Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Hydroelectricity: The Negative Ecological and Social Impact and the Policy That Should Govern It

Energy Economics and Policy, ETH 2011

Term Paper

By: Mark Commerford

Contents

Introduction:

On today's news, one cannot escape the various reports and commentary concerning energy demands and the rising costs of electricity. Especially now in the aftermath of the 2011 nuclear disaster in Japan, the question as to how to produce cheap electricity if we forego nuclear power plants looms large. The industrialized world has become extremely dependent on electricity and expects and demands supply at reasonable prices. Why can supply not meet demand anymore? First, the world's population is exponentially increasing. Secondly, the demand for energy is constantly increasing in less developed or developing countries. Thirdly, the scarcity of fossil fuels is fundamentally responsible for the increased costs. With these three concerns in mind, hydroelectricity is a very tempting alternative especially given easy use and apparent lack of carbon dioxide emissions. However, when the total environmental and social impacts are included, hydroelectricity might not be an appropriate solution to meet the world's future energy needs.

Population:

The current world population is approximately 6.9 billion people and is anticipated to grow by leaps and bounds. Population growth means among other things more demand for electricity. Figure 1 shows compilations of multiple projections to show a prediction of world growth in the next ninety years. Some estimates have the population of the world reaching up to 15 billon people by 2100 as opposed to today's 6.9 billion inhabitants. This would represent a 120% increase in the world's population subsequently increasing the demand for energy significantly. According to Wolfgang Lutz from the International Institute for Applied Systems Analysis in Laxenburg, Austria, the world's growing population will eventually stabilize. Lutz states "There is a 60 percent probability that the world's population will not exceed 10 billion people before 2100 (Lutz, Sanderson and Scherbov)." If Lutz's conjecture of a stabilized world population of 10 billion people is correct, the world's population will increase roughly 45% in the next 90 years. With this staggering number in mind, electricity production is of the utmost importance for the near future.

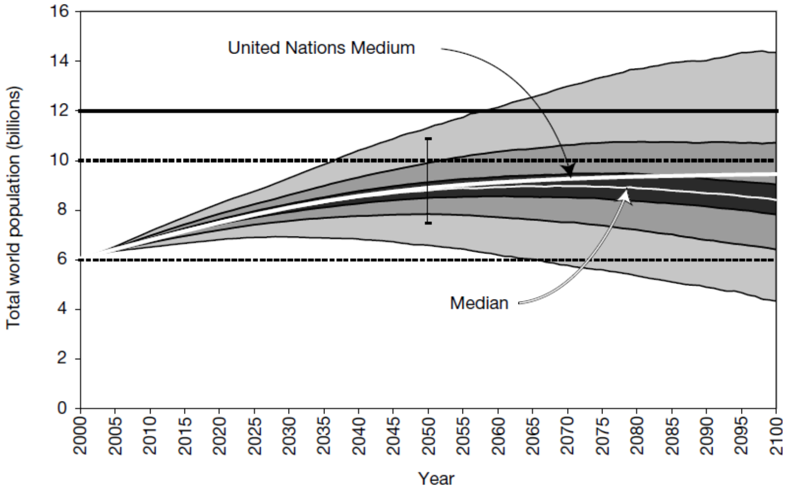


Figure 1: World Population (Lutz, Sanderson and Scherbov).

Demand for Energy:

As highly populated countries such as China and India [combined, approximately 38 percent of world's population] are becoming more industrialized the resulting demand for energy rises as well, thus the rate of increase in electricity production must be greater than that of the projected population increase. As seen in Figure 2, the projected world energy uses will increase roughly 33% by 2035.

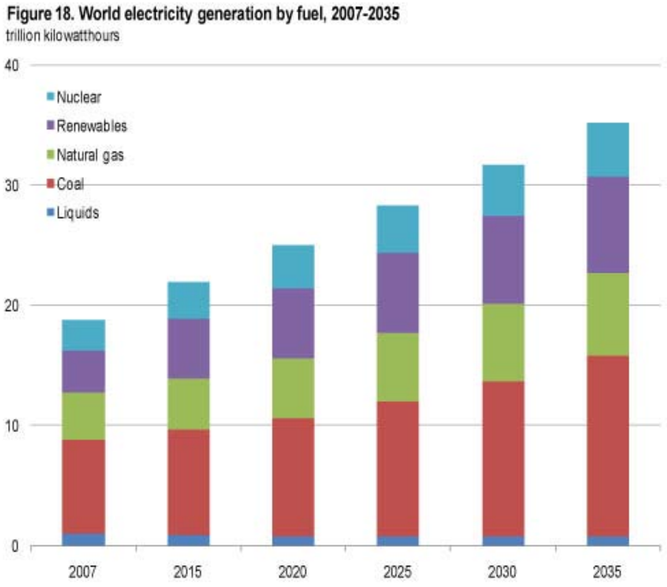


Figure 2: World energy use by Fuel Type (EIA 2010)

Scarcity of Fossil Fuels:

Currently, the primary fuel sources for the world's electrical generation are fossil fuels such as oil, natural gas and coal. These sources are being depleted while the demand for electricity continues to rise. The economic consequence of demand exceeding supply after peak oil is reached is a subsequent increase in price. Peak oil is often stated as the point in which half of the global reserves for oil have been depleted. This is also the point where a maximum production occurs. Many economists differ on the date this situation will occur but many agree it will happen in the near future (Hirsch 2005). Figure 3 shows the contrast between oil production and current reserves and projected future reserves. This raises concerns for future generations as to the type of fuel or source to be used to produce the energy required to sustain the electricity demands of the planet.

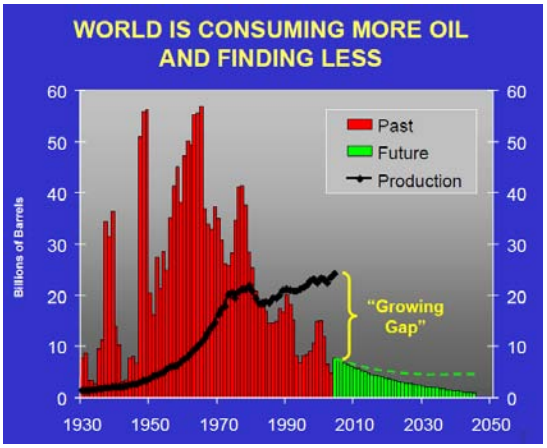


Figure 3: Growing gap in oil production and oil reserves.

An increasing population dependent on one type of fuel, oil, combined with a decreasing availability of the fuel, makes hydroelectricity a very attractive source of energy. This is especially the case if economic benefits alone are considered and ecological and social damages are ignored.

Beside general policy questions on where and to what extent hydroelectricity should be used, two questions arise when considering the advantages and disadvantages of hydroelectricity:

- What is the timeframe for the return on investment of the construction of a hydroelectric facility-when the total cost includes:

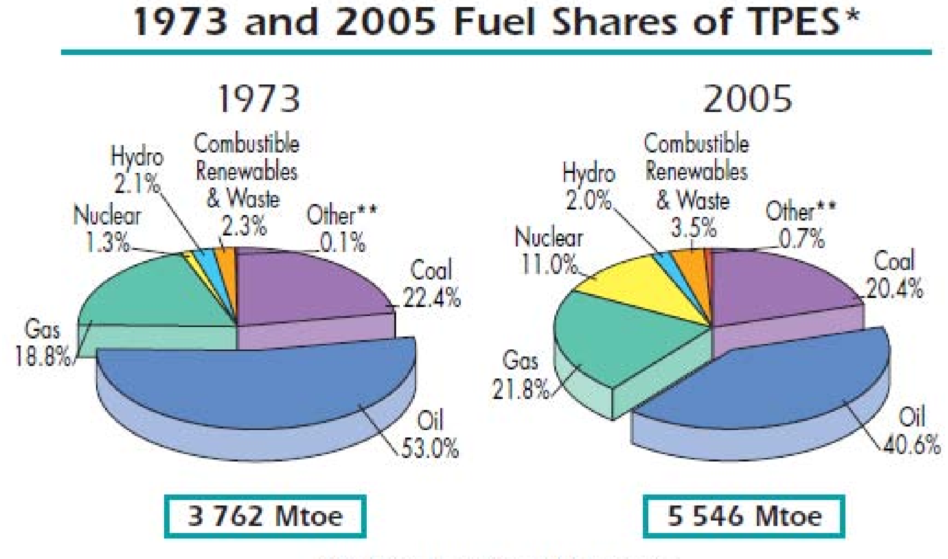
    1. Relocation of Population;

2. Destroying historical monuments;
3. Loss of labor;
4. Environmental impacts; and
5: Social impacts?

- Is there an alternative solution other than building hydroelectric dams that is more economical, more stable and that make more sense?

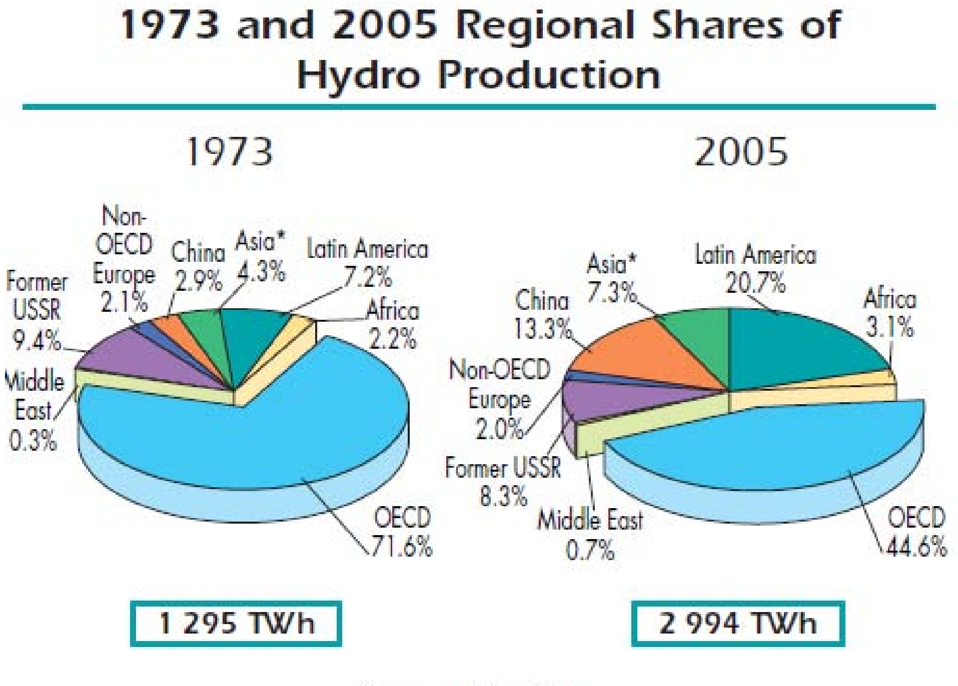
Overview of Hydroelectricity:

Water has been used as an energy source for generations, first in mills to grind flour and later, after the invention of the electric generator, to produce electricity. After the industrial revolution, the need for electricity became greater and the use of hydroelectricity increased. "By 1920, hydroelectric plants accounted for 40 percent of the electric power produced in the United States (Atkins)." This number has since been reduced to approximately 12% in the United State as the focus shifted to other types of fuel that were able to meet electricity demands easier and cheaper. Figure 4 shows fuel shares of hydroelectricity compared with the other types of primary energy supplies, while Figure 5 shows the percentages each region contributes to the total hydroelectric power.



*Excludes electricity and heat trade.
**Other includes geothermal, solar, wind, heat, etc.

Figure 4: Shares of Total Primary Energy Supply (EIA 2007).



*Asia excludes China.

Figure 5: Regional shares of Hydroelectric Power Generation (EIA 2007).

Hydroelectricity works by using water to turn a turbine, which in turn generates electricity. This can be done in various forms as shown in Table 1.

Table 1: Types of hydroelectric dams

Type	How it functions:
Conventional Dam	Uses the difference of height (head) and the potential energy of the water to turn a turbine.
Pumped-storage	Uses cheap electricity at low demand to pump water up higher. This water is then released when there is a higher demand.
Run-of-the-river	Uses small or no reservoir and the water must be used to generate electricity or bypass the dam.
Tide	Use the changes in height of the water associated with the tide to produce electricity.

Due to the controllability in hydroelectricity and its ability as an on-demand energy source, hydroelectricity is employed by many countries as an energy storage option. During a normal day, electricity demand varies by time as seen in Figure 6. The electrical load curve of New England in the United States is shown. As one can see there are two main shifts in demand of electricity throughout the day. First the "morning ramp" in which people begin to use electricity again in the morning hours after they wake up in preparation for work. Another big jump occurs later at night after people return home from work and begin to cook dinner and in the course of regular evening activities, the use of many major electrical appliances such as dishwashers, televisions, computers, washers, and dryers come into play. A base load, such as nuclear energy is used to cover the part of the load curve that is not fluctuating as shown in blue in Figure 6. The remaining output is produced by power plants where the electricity produced can easily be adjusted to fit the load curve profile, such as hydroelectricity.

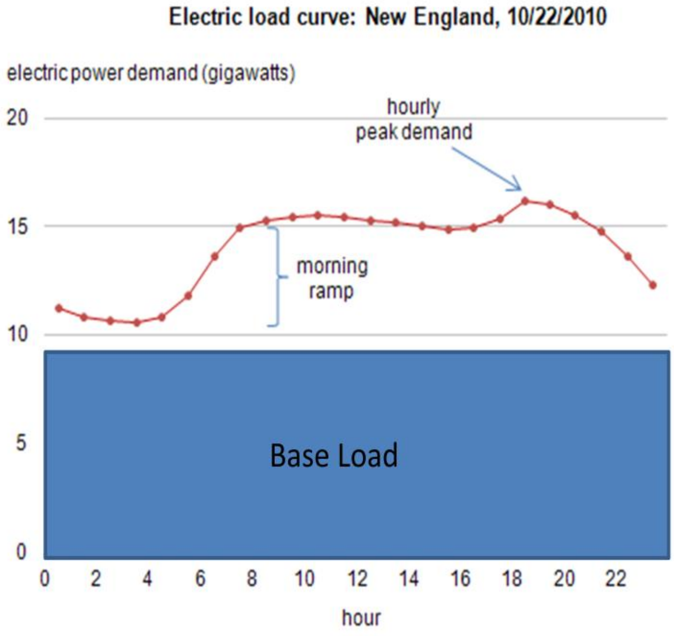


Figure 6: Electricity Load Curve. [IEA 2010]

One important benefit of hydroelectricity is the apparent lack of CO_2 production as a byproduct of power generation. Second, the elimination of extra fuel cost makes hydroelectricity a very economical decision. Finally, the creation of large reservoirs if maintained and marketed well can accumulate additional revenue due to water sports and tourism. These benefits however, when weighted against the many disadvantages of hydroelectricity make it difficult to determine if hydroelectricity is truly the best option.

Policy Issues of Hydroelectricity:

There are many drawbacks and concerns associated with hydroelectric dams: loss of land, relocation of animals and humans, change in ecosystems, methane emissions, as well as safety. A sound policy must to determine whether or not it would make sense to build hydroelectric dams and all possible factors, not necessarily limited to the above mentioned examples must be considered.

Relocation:

Hydroelectric dams require large quantities of water which greatly reduce the livable land for both humans and animals. These large reservoirs are required for each hydroelectric plant to meet the electrical generation demands. The Merowe Dam in Sudan was built to supply the nearby city of Karima with electrical power (NASA). "Once finished, its reservoir will contain 12.5 km^3 (3.0 cu mi), or about 20% of the Nile's annual flow. The reservoir lake is planned to extend 174 km (108 mi) upstream (NASA)" as shown in Figure 7.

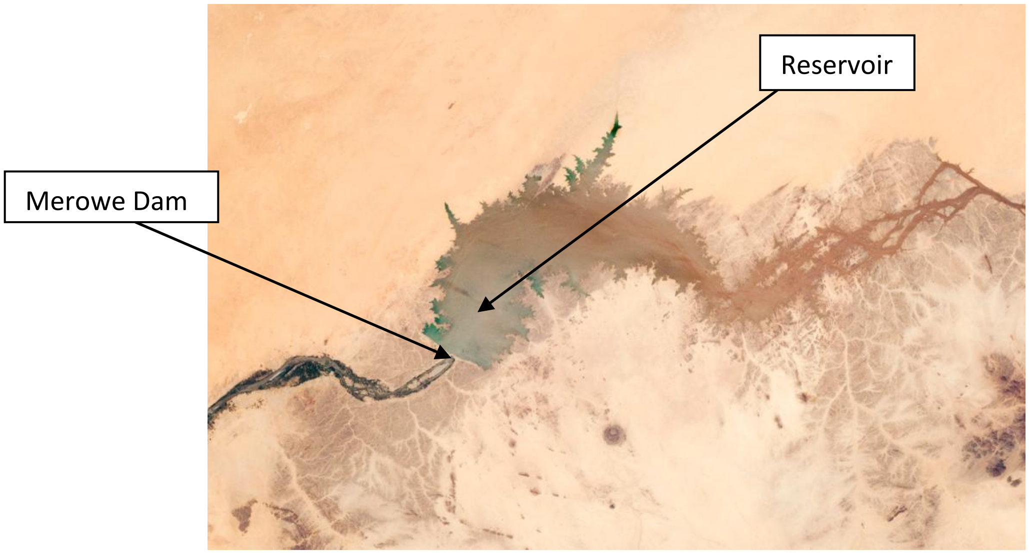


Figure 7: The Merowe Dam (NASA).

The Merowe dam displaces so much water that many tribes in the area had to be relocated and their sacred land and cultural landmarks were destroyed. This raises ethical questions.

> "Beyond the issues of water rights, several local tribes will be displaced by the planned 170 kilometer (105 mile) reservoir, and the flooded region contains significant but little-studied archeological sites. The Sudanese government has a resettlement program in place for the tribes, and a variety of international institutions have been conducting "salvage" or "rescue" archeological surveys since 1999 (NASA). "

An estimated 55,000 to 77,000 people had to be relocated once the dam was approved.

Changes to Ecosystems:

Hydroelectric dams can also change the ecosystem of flora and fauna upstream as well as downstream of the plant. The once flowing water is suddenly blocked and a reservoir is formed; plant life and animal life changes drastically following construction. For instance, salmon species are often affected because of their need to spawn up river and since they are cut off from their spawning area there is the fear of species endangerment as well as potential gaps in the overall food chain. Often fish ladders are used to try to prevent this. A fish ladder is a structure used in a dam to artificially create a passage for the fish to migrate through as shown in Figure 8. These however do not always work as intended such as for example at the Marmot Dam on the Sandy River in Oregon.

> "The dam included a fish ladder, but it was usually blocked to capture brood stock for hatchery production. The ladder also suffered repeated flood damage and required regular repair. Additional fish losses occurred when downstream migrating fish were swept into the dam's diversion canal. Stream flow diversions also affected fish migration and production below the dam for many years (Taylor)"

The dam was later taken down in 2007 and 2008 due to the severe changes in salmon populations.

Figure 8: Fish Ladder (Corps of Engineers).

Methane production:

Another severe consequence of hydroelectric plants is the byproduct of methane from decomposing trees and other plant life in an anaerobic environment. Methane is created when reservoirs are built without prior deforestation and removal of various other plant life, thus trapping plant material underwater which in turn decomposes without oxygen. Methane, like carbon dioxide, is a very potent greenhouse gas that can effectively change our climate. "Hydroelectric dams produce significant amounts of carbon dioxide and methane, and in some cases produce more of these greenhouse gases than power plants running on fossil fuels (Graham-Rowe)." Phillip Fearnside, a conservation biologist at the National Institute of Research in the Amazon in Manaus says, "His latest results suggest a typical tropical hydropower plant will, during the first ten years of its life, emit four times as much carbon as a comparable fossil fuel station (Giles)." This is conflicting information when considering the media calling hydroelectricity "clean" energy. There is a need for a uniform tax to offset the costs for social damages caused by an increase of greenhouse gases. Currently this tax is either low or non-existent, thus favorably influencing the decision to build a dam. If this tax levy is figured into the calculation of a hydro-power plant the resulting increase in cost makes hydroelectricity neither "clean" nor "cheap".

Safety:

The last and most well known problem is that of safety. With vast amounts of water held back by a dam, there is always the potential of terroristic acts, accidents and major flooding downstream caused by faulty construction or natural catastrophes, evoking natural fear in the population living in the surrounding and possibly affected areas. During times of war, dams are major targets for destruction because they can not only disrupt power, but they also create a large number of casualties as water is released from the damaged reservoir. During the Second World War, the British Royal Air Force used specially designed "Bouncing Bombs" that would essentially skip across the water and sink at the edge of the dams causing the most amount of damage to them (CWGC 2005). This tactic was used on the Moehne and Edersee dams in Germany, releasing millions of tons of water into the Rhine valley as seen in figure 9.

Figure 9: Moehne Dam destruction (Fray 1943).

Faulty construction such as that of the Banqiao Dam in the Henan province of China, killed an estimated "26,000 people directly when it broke in 1975 and another 145,000 died of disease and famine. Unofficial estimates put the total number of deaths as high as 230,000 people (Goldstein)." Here the dam was constructed with an extra reservoir capacity to account for a 1 in 1000 year rain storm. On August 8, 1975 China experience a 1 in 2000 year rain storm in which there was "rainfall recorded at 1.060 meters in 24 hours near the typhoon center (Xinhau)." 700 million cubic meters of water were released within the first 6 hours of the breach. "Official statistics recorded 30 years after the dams burst show more than 26,000 people were killed in the floods [and] the life of more than 10 million people was affected (Xinhau)."

Economic analysis:

As mentioned above, relocation of both animals and humans and the associated costs pose one of the major problems not always looked into by developing countries. Often the need for more electricity supersedes any other consideration. There should be a formula to assess what fiscal responsibility the government should employ to reimburse for population relocation, including the loss of ancestral land, impact from ethical and ethnical damages. Unfortunately, ethics are not always the guiding factor and give way to greed.

> "For example, dams have physically displaced 40-80 million people worldwide, and most of these people have never regained their former livelihoods. In many cases, dams have led to a significant and irreversible loss of species and ecosystems, and efforts to mitigate these impacts have often not been successful (Bosshard)."

Table 2 shows relocation figures for some dams with major relocation before 1982 (Fearnside) and the most controversial one in recent history, the Three Gorges Dam. The costs of methane emissions as mentioned before, as well as costs for insurance have to be taken into consideration when the total cost is to be determined.

Table 2: Relocation Figures

Dams	**Number of people relocated**
Aswan	120,000
Bkakra	36,000
Brokopondo	5,000
Damodar	93,000
Gandhi Sagar	52,000
Kainji	42,000-50,000
Kariba	50,000-57,000
Keban	30,000
Kossou	75,000
Lam Pao	130,000
Nam Ngum	3,000
Nam Pong	25,000-30,000
nanela	90,000
netzhualcoyoti	3,000
Sanmenxia	870,000
Pa Mong	310,000-480,000
Tarbela	86,000
TVA	60,000
Uper Pampanga	14,000
Volta	80,000-84,000
Three Gorges Dam [17]	6,000,000

Looking at the Three Gorges Dam in the Hubei province of China, with a capacity of 18,200 MW of electricity (Acker) how can we determine the breakeven point taking the cost of the dam plus the relocation of the people into consideration?

First the total costs should be approximated using Equation 1.

$$C_{total} = C_{relocation} + C_{Dam} + C_{O\&M} + C_{Methane} \quad \text{(Eq. 1)}$$

Where C_{total} is the total cost of the dam, $C_{O\&M}$ is the cost of operation, and maintenance, $C_{Methane}$ is the cost associated with the methane production; C_{Dam} is the cost for building the dam, and $C_{relocation}$ is the cost for relocation of the people approximated by equation 2.

$$C_{relocation} = H * P_{relocation} + H * P_{annual} * t + H * P_{historical} \quad \text{(Eq. 2)}$$

Where $P_{relocation}$ is an estimated relocation cost to move a rural Chinese household to a new house, P_{annual} is the annual salary the rural Chinese worker earns in a year, t is the time in years, $P_{historical}$ is the estimated price to compensate the historical loss of land from generations of families living there and H is the number of households that have to be moved. The average household in rural China is limited by law to only one child (BBC), creating an average person to household ratio of 3. This might be an under estimation because of larger families living together for economic as well as cultural reasons (i.e., cohabitation of multi-generational families within one structure).

The calculation of the amount of households that are then affected by the relocation can be done using Equation 3.

$$H = Q_{people} * \frac{1}{h_{ratio}} \quad \text{(Eq. 3)}$$

where Q_{people} is the amount of people that are affected by the building of the dam, and h_{ratio} is the person to household ratio. With 6 million people being relocated due to the Three Gorges Dam as mentioned above, the amount of households is approximated as 2 million. Additionally the yearly income of a rural Chinese worker is roughly 4,140 Yuan a year. When converting this yearly salary to dollars, the average Chinese worker in rural areas earns only \$572.61 a year (Subler). Using an estimated \$5,000 as the relocation amount and a historical compensation price of \$1,000 the relocation cost equation, Equation 2 above turns into Equation 4, below where the relocation costs are only given for the first 15 years.

$$C_{relocation} = \$10{,}000{,}000{,}000 + \$1{,}145{,}220{,}000/year * t + \$2{,}000{,}000{,}000$$

$$= \$12{,}000{,}000{,}000 + \$1{,}145{,}220{,}000/year * t \qquad \text{(Eq. 4)}$$

The total cost for construction and financing for the dam project is estimated at roughly 80 billion Yuan or approximately 11.1 billion dollars "Operation and maintenance (O&M) costs of hydropower are between 1.5% and 2.5% of investment cost per year (Hydropower)." This correlates to a yearly operation and maintenance cost of $221,000,000/year.

When considering the social cost associated with Methane, first the chemical reaction of anaerobic decomposition is needed as shown in Equation 5.

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4 \qquad \text{(Eq. 5)}$$

where $C_6H_{12}O_6$ is glucose that is found in plant life that decomposes to carbon dioxide and methane. "Plant biomass varies in different ecosystems (e.g., .7 kg C/m^2 in grasslands to 20 kg C/m^2 in tropical rain forests: boreal ecosystems are approximately midway in this range) and so does soil carbon (low in the tropics to high in boreal peat lands) (Kelly et al.)". Assuming the area used to make the reservoir for Chinas Three Gorges Dam consists of an average of 10 kg C/m^2, then a calculation for the amount of Carbon can be performed. The submerged area of the reservoir for the Three Gorges Dams is roughly 632 km^2 (Ibiblio). This translates into a value of 6.32*10^9 kg of Carbon being divided equally between formation of carbon dioxide [CO_2] and methane [CH_4], resulting in 3.16*10^6 tons of carbon dioxide and methane. Danny Cullenward, an energy-policy expert at Stanford University "Stresses that more data are needed, but his estimates suggest that dams release between 95 million to 122 million tons of methane per year(Giles)." "The global warming potential of CH_4 is 20-40 times that of CO_2 (per g basis), so the percentage of CH_4 released is important (Rosenberg et al.) ." Assuming that the methane release from the Three Gorges Reservoir is 30 times the global warming potential (GWP) the calculation of CO_2 equivalent can be calculated as seen in Equation 6. The value of approximately 98 million tons of CO2 falls within the range specified by Dr. Cullenward.

$$3.16 * 10^6 + 30 * 3.16 * 10^6 = 9.796 * 10^7 tons\ of\ CO_2\ Equvilant \qquad \text{(Eq. 6)}$$

Social Cost of Carbon Dioxide:

When considering social costs associated with CO_2 output, an optimal amount, not zero, of CO_2 is used to find the appropriate price to be paid for emission of 1 ton of CO_2. An output of zero CO_2 is not considered optimal because there are costs associated with not producing any additional units. For example people want cars or other products but if the CO_2 output is zero these products would not be made or sold and the opportunity cost associated with not producing any CO_2 is not producing any cars. As seen in Figure 10, the optimal price of output of CO_2 is where the marginal control cost or benefits equal that of the marginal damage costs (Kiel, Matheson and Golembiewski). This price has been disputed and a wide range of prices have been suggested ranging from $1/ton to $1500/ton. In Europe it has been suggested to use values of €4 to €30 per ton of CO_2.(Kanter).

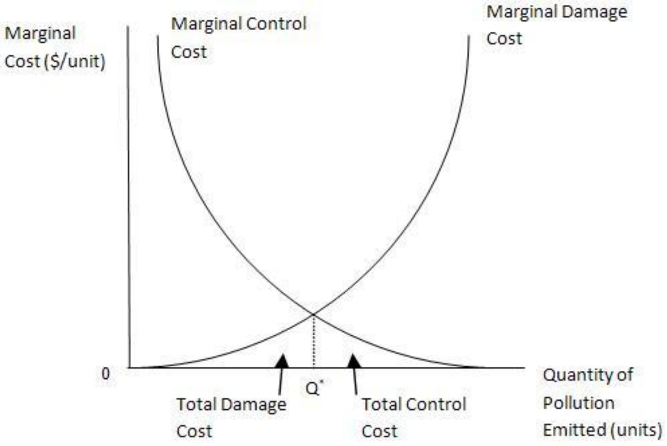


Figure 10: Optimal Price of CO_2

According to Pearce (2003), total damages from the emissions of 1 ton of carbon dioxide or other green house gas can be calculated through a string of complex equations. First the total damage function is presented in Equation 7.

$$V = \sum_0^T \frac{\partial D_t}{\partial E_t} * (1+s)^{-t} \qquad \text{(Eq.7)}$$

where V is the total damages done by the emission on the greenhouse gas, $\frac{\partial D}{\partial E}$ is all future incremental damages, t is time and s is the social discount rate. In this instance, the social discount rate is estimated to range from 1% to 5% and can be formulated using Equation 8.

$$s = \rho + \mu g \qquad \text{(Eq. 8)}$$

Where s is the social discount rate, ρ is the rate at which wellbeing is discounted, μ is the elasticity of the marginal utility of income and g is the expected growth rate per-capita consumption.

The annual damages, D_t can be approximated using the following Equation 9, proposed by Fankhauser (1995).

$$D_t = k_t\left(\frac{T_t^U}{\ }\right)^{\ } * (1 + \quad)^{t^*-t} \qquad \text{(Eq. 9)}$$

Where is the amount of warming, in degrees Celsius associated with the doubling of carbon dioxide from pre-industrial levels, t^* is the year in which the doubling of CO_2 is to occur, is a parameter that makes the impacts greater if they occur before t^* and lower if the occur after t^*, k_t is the damage done by doubling the CO_2 which is estimated to happen in 2050, and T_t^U is the temperature increase on the upper ocean layer.

Using numbers from Frankhauser (1995), shown in Table 3, the model for damages can be seen for a .1 degree increase per decade.

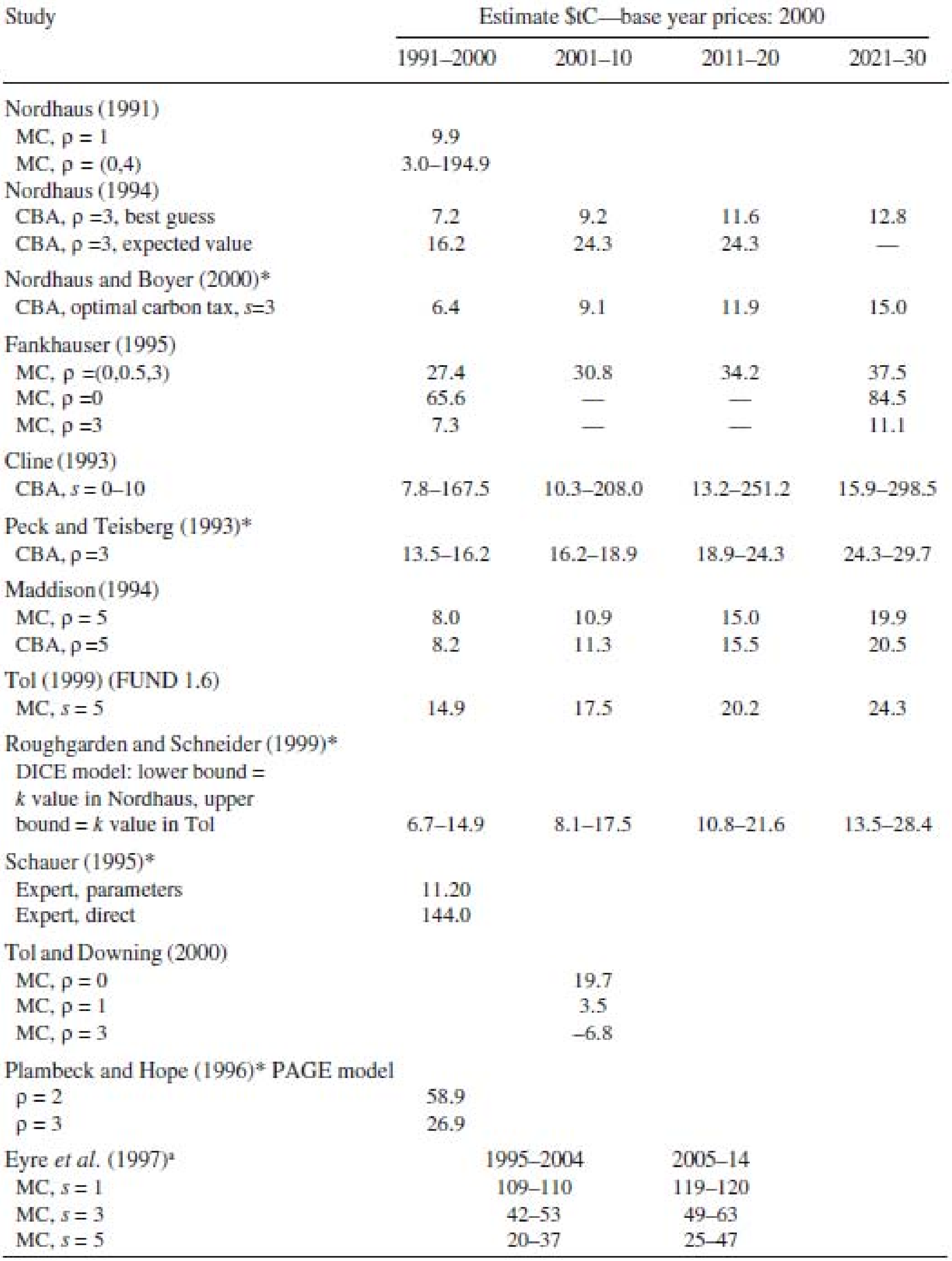
Table 3: Parameters for Damage.

Parameter	Value	Units
ϒ	1.3	[-]
ʌ	2.5	[degrees]
	0.006	[-]
t^*	2050	[year]
k_t	270 billion	[$]
T_t	2.6	[degrees]
t	2010	[year]

Using these values Equation 9 can be rewritten into Equation 10.

$$D_{10} = 270 * 10^9 * (\frac{2.6}{2.5})^{1.3} * (1.006)^{10} = \$301.3\ billion \qquad \text{(Eq. 10)}$$

Using these values, calculations for the price per ton of CO_2 can be formulated using the above mentioned Equation 10. Multiple methods for calculation are shown in Figure 11, where MC stands for a marginal cost approximation and CBA is the cost benefit analysis that is shown above.



Study	Estimate $tC—base year prices: 2000			
	1991–2000	2001–10	2011–20	2021–30
Nordhaus (1991)				
MC, ρ = 1	9.9			
MC, ρ = (0,4)	3.0–194.9			
Nordhaus (1994)				
CBA, ρ =3, best guess	7.2	9.2	11.6	12.8
CBA, ρ =3, expected value	16.2	24.3	24.3	—
Nordhaus and Boyer (2000)*				
CBA, optimal carbon tax, *s*=3	6.4	9.1	11.9	15.0
Fankhauser (1995)				
MC, ρ =(0,0.5,3)	27.4	30.8	34.2	37.5
MC, ρ =0	65.6	—	—	84.5
MC, ρ =3	7.3	—	—	11.1
Cline (1993)				
CBA, *s* = 0–10	7.8–167.5	10.3–208.0	13.2–251.2	15.9–298.5
Peck and Teisberg (1993)*				
CBA, ρ =3	13.5–16.2	16.2–18.9	18.9–24.3	24.3–29.7
Maddison (1994)				
MC, ρ = 5	8.0	10.9	15.0	19.9
CBA, ρ =5	8.2	11.3	15.5	20.5
Tol (1999) (FUND 1.6)				
MC, *s* = 5	14.9	17.5	20.2	24.3
Roughgarden and Schneider (1999)*				
DICE model: lower bound = *k* value in Nordhaus, upper bound = *k* value in Tol	6.7–14.9	8.1–17.5	10.8–21.6	13.5–28.4
Schauer (1995)*				
Expert, parameters	11.20			
Expert, direct	144.0			
Tol and Downing (2000)				
MC, ρ = 0		19.7		
MC, ρ = 1		3.5		
MC, ρ = 3		–6.8		
Plambeck and Hope (1996)* PAGE model				
ρ = 2	58.9			
ρ = 3	26.9			
Eyre *et al.* (1997)[a]	1995–2004	2005–14		
MC, *s* = 1	109–110	119–120		
MC, *s* = 3	42–53	49–63		
MC, *s* = 5	20–37	25–47		

Figure 11: Estimated cost per ton of Carbon

As seen from the graph, the social cost of CO2 emissions is increasing as the effects of global warming become more noticeable. Looking at both approximations, an intermediate price of \$25 per ton of CO_2 can be used, the price from methane and carbon dioxide can then be approximated using Equation 11.

$$9.796 * 10^7 tons\ of\ CO_2\ Equvilant * 25 \frac{\$}{ton\ CO_2} = \$2.45 * 10^9\ tons\ of\ CO_2\ Equivalent \quad \text{(Eq. 11)}$$

This amounts to a price of approximately 2.45 billion dollars. Equation 1 can now be reevaluated as shown in Equation 12.

$$C_{total} = (\$12.0 * 10^9 + \$1.145 * 10^9 * t) + (\$11.1 * 10^9) + (\$.221 * 10^9 * t) + \$2.45 * 10^9$$

$$= \$25.55 * 10^9 + 1.366 * 10^9 * t \quad \text{(Eq. 12)}$$

Approximating the amount of income the dam receives a year can be achieved by a rough cost calculation of the residential use of electricity which is about.50 Yuan per kilowatt hour (Tang). This corresponds to approximately \$.07/kWh. Using the estimated output of 49 billion kWh per year a formula for income is formulated in Equation 3.

$$Income = 49 * 10^9 [kWh] * .07 \left[\frac{\$}{kWh}\right] * t = \$3.43 * 10^9 * t \quad \text{(Eq. 13)}$$

To finally calculate the time required to pay off the dam, equation one must equal equation two, where total costs have to equal total income as seen in Equation 14.

$$C_{relocation} + C_{Dam} + C_{O\&M} + C_{Methane} = Income \quad \text{(Eq. 14)}$$

Using this equation multiple scenarios can be performed to see the importance of each individual cost on the overall costs of the plant and in turn the breakeven time. Four different scenarios are shown in Table 4, where Scenario 1 represents a case when everything from relocation to historical costs are considered. Scenarios 2 through 4 are using other considerations to evaluate the breakeven point for the hydroelectric plant.

Table 4: Scenarios of Different Taxations.

Inputs	Scenario 1, Everything Considered	Scenario 2, No CO_2 taxation and no relocation costs	Scenario 3, Low cost of CO_2	Scenario 4, High cost of CO_2
Households	2,000,000	2,000,000	1,000,000	1,000,000
Yearly Income	$572.61	$0.00	$572.61	$0.00
Duration of Yearly Income [Years]	15	15	15	15
Relocation Amount	$1,000	$0	$1,000	$1,000
Capital Cost	$25,000,000,000	$25,000,000,000	$25,000,000,000	$25,000,000,000
Historical Compensation	$2,000	$0	$2,000	$2,000
Operation and Maintenance Percentage	2.00%	2.00%	2.00%	2.00%
Operation and Maintenance Total	$500,000,000	$500,000,000	$500,000,000	$500,000,000
Area of Land [m^2]	632,000,000	632,000,000	632,000,000	632,000,000
Plant Biomass Density [.7-20 kg/m^2]	10	10	10	20
Amount of Carbon	6,320,000,000	6,320,000,000	6,320,000,000	12,640,000,000
Cost of CO_2 [$/ton CO2]	$25	$0	$15	$100
Global warming Potential	30	0	30	20
Total Cost	$2,480,000,000,000	$25,000,000,000	$1,497,400,000,000	$13,300,000,000,000
Varying cost initially [$/year]	$1,645,220,000	$500,000,000	$1,072,610,000	$500,000,000
Varying Cost Finally [$/year]	$500,000,000	$500,000,000	$500,000,000	$500,000,000
Inputs				
Estimated Output [kWh]	49,000,000,000	49,000,000,000	49,000,000,000	49,000,000,000
Price per kilowatt	0.07	0.07	0.07	0.07
Total Income	$3,430,000,000	$3,430,000,000	$3,430,000,000	$3,430,000,000
Breakeven Point [years]	**852.28**	**8.53**	**513.99**	**4539.25**

Graphically this is represented in figure 12, where the cost is plotted versus the income to determine, at the intersection, where the breakeven point is located. The total revenue earned is depicted in green while the total amount spend is depicted in red.

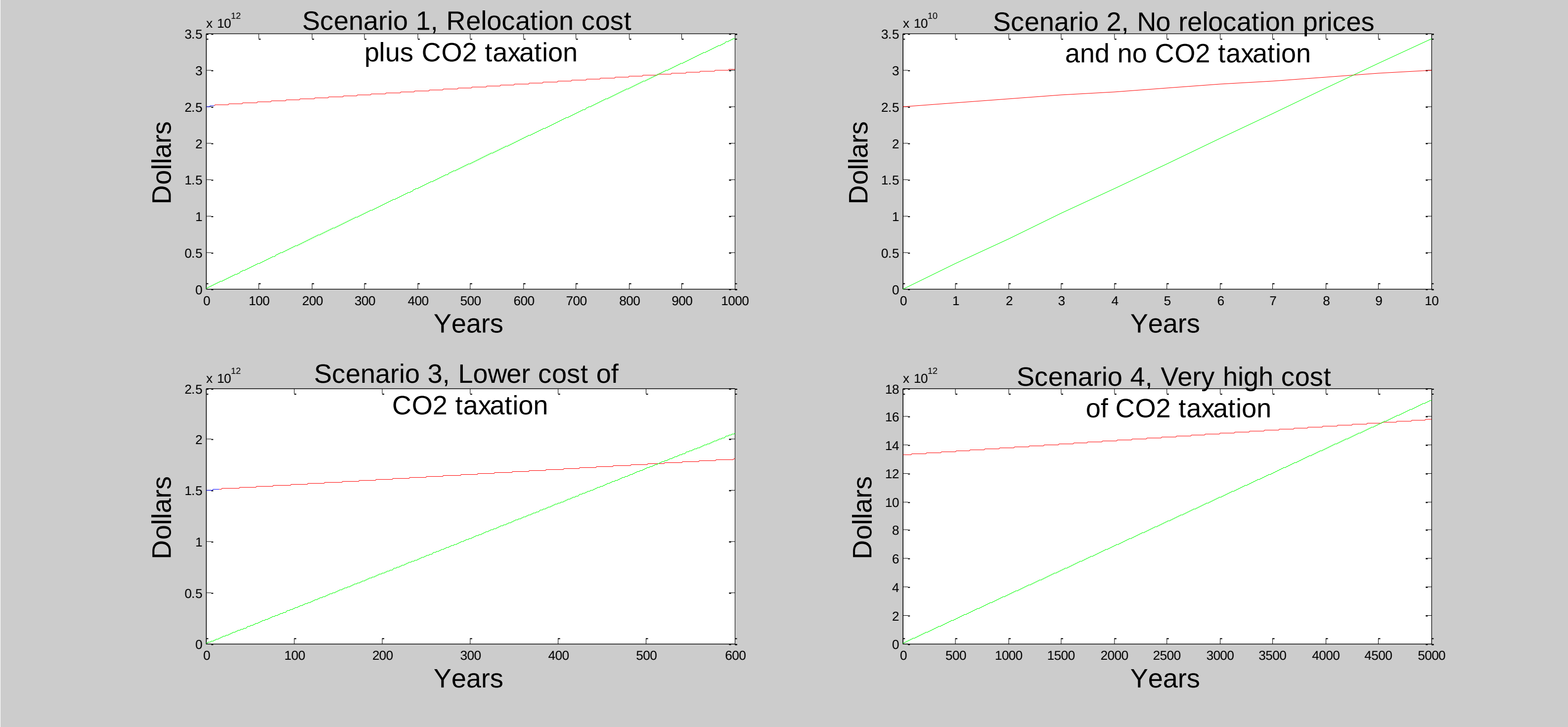


Figure 12: Graphic Depiction of the Breakeven Point.

From these graphs, one can easily see that depending on the social importance for a taxation of CO_2 the time frame for when the hydroelectric dam will pay for itself drastically changes. For scenario 2, for example, there is no cost associated with relocating the people, compensation for lost land, salary loses or CO_2 taxation. This brings the overall cost of the plant construction and operation drastically down which makes the breakeven point a very desirable 8.5 years. On the other hand, in scenario 1 relocation costs as well as CO_2 taxation is considered and the breakeven period jumps to an astonishing 852.28 years. The other extreme case is that in which the CO_2 is taxed greatly, at a value of $100 per ton of CO_2. Here the breakeven point is calculated at over 4000 years. These calculations of course use assumptions of constant price and constant CO_2 output. In reality the price of electricity will be increased to pay for different taxations and the methane that is produced through the anaerobic decomposition will only be affective for a limited time, where the peak output is release in the first 10 years.

Conclusion:

Obviously, there are many factors to consider when determining if an area is suitable for construction of a hydroelectricity plant. Great social impact caused by moving entire villages from one place to another in order to make room for the vast reservoirs that are needed, create many facetted problems, not only economical and religious but also environmental and historical. As presented above the number of people forced to relocate due to the Three Gorges Dam created an immense cost that is hard to ever pay off. When moving 6 million people the costs associated with the loss of work and the loss of the ancestral land greatly impact the breakeven point of the entire project. With the growing need for more electricity due to the increase in population and the increasing development of countries such as China and India, a "clean" and "cheap" energy source is needed. The panacea was always believed to be hydroelectricity. However, if governments only enforce a selective few policies and not consider all factors and impacts, this can be very far from the truth and will greatly affect the overall socio-economic and environmental well-being of the world. A policy that considers social well being more than economic gain has to be enforced to eliminate this huge social cost. Weighting factors should be employed to consider the importance of electricity vs. the damages that will be caused by relocating this amount of people.

Other factors, such as the emission of methane and carbon dioxide produced as a side effect of the anaerobic decomposition of bio mass, also play a giant role in the decision as to whether to invest in hydroelectric dams. "Pearce estimated that CO_2 emissions from reservoirs globally amount to 7% of total, man-made emissions of CO_2." A policy of determining methane and CO_2 emissions from these potential sites is a must. As mentioned above the density of the forest or plant life in the affected area used for the reservoir greatly impacts the amount of CO_2 and methane that will be produced. This density must be examined and used for a cost benefit analysis to see whether the site for the dam makes economical and ecological sense. Surveys sponsored from the state or independent research groups have to be performed to find suitable locations for the hydroelectric dams and to map out the plant densities to create an overall hydroelectric potential map for the specified land. Then either trees or plant life must be eliminated through expensive deforestation plans before the dam is built, or the reservoir must be built in a place with very low forest density. This would have to become a law to eliminate these very costly social damages created by the methane.

CO_2 accounting in countries pose the dilemma that local regulations only hurt the countries that actually abide by these rules. These countries are considered free riders; the ones who do not conform to these laws, are still able to output high levels in gases without having to abide by the restricting and costly regulations of other countries. This brings up the classic point of "the race to the bottom" in which countries notice that free riders are producing the same amount and are not having any of the negative effects of the regulations and therefore lower or eliminate the regulations in order to be competitive. This is of course a major issue when considering developing countries which require more electricity to become competitive in the future but still need it at low cost.

When deciding on where and if construction of a dam is feasible a few measures must be taken into account. First the number of people to be relocated and the overall cost associated with this move have to be considered, where the importance of electricity has to be weighed against the damages associated with the many people that have to relocate. It will also have to incorporate the population's salary loss because of this relocation. Other social costs such as the price of having to abandon an area of great historical meaning for past generations and the cost of losing historical artifacts must be incorporated and a quantitative estimation of this cost has to be attempted and achieved. Cost associated with the emission of methane and carbon dioxide as well as a quantitative estimation of the price associated with real or perceived safety issues of the people. All this and more have to be factored into the overall price of the dam to legitimize the economic benefit of building a dam.

References:

Acker, F. "Taming the Yangtze." *Engineering and Technology Magazine*. Volume 4. Issue 4. 2 March 2009. 13 April 2011. <http://eandt.theiet.org/magazine/2009/04/taming-the-yangtze.cfm>.

Atkins, W. "Hydroelectric Power." Water Encyclopedia. 4 April 2011 <http://www.waterencyclopedia.com/Ge-Hy/Hydroelectric-Power.html>.

BBC. "China steps up 'one child' policy." *BBC News.* 25 September 2000. 16 April 2011. <http://news.bbc.co.uk/2/hi/asia-pacific/941511.stm>.

"Beyond Three Gorges in China." International Water Power and Dam Construction. 10 January 2007. 15 April 2011. <http://www.waterpowermagazine.com/story.asp?storyCode=2041318>.

Bosshard, P. "The World commission on Dams Framework-A Brief Introduction." International Rivers. 29 February 2008. 12 April 2011. <http://www.internationalrivers.org/en/way-forward/world-commission-dams/world-commission-dams-framework-brief-introduction>.

"China's Three Gorges Dam" Mtholyke. 12 April 2010. <http://www.mtholyoke.edu/~vanti20m/classweb/website/current.html>.

"Demand for electricity changes through the day" EIA - 2010 International Energy Outlook. 2010. 6 April 2011. 7 April 2011 <http://www.eia.doe.gov/oiaf/ieo/world.html>.

EIA - 2010 International Energy Outlook. 2010. 4 April 2011 <http://www.eia.doe.gov/oiaf/ieo/world.html>.

Eyre, N., et al. "Externe–Global Warming Damages." *Final Report of the Global Warming Sub-Task of the Project JOS3-CT95-0002. Brussels* (1997). Print.

Fearnside, P. "Greenhouse Gas Emissions from Hydroelectric Dams: Controversies Provide a Springboard for Rethinking a Supposedly 'Clean' Energy Source. ≪I≫an Editorial Comment≪/I&Gt." *Climatic Change* 66.1 (2004): 1-8. Print.

Giles, J. "Methane Quashes Green Credentials of Hydropower." *Nature* 444.7119 (2006): 524-25. Print.

Fish Passage Technologies: Protection at Hydropower Facilities. OTA-ENV-641 (Washington, DC: U.S. Government Printing Office, September 1995).

Fray, J. "Mohne Dam breached." *Allied Phot Reconnaissance of World War II*. Ed. Staeker, Chris. 17 May 1943. 10 April 2011.

Fankhauser, S. "Valuing Climate Change: The Economics of the Greenhouse." (1995). Print.

Graham-Rowe, D. "Hydroelectric Power's Dirty Secret Revealed." *new scientist* 4 (2005). Print.

Goldstein, L. "'Safe' power an oxymoron." *Toronto Sun*. 20 March 2011. 11 April 2011. <http://www.torontosun.com/comment/columnists/lorrie_goldstein/2011/03/18/17675461.html>.

Hirsch, R. "PEAKING OF WORLD OIL PRODUCTION; How Do We Mitigate the Problem?" SAIC, July 2005. 4 April 2011 <https://secure.ametsoc.org/atmospolicy/documents/July252005 Dr.Hirsch.pdf>.

"Hydropower." Energy Technology Network. 15 April 2011. < http://www.etsap.org/E-techDS/PDF/E07-hydropower-GS-gct.pdf>.

Ibiblio. "Exploring Chinese History: The Three Gorges Dam Project." Ibiblio. 22 March 2011. 15 April 2011 <http://www.ibiblio.org/chinesehistory/contents/07spe/specrep01.html#Quick%20Facts>.

IEA. "Key World Energy Statistics." International Energy Agency. 2007. 4 April 2011 <http://www.iea.org/Textbase/nppdf/free/2007/key_stats_2007.pdf>.

John Day Dam and Lake Umatilla, photograph by the Corp of Engineers. April 7 2010. <http://www.nwd-wc.usace.army.mil/report/jda.htm>.

Kanter, J. "Europe Considers New Taxes to Promote 'Clean' Energy." The New York Times. 22 June 2010.

Kelly, C., et al. "Turning Attention to Reservoir Surfaces, a Neglected Area in Greenhouse Studies." *EOS Transactions* 75 (1994): 332-32. Print.

Kiel, K.A., V.A. Matheson, and K. Golembiewski. "College of the Holy Cross, Department of Economics Faculty Research Series, Paper No. 09-08." (2009). Print.

Maddison, D. "Economics and the Environment: The Shadow Price of Greenhouse Gases and Aerosols." *Surrey Energy Economics Centre (SEEC), Department of Economics Discussion Papers (SEEDS)* (1994). Print.

NASA. "Merowe Dam, Nile River, Republic of the Sudan: Image of the Day." NASA Earth Observatory. 25 October 2010. April 7 2011. <http://earthobservatory.nasa.gov/IOTD/view.php?id=46505 &src=eorss-iotd>.

Nordhaus, W.D. "Managing the Global Commons: The Economics of Climate Change." (1994). Print.

---. "To Slow or Not to Slow: The Economics of the Greenhouse Effect." *The economic journal* 101.407 (1991): 920-37. Print.

Pearce, D. "The Social Cost of Carbon and Its Policy Implications." *Oxford Review of Economic Policy* 19.3 (2003): 362-84. Print.

Pearce, F. "Trouble Bubbles for Hydropower." *new scientist* 150.28 (1996): 28-31. Print.

Peck, S.C., and T.J. Teisberg. "Global Warming Uncertainties and the Value of Information: An Analysis Using Ceta* 1." *Resource and Energy Economics* 15.1 (1993): 71-97. Print.

Plambeck, E.L., and C. Hope. "Page95:: An Updated Valuation of the Impacts of Global Warming." *Energy Policy* 24.9 (1996): 783-93. Print.

Lutz, W. Sanderson, W., and Scherbov S. "The End of World Population Growth." *Nature* 412.6846 (2001): 543-45. Print.

Rosenberg, D M, et al. "Large-Scale Impacts of Hydroelectric Development." *Environmental Reviews* 5.1 (1997): 27-54. Print.

Roughgarden, T., and S.H. Schneider. "Climate Change Policy: Quantifying Uncertainties for Damages and Optimal Carbon Taxes." *Energy Policy* 27.7 (1999): 415-29. Print.

Schauer, M.J. "Estimation of the Greenhouse Gas Externality with Uncertainty." *Environmental and Resource Economics* 5.1 (1995): 71-82. Print.

Subler, J. "China urban-rural income gap continues to widen" *Reuters*. 24 January 2008. 14 April 2011. <http://in.reuters.com/article/2008/01/24/china-economy-incomes-idINPEK171502008 0124>.

Tang, A. "China raises price of electricity for non-residential use." *China View*. 19 Novemeber 2009. April 14 2011. <http://news.xinhuanet.com/english/2009-11/19/content_12492364.htm>.

Taylor, B. "Salmon and Steelhead Runs and Related Events of the Sandy River Basin–a Historical Perspective." *Prepared for Portland General Electric Company* (1998). Print.

"The Dams Raid." Commonwealth War Graves Commission. 2005. 10 April 2011. <http://www.cwgc.org/admin/files/The%20Dams%20Raid.pdf>.

Tol, R.S.J. "The Marginal Costs of Greenhouse Gas Emissions." *The Energy Journal* 20.1 (1999): 61-82. Print.

Tol, R.S.J., T.E. Downing, and Vrije Universiteit te Amsterdam. Instituut voor Milieuvraagstukken. *The Marginal Costs of Climate Changing Emissions*. Institute for Environmental Studies, 2000. Print.

Xinhau. "After30 years, secrets, lessons of China's worst dams burst accident surface." Peaple's Daily Online. 1 October 2005. April 12 2011. <http://english.people.com.cn/200510/01/eng20051001_211892.html>.