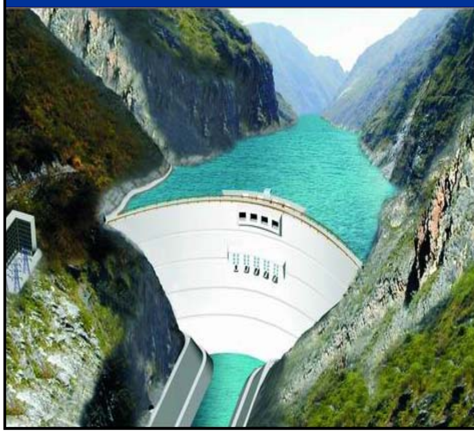
Is Large Hydro Sustainable?

- Life Cycle Inventory of Energy Use and GHG Emissions for Hydropower Projects



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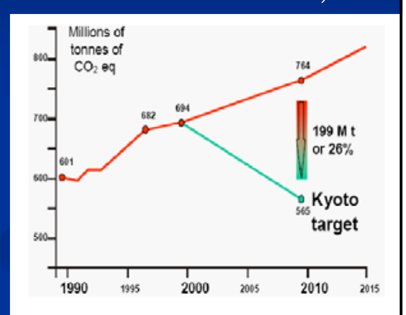
Introduction

- **Research purposes**
  1. Environmental challenge from energy generations (e.g., Canadian Challenge)
  2. Controversy of large hydro development
  3. Let data speak! LCA is a useful quantitative envt. assessment tool.

(Gap: Kyoto target *vs.* reality -- *Natural Resources Canada*)



- **Organization of presentation**
  1. Introduction of studied cases
  2. Objective and scope of research
  3. LCA approaches
  4. Summary of inventories (energy use and GHG)
  5. Results comparison & sensitivity analyses
  6. Conclusions & comments

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Facts of Studied Hydro Projects

Technical & Economic Data	Project A	Project B
Dam Type	Rock-fill Concrete	Double Arch Concrete
Max H/ Max L/Dam V	88.8m/186m /740 km^3	305m/569m/4360 km^3
Reservoir Capacity	46.61 million m^3	7760 million m^3
Flooded Land	0.44 km^2 (668 mu)	9.44 km^2 (14163 mu)
Generation Capacity	22 MW*2 = 44 MW	600 MW*6 =3600 MW
Avg. Energy Output	105.7 million KWh /yr	16620 million KWh /yr
Design Lifespan	50 years	100 years
Total Capital Investment	289.6 million RMB (1992)	18371.66 million RMB (2003)

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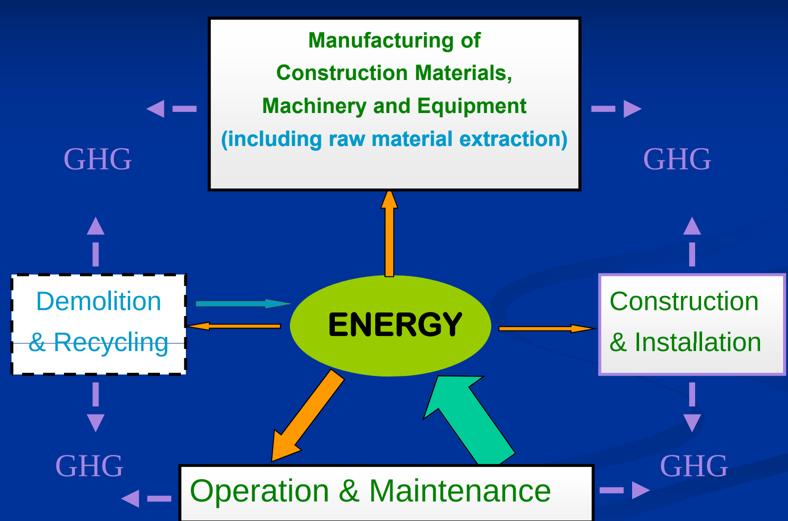
Hydro Project LC & System Boundary



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LCA Method and Application

- What's LCA?
- Process Chain Analysis (PCA)
- Economic Input-Output LCA (EIO-LCA) (Carnegie Mellon EIO based model)
- Data sources:

  1) Manufacturing/Construction & Installation Stages:
  Project Engineering Budget Estimate Reports
  2) O&M Stage (including emissions from reservoir):
  Expertise & experience of similar projects
  3) Economic indices & other data: Literature & internet

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How US EIO Based Model Used here? -- Dollar Cost Conversion

- No available EIO-LCA model based on Chinese economy yet, so Carnegie Mellon EIO-LCA model (92 Version) "borrowed".
- PPP – Purchase Power Parity
  Chinese RMB → US $
- CPI – Consumer Price Index (US)
  US $ in any year → dollar cost in 92

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Could US EIO Model run for projects in China?

- e.g., the energy input for manufacturing of 1 tonne of hot-roll steel bar

----a partial verification of the applicability

1. 92 Chinese market price: 1747 RMB/ tonne Steel
   92 US$ cost (PPP=1.2) : 1456 US$ / tonne Steel
   C. M. EIO model result: **23.8 GJ / tonne steel**

2. The energy efficiency of steel manufacturing in China:
   20-25 GJ / tonne steel (Dhakal 2004)

3. Actual US market price (92): 385.4 US$ / tonne Steel
   C.M. EIO model result: 6.3 GJ / tonne steel

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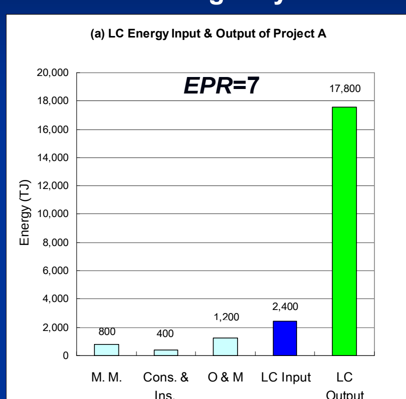
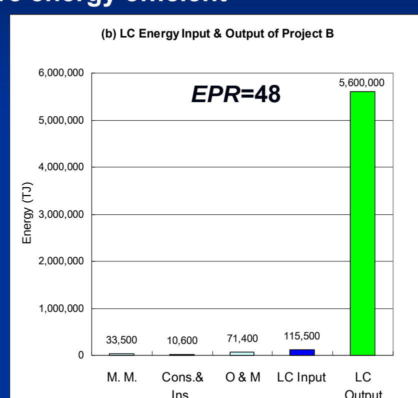
Summary of Energy Analysis

- Larger hydro is more energy efficient





Energy Payback Ratio (EPR) = the ratio of net electrical energy produced over a given project lifetime and total energy invested during lifecycle of the project but excluding the "fuel".

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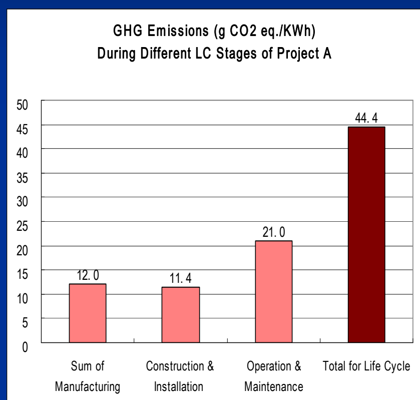
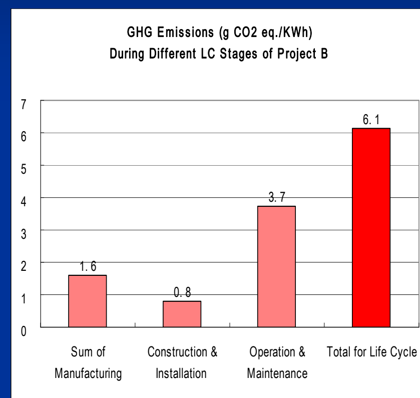
Life Cycle Inventory of GHG Emissions

- Larger hydro is more environmentally favorable





- LC emissions from this study are within the range of 2-48 g CO_2 eq./KWh (the referenced normal range for hydro)

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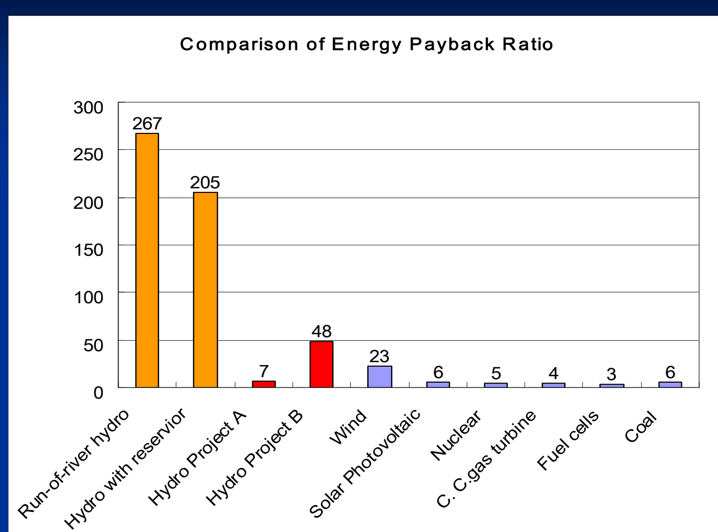
EPR Comparison



Hydro is a competitive option among renewable sources, and more energy efficient than non-renewable sources.

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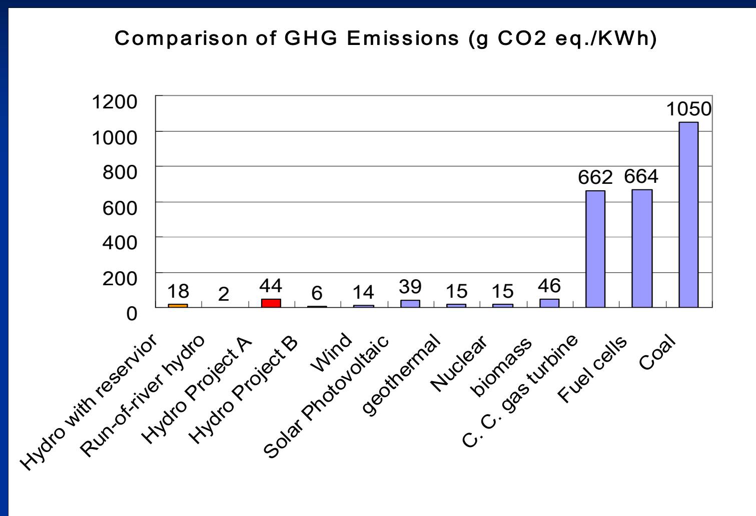
GHG Emission Comparison



Hydro projects are competitive among renewable energy sources; and discharge less GHG than non-renewable sources.

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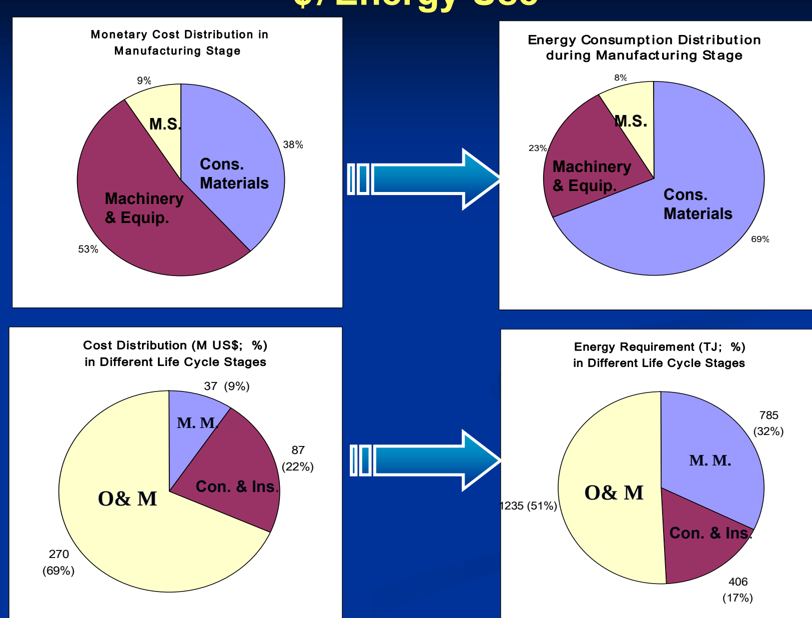
$≠Energy Use



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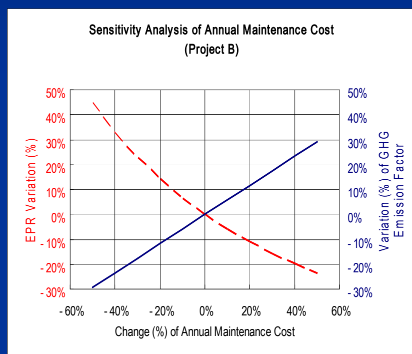
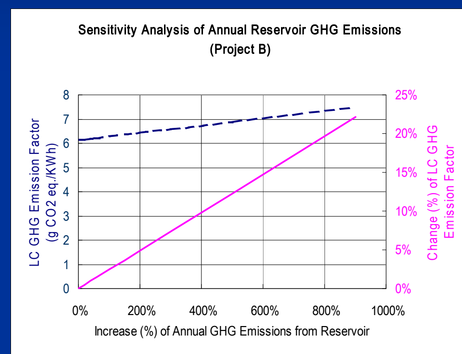
Uncertainties & Sensitivity Analysis

- Annual maintenance cost is very sensitive in terms of both EPR & LC Emission Factor; even more sensitive for larger hydro
- Annual reservoir GHG emissions slightly affects LC emissions only





1) a 50% reduction in ann. maint. ⟹ a 45% increase of EPR (48 up to 70) and a 30% decrease of LC GHG Emission Factor (6 to 4 g CO_2 eq./KWh).
2) 10 times of increase in ann. res. emissions ⟹ 25% up of LC GHG Emission Factor

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Limitations

- The “borrowed” model from the US to China;
- The sector level of aggregate data in the EIO Matrix;
- It is difficult to quantify the multiple functions of a hydro project (such as, flood control and water supply) and the flexibility of hydro operation in a power grid;
- Additional environmental (e.g., landscape change, impacts on territorial and aquatic habitat), economic (e.g., potential loss or gain of tourism) as well as social (e.g., population migration and settlement) metrics should be examined for hydro projects.

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Conclusions & Comments

- A lifecycle perspective is needed for energy decision making. It is feasible to base a LCA for a hydro project on engineering budgetary estimates and this practice should become routine for feasibility study of hydro projects.
- An *a priori* assessment of project scale should not be used uncritically as a criterion for sustainability assessment because of inherent economies of scale.
- **$≠Energy Use**
- **Advanced technologies** can influence the LCA of hydro projects. the optimization of structural design and application of new construction materials and technologies benefit the environment significantly by reducing construction impacts (e.g., **the design of double arch dam in Project B** significantly reduces the concrete volume, and thus improves the specific indicators of energy efficiency and GHG emissions).
- **Sensitivity analysis shows** that variations in annual maintenance costs significantly influence both LC energy efficiencies and GHG emissions, Thus, it is as **important to improve the O&M efficiencies** as to advance construction technologies.

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Data Acquisition & LCI Steps

- **Manufacturing Stage (including raw material extraction)**
  - Quantities & prices of major construction materials (steel, lumber, cement, sand, gravel, dynamite…)
  - Costs of equipment, devices used
  - * These data cited from Project Budget Estimate Report
- **Construction & Installation Stage**
  - Aggregate quantities & prices of gasoline & elec. used during con.
  - * These data cited from Project Budget Estimate Report
- **Operation & Maintenance Stage (O & M)**
  - Plant electricity use: 6% of annual electrical energy output
  - Annual maintenance/replacement cost: 2-3% of total investment
  - GHG emitted from reservoir: 250 tonnes CO_2 eq./(yr. km_2)
  - * These data estimated by expertise & experience of similar projects
- **Decommissioning Stage**
  - * Not common for large hydro projects, no data referenced

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Summary of Life Cycle Inventory of Project A

LC Stages	Cost (M RMB 92)	Cost (M US $ 92)	Non-fossil Elec. Use (GWh)	Energy Use (TJ)	GHG Emissions (t CO_2 eq.)	GHG Emission Factor (g CO_2 eq./kWh)
Manufacturing	44.6	37.1	38.6	785.1	58652.0	12.02
Construction & Installation	106.6	88.7	5.8	406. 6	55655.6	11.40
Operation & Maintenance	324.5	270.5	359.0	1235.0	102431.5	20.98
Total	475.4	396.3	403.4	2426.6	216739.0	44.40

- **Power losses in transformer & transmission not included**
- **All non-fossil electricity use is accounted approximately as hydroelectricity output reduction**
- **GHG Emission Factor = GHG emission mass (g CO_2 eq.) / Lifetime net electricity output (KWh)**

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Summary of Life Cycle Inventory of Project B

LC Stages	Cost (M RMB 2003)	Cost (M US $ 1992)	Non-fossil Elec. Use (GWh)	Energy Use (TJ)	GHG Emissions (t CO_2 eq.)	GHG Emission Factor (g CO_2 eq./kWh)
Manufacturing	3938.4	1669.4	1863.8	33543.9	2504249.7	1.61
Construction & Installation	11562.1	4901.2	129.4	10643.9	1221745.8	0.78
Operation & Maintenance	36743.0	15575.0	102126.0	71379.0	5817173.0	3.73
Total	52243.5	22145.6	104119.2	115566.8	9543168.5	6.13

- **Power losses in transformer & transmission not included**
- **All non-fossil electricity use is accounted approximately as hydroelectricity output reduction**
- **GHG Emission Factor = GHG emission mass (g CO_2 eq.) / Lifetime net electricity output (KWh)**

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