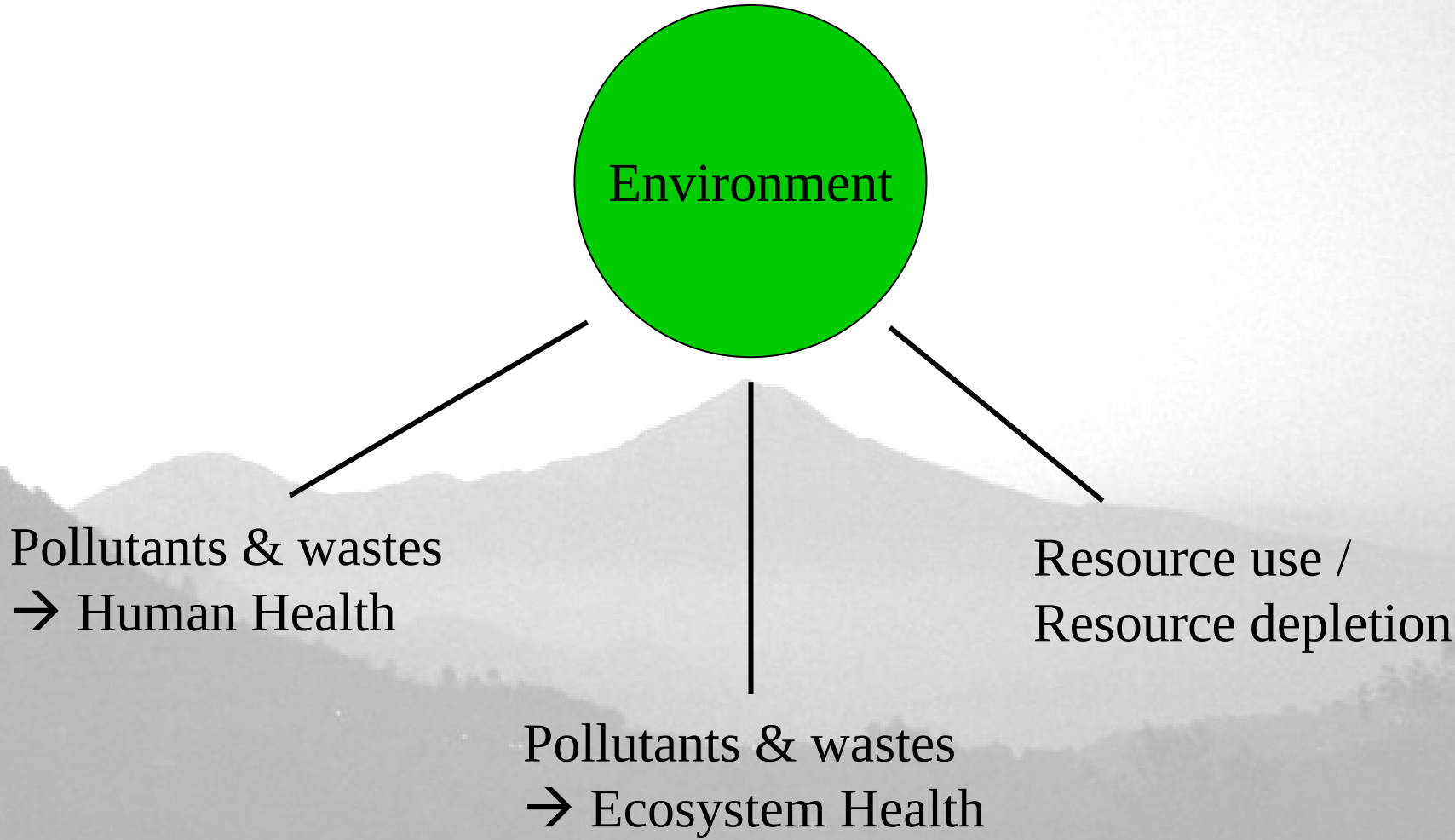




Utility wind (offshore) vs. Small-Scale Wind



Utility wind vs. Utility PV


Environment
Pollutants & wastes
→ Human Health
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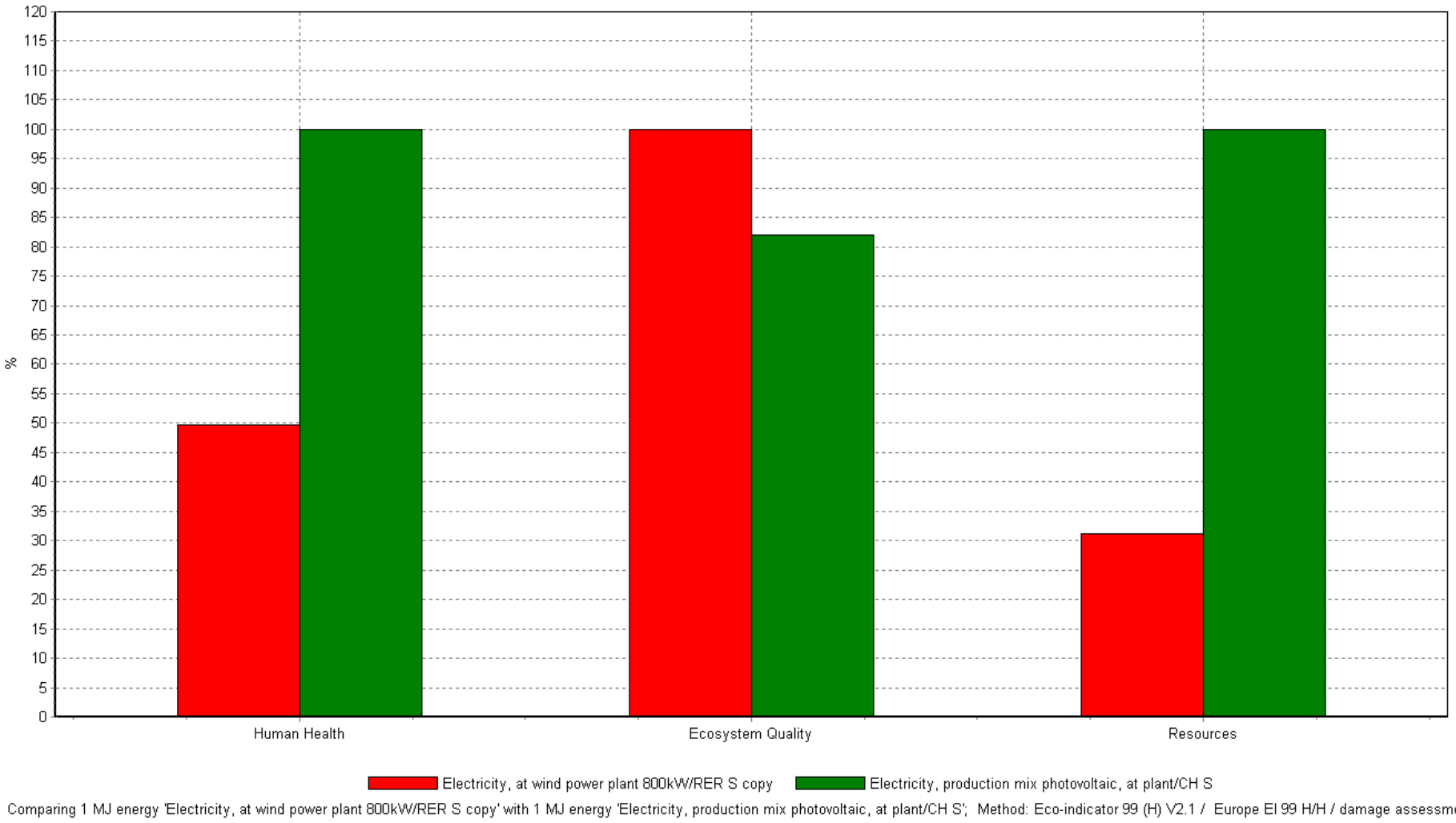
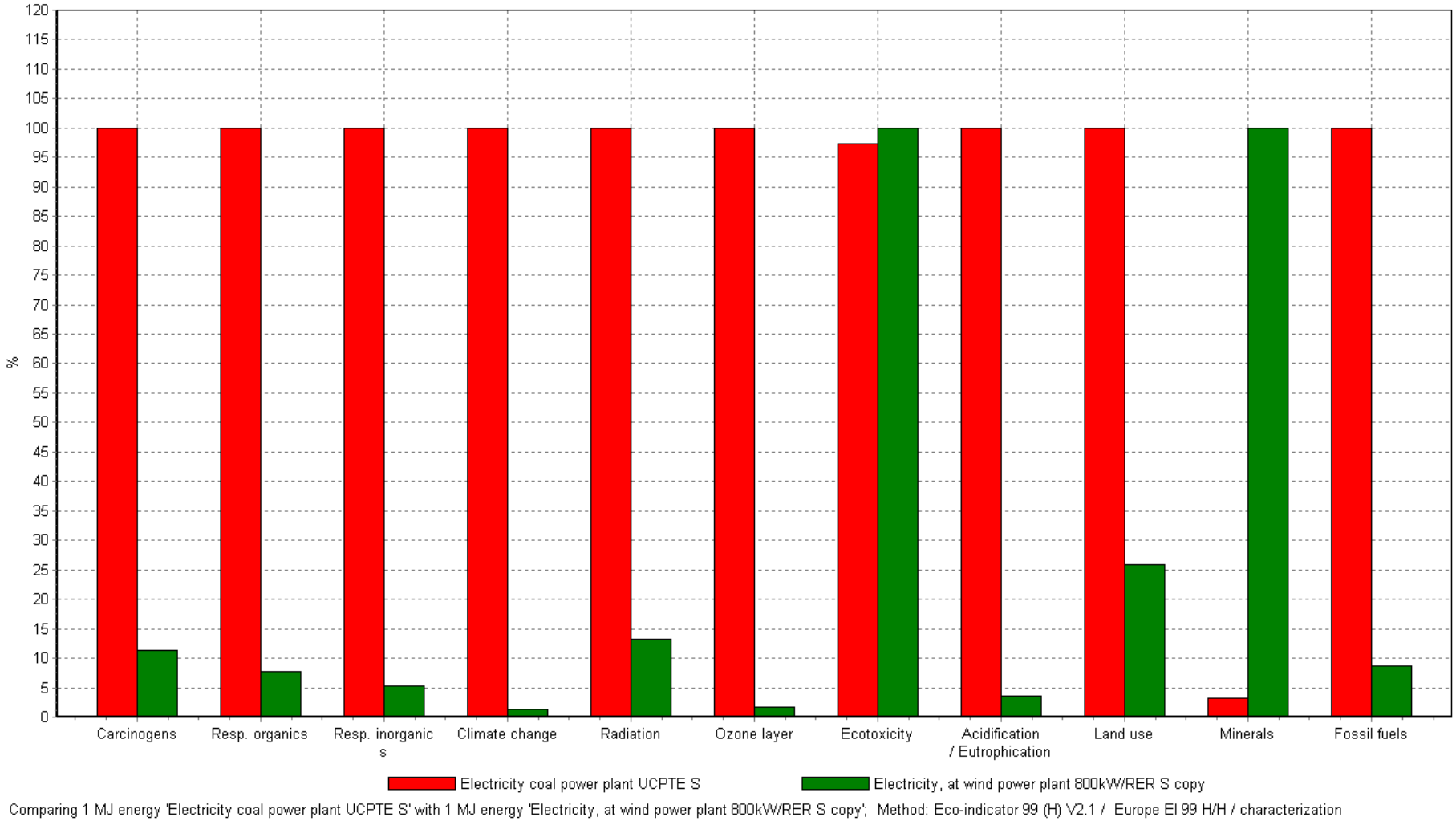
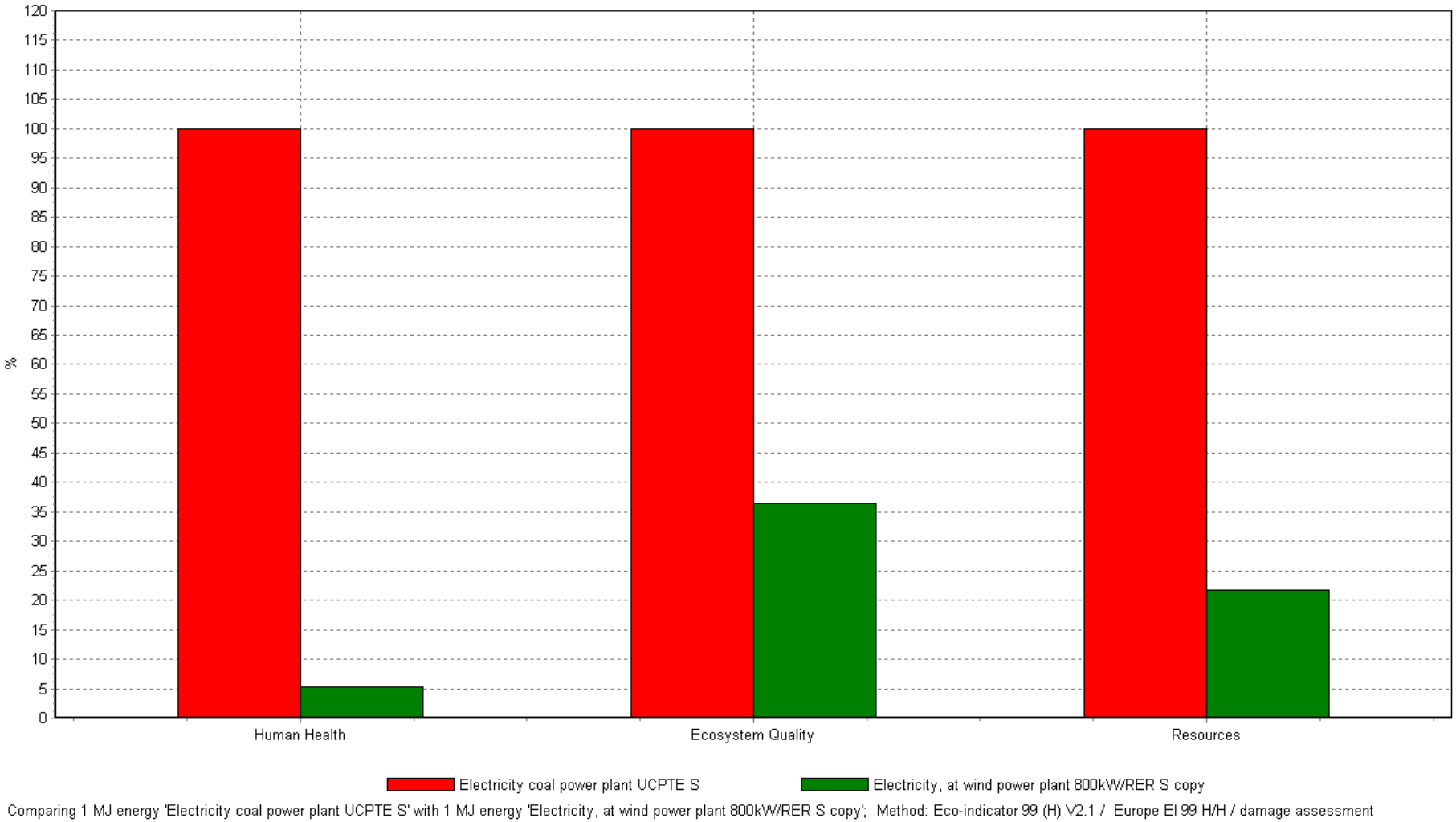


Utility wind vs. Utility PV



Comparing 1 MJ energy 'Electricity coal power plant UCPTE S' with 1 MJ energy 'Electricity, at wind power plant 800kW/RER S copy'; Method: Eco-indicator 99 (H) V2.1 / Europe EI 99 H/H / characterization

Utility coal vs. Utility wind



Utility coal vs. Utility wind