University of Alberta Department of Mechanical Engineering

GREENHOUSE GAS MITIGATION POTENTIAL IN CHINA'S POWER SECTOR: A 20 YEAR FORECAST

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EXECUTIVE SUMMARY

The International Energy Agency has stated that if China and other rapidly emerging industrial nations fail to gain increased control on their national greenhouse gas emissions levels, catastrophic climate change will become inevitable by mid-century. This study focused on China's power sector, as it accounts for 42% of the nation's GHG emissions. The paramount objective was to determine the GHG mitigation potential associated with meeting the long term electric energy generation requirements for sustaining China's recent economic growth trends, with the comparison of two scenarios, over a forecast period of 20 years from a 2007 baseline. The two scenarios considered consist of a Business as Usual (BAU) scenario, in which current trends are continued and, a Sustainable Development (SD) scenario in which China's stated potential for the increased exploitation of renewable energy resources is realized.

The Long-range Energy Alternatives Planning - LEAP system was employed to model long term electric energy demand in the People's Republic of China, the results of which were used to calculate the required energy generation forecast and final energy mix for either scenario. China's required electric energy generation is forecasted to increase threefold to 11,070TWh in the year 2027. The BAU scenario forecast shows coal fired generation will remain dominant at 76.4% of the overall energy mix in 2027; a small decrease from the current fraction of 82.5%. The SD scenario forecast reveals the possibility that the required energy could be provided in an alternative manner with renewable sources, mainly hydro, nuclear, wind and solar PV energy, constituting 78.8% of energy generation in 2027.

Due to the increased use of coal fired energy generation in the BAU scenario, emissions levels of 8,591Mt CO_{2e} are realized in the year 2027. This represents an increase of 155% relative to 2007 levels. The SD scenario exploits renewable energy potential in China's power sector to a large degree, thus decreasing the use of fossil fuels significantly; this results in 2027 emissions levels of 2,241Mt CO_{2e}, a decrease of 34% relative to 2007 levels. Over the 20 year forecast period, the BAU and SD scenarios deliver net cumulative GHG emissions of 116,062 and 43,523Mt CO_{2e}, respectively. Therefore, the resulting GHG mitigations potential in China's power sector is 72,539Mt CO_{2e} during the 2007 to 2027 period of study.

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INTRODUCTION

Over the past decade, China has experienced significant economic growth which has been reflected in the growth rate of the nation's electricity consumption and greenhouse gas (GHG) emissions profile. As of 2005, the People's Republic of China overtook the United States of America to become the world's largest GHG emitter at 7,527Mt CO_{2e}/yr and it is expected that China will account for approximately 39% of global GHG emissions between now and 2030 [1]. An alarming aspect of the situation is that as a developing nation, China has no GHG reduction targets under the Kyoto Protocol; many analysts maintain that if China and other emerging industrial economies do not succeed in controlling GHG emissions, catastrophic climate change may become inevitable by mid century [1]. In fact, China has been constructing the equivalent of two new 500 MW coal fired power plants every week and experts agree that the nation's electricity consumption will more than double over the next decade [1].

Given the potential for negative global environmental impact due to continued growth in the People's Republic of China, it is important to understand which sectors of the economy are responsible for the bulk of national GHG emissions. Based on 2005 data, Figure 1 shows China's GHG emissions by sector [2]. It is clear that the energy generation & transformation (Power) sector is responsible for the bulk of national GHG emissions (42%) while the industry and agriculture sectors are responsible for 21% and 20% of emissions, respectively.

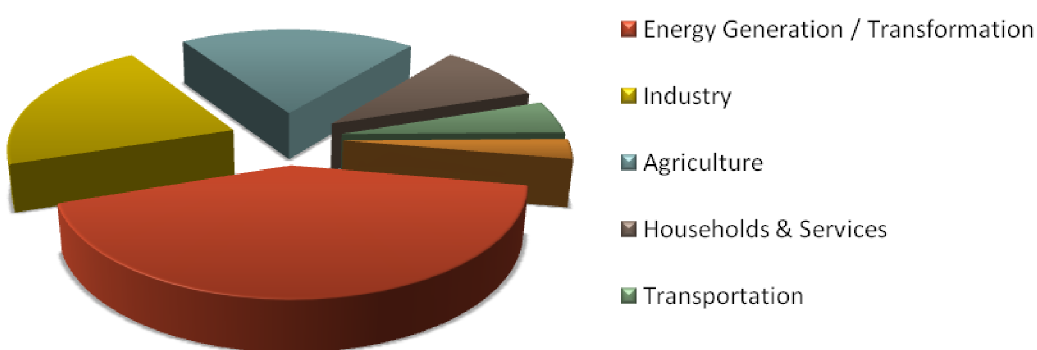

Figure 1: China GHG Emissions by Sector (2005)

Therefore, with focus on electric energy generation in China's power sector, the paramount objective of this study is to *determine the GHG mitigations potential associated with meeting the* *long term electrical energy generation requirements for sustaining China's recent economic growth trends with the comparison of two scenarios over a forecast period of 20 years* beginning with the baseline year 2007. The baseline year of 2007 was chosen due to data constraints; historical data from 1995 to the year 2007 used in trend forecasting, were taken from official government data compiled from the National Bureau of Statistics of China, via the 2008 China Statistical Yearbook [3], and the 2007 China Energy Statistical Yearbook [4].

The two scenarios under consideration in this study consist of the following features:

1) **Reference: Business as Usual (BAU)** scenario in which current trends and modest Chinese government stated targets for electric energy generation continue. In China, emphasis is placed on addition of energy generation capacity in an accelerated and economic manner.

2) **Alternative: Sustainable Development (SD)** scenario in which the development of renewable resources is strongly encouraged. The Chinese government has also set aggressive capacity goals for select renewable energy technologies; goals and assumptions deemed achievable by analysts are incorporated.

The following sections detail the modeling methodology used in forecasting energy demand and supply (transformation), the results obtained pertaining to energy generation, resulting GHG emissions and economic investment associated with either scenario, a discussion on the comparison of scenario results and constraints, followed by conclusions and technical recommendations.

MODEL METHODOLOGY

The software used to perform all forecasting and analysis was LEAP - the Long-range Energy Alternatives Planning system. LEAP is an integrated energy-environment modeling tool designed and maintained by the Stockholm Environment Institute. The methodology incorporated in the software is based in the comprehensive accounting of how energy is consumed, converted and generated in a given region. Essentially, users model both the manner in which energy demand is created and the processes used for transforming and generating the energy required to meet demand. To be noted, LEAP has recently been chosen by 85 countries as the primary modeling tool for climate change mitigation assessments which are to be presented to the United Nations Framework Convention on Climate Change (UNFCCC) [5].

DEMAND INPUTS

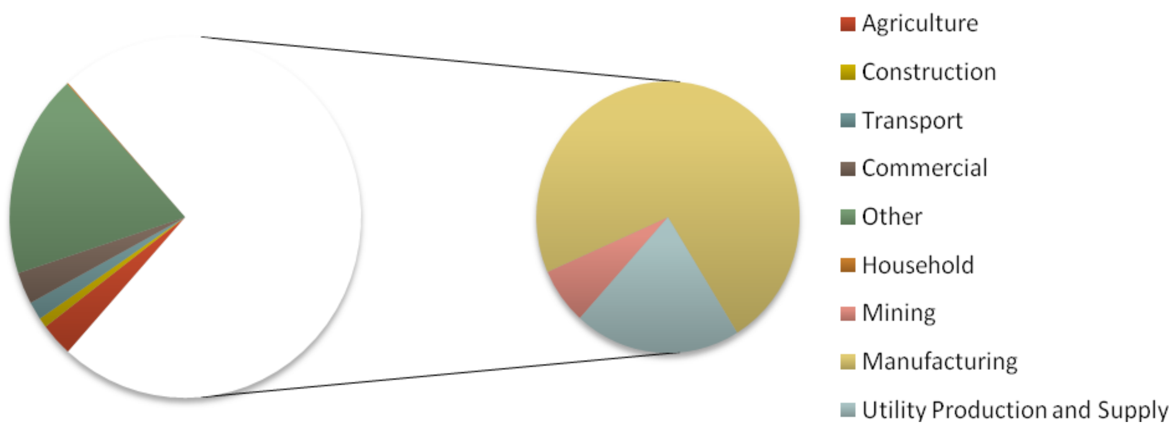

Figure 2: 2007 Baseline electric energy demand break down

Official data was used to provide certainty in the baseline demand data. As seen in Figure 2, 9 main sectors were investigated. Industrial (mining, manufacturing and utility) sectors were further broken down, for a total of 34 individual electric load categories. In the 2007 base year, these loads comprise approximately ¾ of total demand. Within the industrial loads, almost ¾ is due to manufacturing alone.

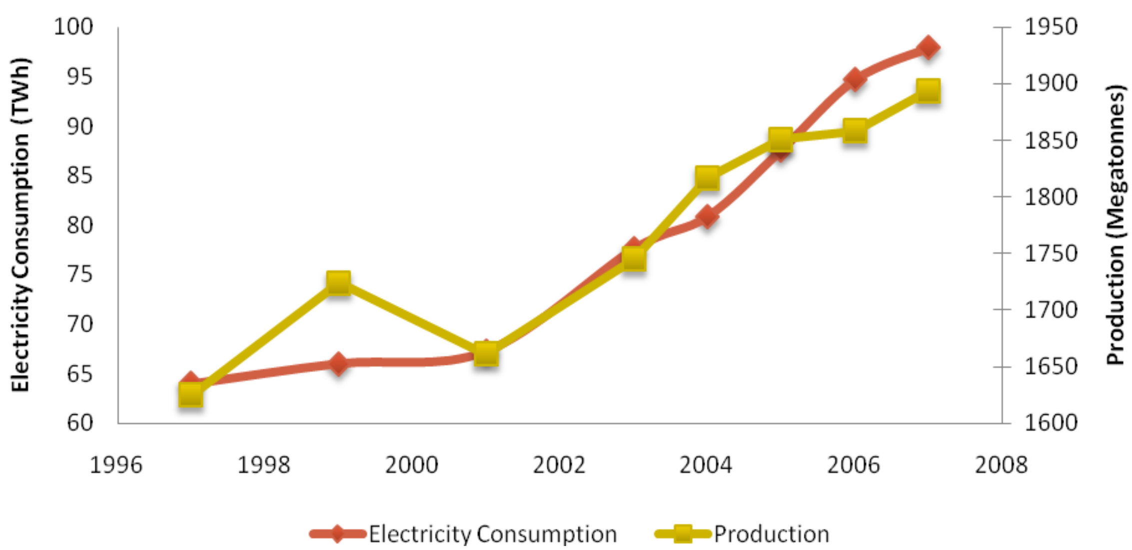

Figure 3: Historical agricultural electricity consumption and production of 15 crops

To extend these loads over the 2007-2027 forecast period, activities were assigned to each individual demand category. For agriculture, the masses of the 15 agricultural crops were selected. The historical correlation between this activity and electricity consumption can be seen in Figure 3. This relationship was used to determine an energy intensity of a particular activity. A complete list of demand category activities is shown in Table 1.

The recent economic growth in China has led to exponential growth in most of the selected activities. This trend is particularly prominent in the construction industry. To model this escalation, the rate of floor space completion has been plotted in Figure 4. Should this exponential growth continue, the already booming construction industry would grow by several orders of magnitude by then end of the 20 year forecast, as demonstrated in Figure 5. This was deemed highly unlikely, if not impossible, due to the inevitable physical, financial, societal and environmental constraints. As such a linear progression for activity growth was preferred.

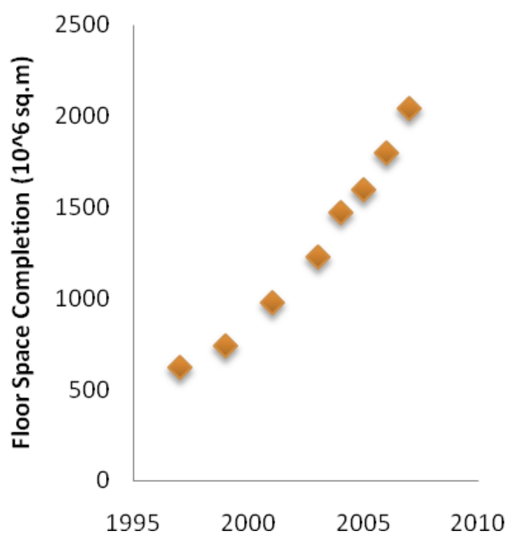

Figure 4: Historical construction sector growth

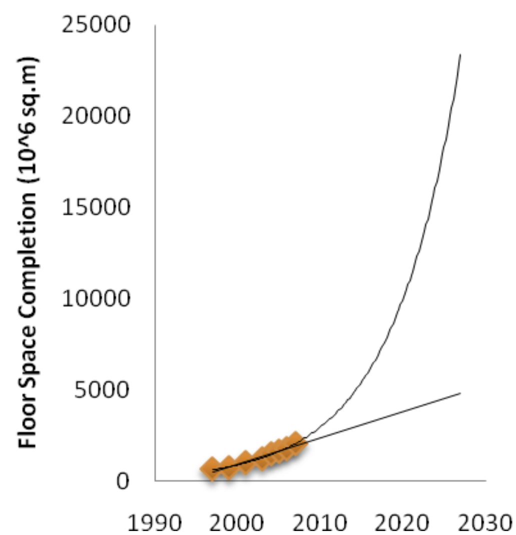

Figure 5: Construction exponential and linear trends

Conversely, a linear development for activity energy intensities was not logical. The historical improvement in energy intensities of chemical fiber manufacturing is shown in Figure 6. If this linear trend was extended over 20 years, the industry would have a negative energy demand per unit production as seen in Figure 7. To prevent this physically impossible measure, an exponential development pattern was selected, to allow for efficiency gains to slow over time.

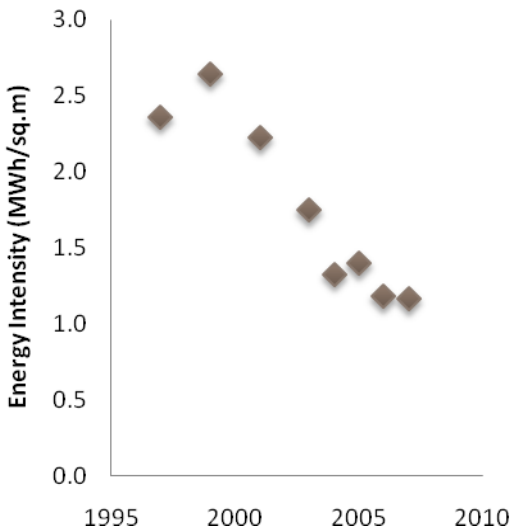

Figure 6: Historical chemical fiber energy intensity

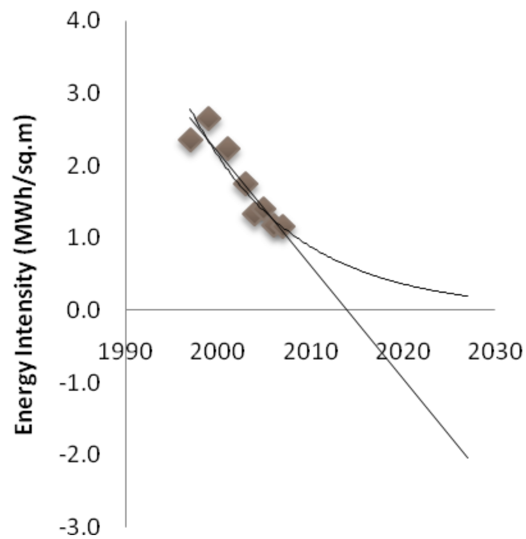

Figure 7: Chemical fiber exponential and linear energy intensity trends

It is important to note that not all categories experience decreasing energy intensity. Notable in Figure 8, household consumption has rapidly increased per capita in recent years. As the Chinese economy expands and poverty rates decline, the middle and upper classes will grow and consume more electricity as shown in Figure 9. Due to the fact that per capita electricity consumption remains orders of magnitude below that of other developed nations, there is no indication that this trend will cease within the 20 year forecast period. Thus energy intensities for all demand categories were exponentially forecasted, regardless of the direction of the trend.

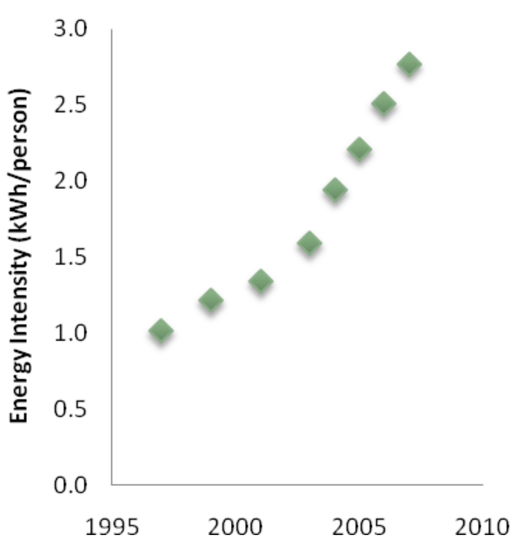

Figure 8: Historical Household Energy Intensity

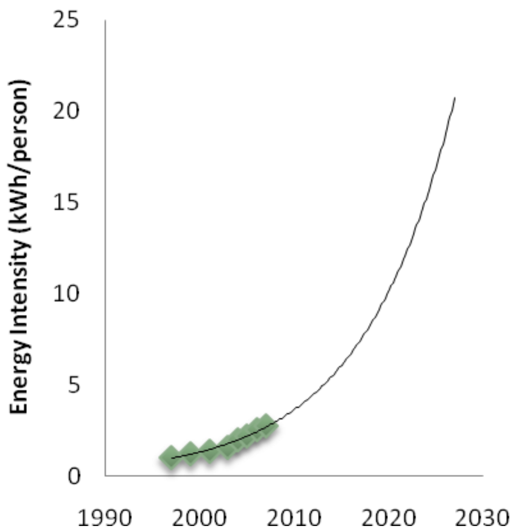

Figure 9: Household Exponential Energy Intensity Trend

The activity and energy intensity trends were combined to produce a resultant forecast for each demand category. By considering both activity growth and efficiency gains, a more nuanced portrayal of future consumption can be forecasted. The transportation sector provides the clearest example of how the 2 individual trends can effect overall demand growth. Figure 10 shows the rapidly increasing transportation loads, along with the electric energy intensity decreasing at a more moderate pace. However, should these trends continue, overall demand would peak within a decade, and begin to fall overtime as seen in Figure 11. This pattern can be attributed to the increasing use of private motor vehicles, which do not rely on electric power.

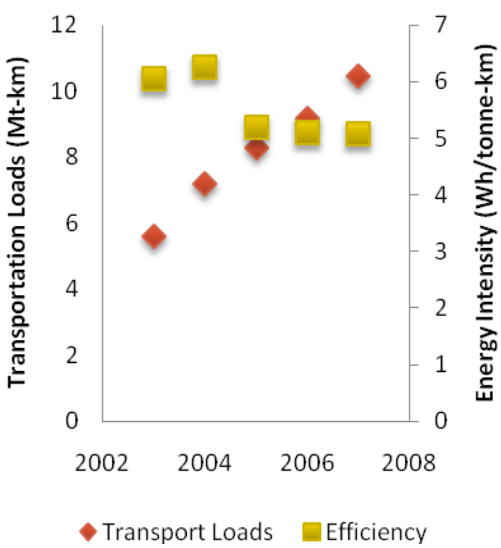

Figure 10: Transportation loads and energy intensity

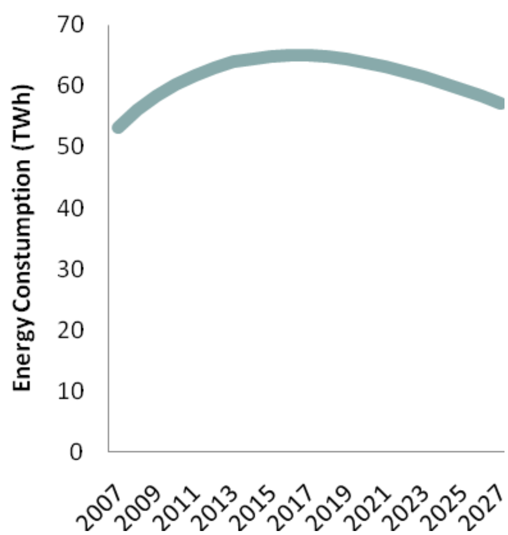

Figure 11: Forecasted transportation demand

While transportation loads are expected to peak, the cumulative trend of the combined 34 demand categories will continue to grow as in Figure 12. From a 2007 baseline consumption of 3271 TWh, it is expected to more than triple to 9912 TWh in 2027. Although there is growth in most categories, the magnitude of the manufacturing sector continues to dominate much of the overall demand, dwarfing many other rapidly growing loads. The uncategorized loads ("Other"), which are believed to increase with the overall economy (as measured by GDP), will also contribute to tremendous growth.

Table 1: Demand side inputs

Demand Category	Activity Measure	Baseline (TWh)
Household	Registered Population	3.6
Tobacco Manufacturing	Cigarette Production	3.7
Gas Production	Gas Production	4.2
Timber Processing	Timber Processing	4.3
Beverages Manufacturing	Beer Production	10.3
Food Manufacturing	Canned Food Production	15.4
Medicine Manufacturing	Medicine Production	17.3
Specialized Machine Manufacturing	Oil Sands and Chemical Industry Machinery	22.0
Municipal Water	Treated Water Production	22.3
Rubber Manufacturing	Synthetic Rubber Production	26.7
Chemical Fibres Manufacturing	Chemical Fibre Production	28.1
Construction	Completed Floor Space	28.7
Ferrous Metal Ore Mining	Steel Production	30.9
Petroleum Extraction	Crude Oil Production	31.5
Food From Raw Agriculture	Salt, Sugar and Vegetable Oil Production	34.1
Other Ore Mining	10 Nonferrous Metal Production	38.0
Plastics Manufacturing	Primary Plastic Production	38.7
Fuel Processing	Crude Oil Production	41.6
Transport Equipment Manufacturing	Motor Vehicle Production	42.4
Paper Manufacturing	Machine-made Paper Production	44.2
General Machinery Manufacturing	Power Generation Equipment Production	45.5
Transport	Passenger and Freight Transport	53.2
Coal Mining and Washing	Coal Production	61.0
Metal Products Manufacturing	Rolled Steel Production	68.7
Electronics Production	Phone, Fax, Computer, Display Production	83.4
Commercial	Retail Sales of Consumer Goods	93.0
Agriculture	Top 15 Agricultural Crop Production	97.9
Textiles and Apparel	Cloth Production	134.3
Non Metallic Mineral Products	5 Non Metallic Mineral Production	188.5
Non Ferrous Metal Manufacturing	10 Nonferrous Metals Production	243.5
Chemical Manufacturing	Chemical Fertilizer and Pesticide	282.1
Ferrous Metal Manufacturing	Pig Iron and Crude Steel Production	371.7
Electric Power and Heat	Coal Production	464.2
Other	Gross Domestic Product	595.9

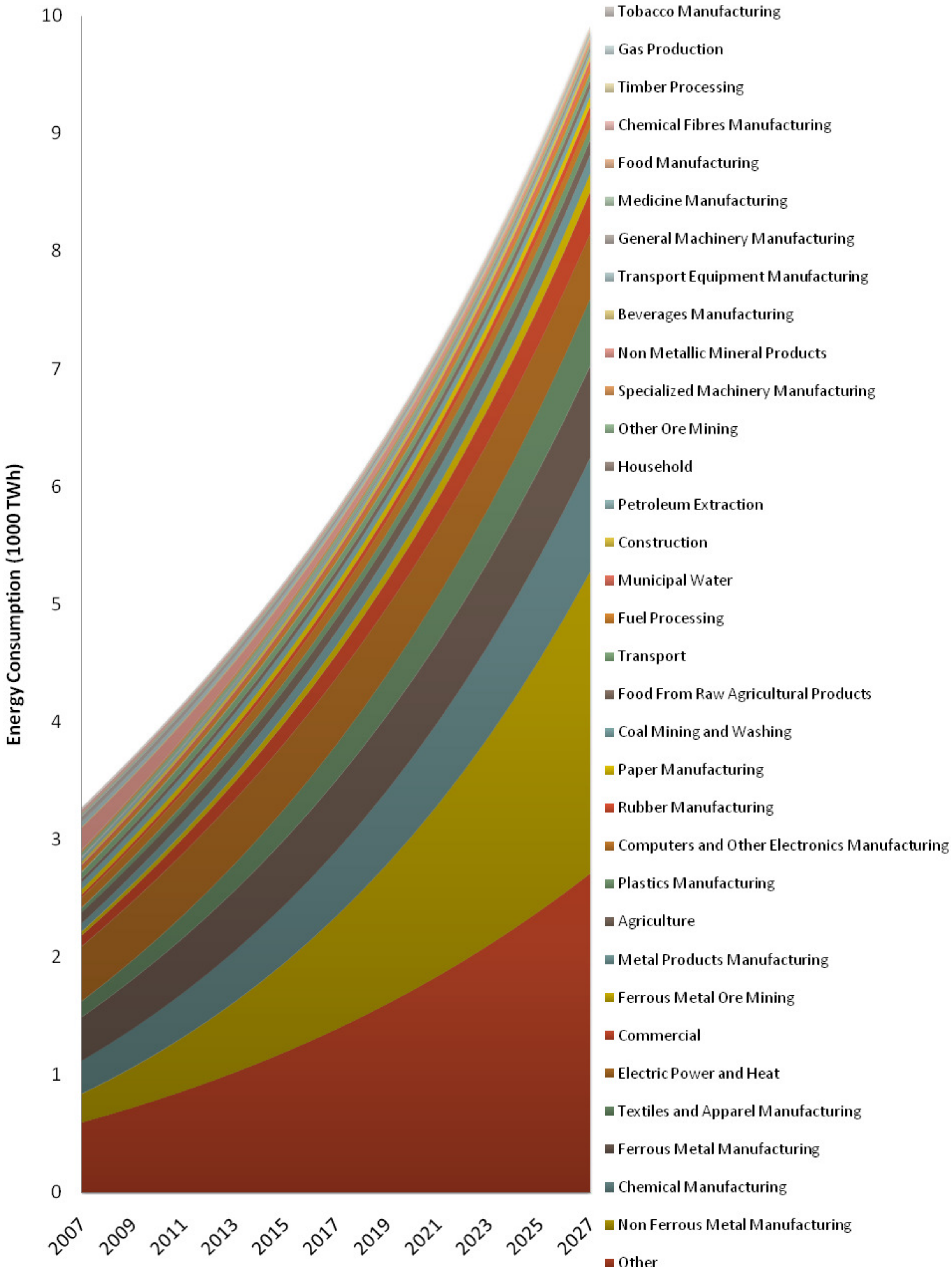
Energy Consumption (1000 TWh)
10
9
8
7
6
5
4
3
2
1
0
2007
2009
2011
2013
2015
2017
2019
2021
2023
2025
2027
Tobacco Manufacturing
Gas Production
Timber Processing
Chemical Fibres Manufacturing
Food Manufacturing
Medicine Manufacturing
General Machinery Manufacturing
Transport Equipment Manufacturing
Beverages Manufacturing
Non Metallic Mineral Products
Specialized Machinery Manufacturing
Other Ore Mining
Household
Petroleum Extraction
Construction
Municipal Water
Fuel Processing
Transport
Food From Raw Agricultural Products
Coal Mining and Washing
Paper Manufacturing
Rubber Manufacturing
Computers and Other Electronics Manufacturing
Plastics Manufacturing
Agriculture
Metal Products Manufacturing
Ferrous Metal Ore Mining
Commercial
Electric Power and Heat
Textiles and Apparel Manufacturing
Ferrous Metal Manufacturing
Chemical Manufacturing
Non Ferrous Metal Manufacturing
Other

Figure 12: 20 Year electric load forecast by demand category

ENERGY RESOURCE SUPPLY

In order to accurately input China's 2007 electric energy generation and capacity, all existing energy resource alternatives were considered. These consist of coal, oil, natural gas and biomass fired power facilities as well as hydroelectric, nuclear, wind, solar photovoltaic (PV), solar thermal and oceanic power facilities. All historical data on primary energy generation sources (coal, oil, natural gas, hydroelectric, nuclear, wind) were taken from the 2007 China Energy Statistical Yearbook [3] while 2007 capacity data for solar was taken from the World Wildlife Foundation [6]. Data on biomass power data was taken from China Holdings [7].Table 2 shows the 2007 base year energy resource alternatives data used as process inputs for LEAP's process share, efficiency and historical production requirements. Capacity factors and thermal efficiencies are based on general technologies and are the authors' assumptions.

Table 2: 2007 energy generation model input data

Process	Renewable (Y/N)	2007 Inst. Capacity (MW)	2007 Generation (TWh)	2007 Process Share	Capacity Factor	Thermal Efficiency
Coal	N	506,796.20	3,244.20	81.59%	79%	33%
Crude Oil & Variants	N	10,437.22	66.80	1.68%	79%	35%
Natural Gas	N	11,577.40	56.30	1.42%	60%	38%
Hydroelectric	Y	149,716.49	486.10	12.22%	37%	95%
Nuclear	Y	10,132.19	62.20	1.56%	70%	32%
Wind	Y	12,110.57	58.90	1.48%	30%	35%
Solar PV	Y	80.00	0.60	0.02%	18%	22%
Solar Thermal	Y	0.00	0.00	0.00%	23%	22%
Tidal & Wave	Y	6.12	0.00	0.00%	35%	80%
Biomass	Y	150.00	1.20	0.03%	60%	35%
Total / *AVG.*	***n/a***	**701,006**	**3,976**	**100%**	***49%***	***43%***

One sees that 10 energy generation resource alternatives were considered; in China as of 2007, it is clear that coal was the dominant source of electricity generation at 81.6% generation process share, followed by hydroelectric power at 12.2%. Other renewable energies consisting of nuclear, wind, solar, ocean and biomass power constitute a cumulative process share of 3.1% while other fossil fuel power sources, oil & natural gas also make up 3.1%. It is clear that the thermal power and hydroelectric sources have the greatest capacity factors while hydroelectric and ocean sources possess the greatest thermal efficiencies. It should be noted that solar power, with its technological immaturity, still suffers from the lowest capacity factor and thermal efficiency of all sources. Figure 13 graphically shows energy generation by process share. The expanded portion of the figure represents other renewable energies which consists of wind, solar PV, solar thermal, ocean and biomass power sources.

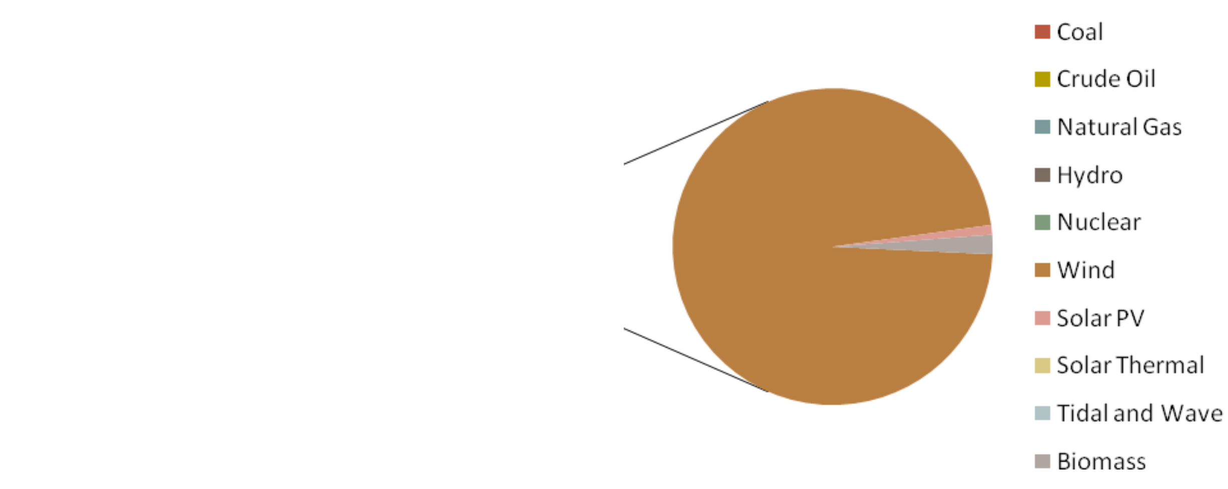

Figure 13: 2007 Chinese energy generation break-down by process share

SUPPLY SCENARIOS - FORECASTING INSTALLED CAPACITY

Once the 2007 base line was established in LEAP, the exogenous capacity forecasts by process were entered for both the Business as Usual (BAU) and Sustainable Development (SD) scenarios. Table 3 holds the forecast data, function type, and assigned merit order for each process under either scenario. All power supply forecasts were based on expected installed power capacities (MW) at certain points in time during the 20 year forecast period. The most significant elements of the forecasting methodology have to do with capacity growth in coal fired and hydroelectric power. In both scenarios, coal fired power capacity was forecasted based solely on historical trends in the years 2000 to 2007 and the fit used in each case was linear. This is because, although there are no released targets for future coal fired generation or capacity, the technology will be heavily relied upon as needed to meet the rapid, but uncertain demand growth. All other historical trend line fits were based on capacity data for the years 1995 to 2007. BAU hydroelectric capacity was forecasted based on historical data while SD hydroelectric capacity was based on extremely aggressive Chinese governmental goals; the forecast inherently exploits China's full potential of 400 GW of hydroelectric power by 2030.

Table 3: Assigned growth trends and merit orders for BAU and SD scenarios (* refers to author's assumption)

Energy Generation Resource	Business as Usual (BAU) Growth Trends	BAU Merit Order	SRC	Sustainable Development (SD) Growth Trends	SRC	SD Merit Order
Coal	Line of Best Fit, Linear	1	[4]	Line of Best Fit, Linear	[8]	4
Crude Oil & Variants	Line of Best Fit, Linear	5	[4]	Smooth decay to 5.2 GW by 2015, continuous	*	5
Natural Gas	Line of Best Fit, Exponential	4	[4]	Maximum at 60 GW by 2020, level afterwards	[9]	3
Hydroelectric	Line of Best Fit, Linear	1	[4]	180 GW (2010), 300 GW (2020), smooth incr.	[10]	1
Nuclear	Line of Best Fit, Linear	1	[4]	114 GW (2015), 205 GW (2020), smooth incr.	[11]	1
Wind	30 GW by 2020, linear	2	[8]	Add 250 GW by 2025, smooth incr.	*	1
Solar PV	1.5 GW by 2020, linear	2	[8]	1 GW (2010), 25 GW (2020), smooth incr.	[10]	1
Solar Thermal	300 MW by 2020, linear	2	[8]	1 GW (2014), linear	*	1
Tidal & Wave	Add 1.8 MW every 3 years, linear	2	*	12 MW by 2012, linear	*	1
Biomass	30 GW by 2020, linear	3	[8]	30 GW by 2020, linear	[8]	2

There are notable assumptions in forecasting oil fired, wind and solar thermal capacities over the years 2008 to 2027. Heavy pollutant oil fired power was assumed to decay to half of 2007 installed capacity by 2015 parabolically with the trend continuing to 2027. China has the potential to exploit 1000 GW of wind power via onshore and offshore means; as such, it was assumed that China will install 250 GW of wind power by 2025 - 72.5 GW on shore and 177.5 GW off shore. Moreover, the average capacity of a solar thermal plant in China is approximately 375 MW and therefore, with aggressive renewable energy policy, China could install 3 solar thermal plants by the year 2014 with the trend continuing linearly.

In LEAP, merit order refers to the manner in which processes are dispatched as energy demand loads peak. In the BAU scenario, the merit order reflects the assigned dispatch rules currently employed by the Chinese government in which base loads are met using coal, hydroelectric and nuclear power. Biomass, natural gas and oil fired power are the last generation alternatives to be dispatched, as they have higher incremental costs. In the SD scenario, the authors assume that all non-emitting renewable sources are dispatched first followed by biomass and fossil fuel fired power during peak loads.

The resulting forecasted capacity mix over the period 2007 to 2027 for the Business as Usual (BAU) scenario is shown in Figure 14. As expected, coal and hydropower continue to dominate installed capacity over the forecast period. We also see the increased capacity related to natural gas, nuclear, wind and biomass fired power. The gross installed power capacity increases by a factor of 2.75 from 701 GW in 2007 to 1,935 GW in 2027. In 2027, fossil fuels make up 74.5% (70.5% coal) of installed capacity while renewable energy constitutes the remaining 25.5% (19.6% hydro).

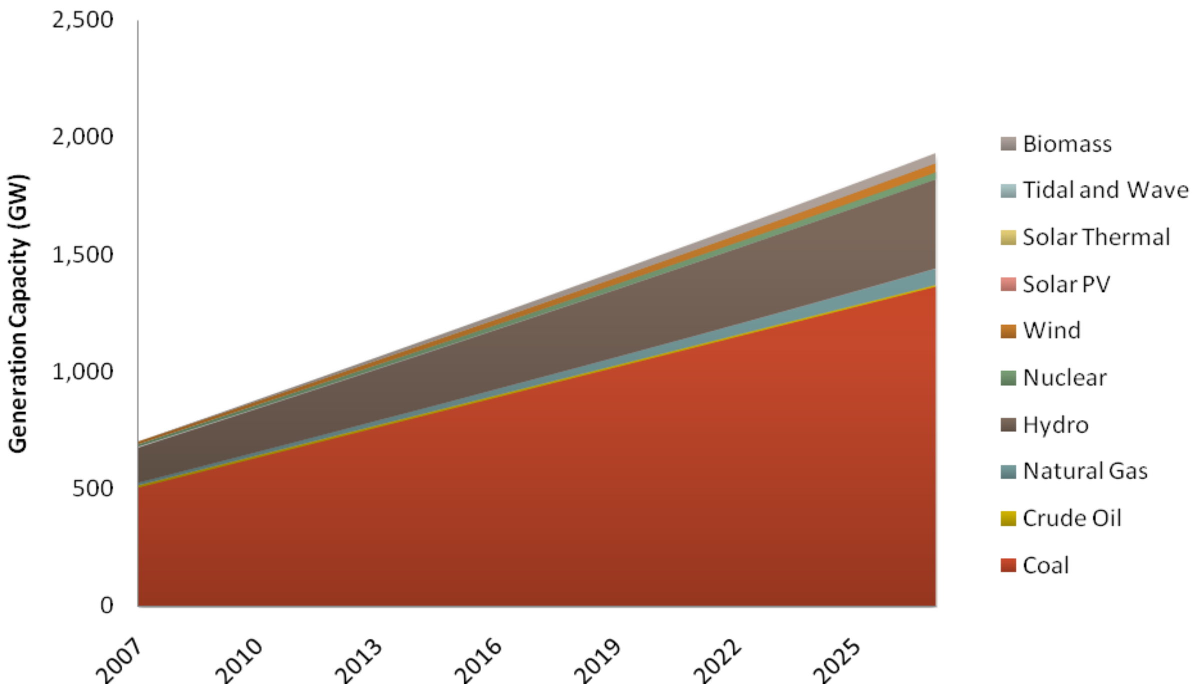

Figure 14: Business As Usual capacity 2007 - 2027

The resulting forecasted capacity mix over the period 2007 to 2027 for the Sustainable Development (SD) scenario is shown in Figure 15. In this scenario, we note the heavily increased use of renewable power sources but note that coal fired power remains dominant. We see that the use of wind and nuclear power is greatly increased while solar PV begins to play a meaningful role. The resulting capacity mix can be seen to be greatly diversified. The gross installed power capacity increases by a factor of 3.6 from 701 GW in 2007 to 2,518 GW in 2027.

In 2027, fossil fuels make up 56.6% (54.1% coal) of installed capacity while renewable energy constitutes the remaining 43.4% (15.9% hydro, 10.7% nuclear, 12.5% wind).

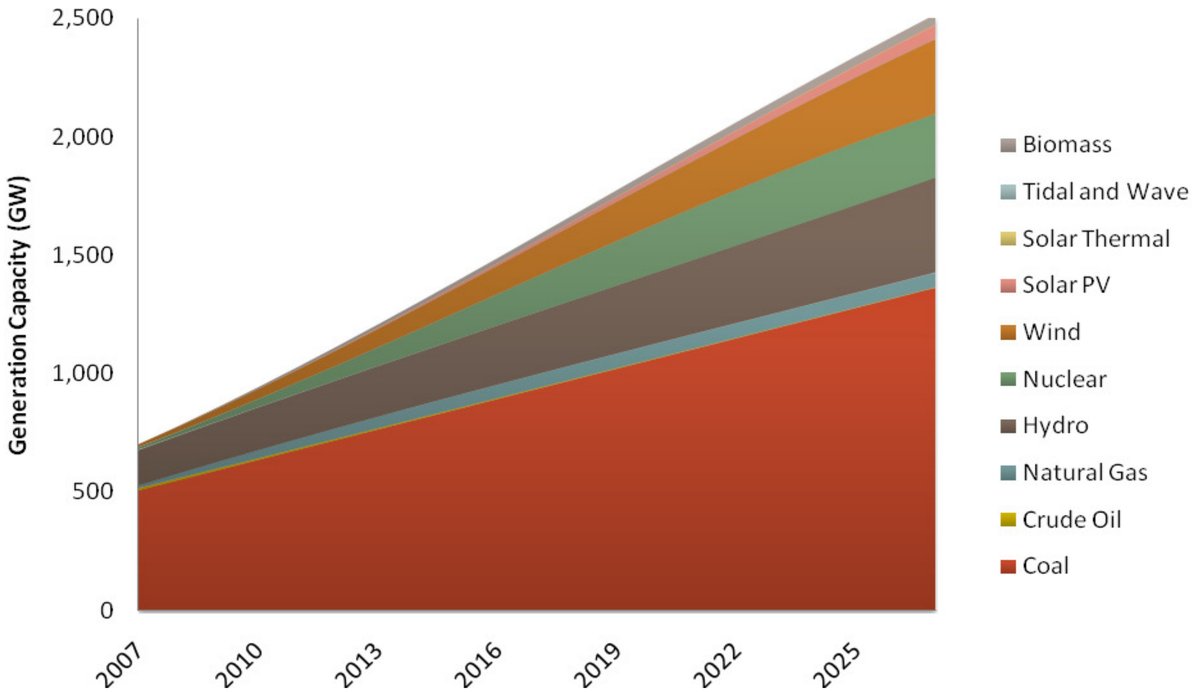

Figure 15: Sustainable Development capacity 2007 - 2027

RESULTS

In order to forecast resultant GHG mitigations via comparison of the BAU and SD scenarios, the results and implications of the energy generation forecasts for either scenario must first be analyzed. For both scenarios, the transmission and distribution losses were assumed to decay linearly from 14% in 2007 to 11% in 2027 due to technological improvements. The results of each scenario show that gross energy generation will finalize at 11,070TWh in the year 2027; the quantity required to meet projected Chinese demand.

ENERGY GENERATION

Figure 16 shows the resultant energy generation mix in the Business as Usual (BAU) scenario. Here, we note that coal fired and hydroelectric power continues to dominate China's power sector similar to today's trends. The energy generated in 2027 is 11,070TWh, a factor of 2.78

increase over generation of 3,980TWh in 2007. In 2027, fossil fuels make up 76.4% of generation (100% coal) while renewable energy constitute the remaining 23.6% (21.2% hydro).

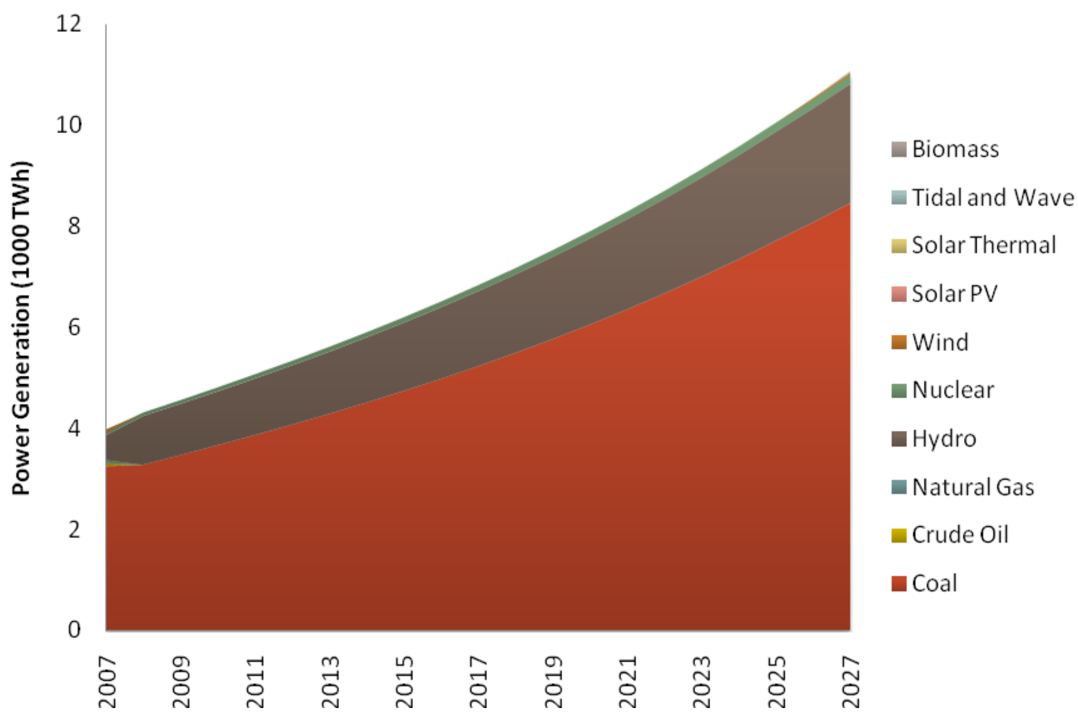

Figure 16: Business As Usual generation 2007 - 2027

The resultant energy generation mix forecast for the Sustainable Development (SD) is presented in Figure 16. In this case, the energy mix is almost immediately diversified due to the increased capacities of renewable sources and the difference in process merit order. As in the BAU scenario, the energy generated in 2027 is 11,070TWh; the energy required to meet forecasted demand. There are significant decreases in coal fired energy generation while hydro, nuclear and wind begin to dominate and the use of solar photovoltaic energy increases modestly. In 2027, fossil fuels make up 21.2% of the energy mix (18.5% coal, 2.7% natural gas) while renewables constitute the large remainder of 78.8% with a breakdown of 29.3% hydroelectric, 19.8% nuclear, 23.1% wind, 4.5% solar PV and 1.9% biomass fired power. This is a dramatic shift from the BAU scenario generation but is expected according to newly drawn governmental policies and goals.

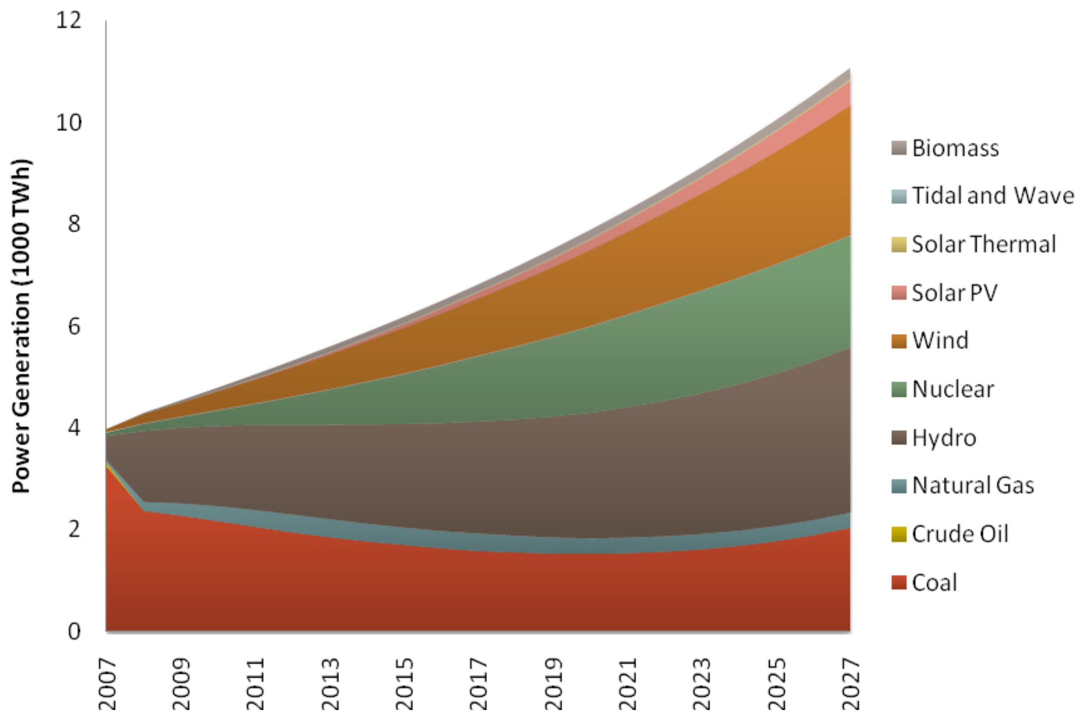

Figure 17: Sustainable Development generation 2007 - 2027

GHG EMISSIONS

Based on the resulting energy generation forecasts, GHG emissions were calculated in LEAP using IPCC Tier 1 Emission Factors. The generation sources which have associated emission factors are coal, oil, natural gas and biomass. Figure 18 shows the forecasted GHG emissions associated with both the BAU and SD scenarios; the solid black line represents net emissions arising from China's power sector in the 2007 base year.

In the BAU scenario, the forecast indicates power sector GHG emissions will rise sharply over the 20 year forecast period eventually surpassing China's National 2007 GHG emissions level (7,527 Mt CO_{2e}) in the year 2024 and the 2007 US National GHG emissions level (7,282 Mt CO_{2e}) in 2023. This is an alarming result which indicates that in the case China continues current practices, increased climate change effects will be realized globally much earlier than predicted. In 2027, power sector GHG emission levels reach 8,591 Mt CO_{2e}; an increase of 155% relative to 2007 levels. This substantial increase is almost entirely related to the continued dependence on coal fired energy generation.

With reference to the SD scenario, an immediate reduction in GHG emissions levels is expected due to the significant decrease in reliance on coal fired power. In this instance, minimal GHG emissions levels of 1,564 Mt occur in the year 2020 representing a 53% decrease relative to 2007 levels. This minimum is realized due to the saturation of renewable source exploitation. In 2027, emissions levels terminate at 2,241 Mt representing a 34% decrease relative to 2007 levels; which is potentially achievable if immediate steps are taken to increase the aforementioned renewable energy capacities in accordance with existing governmental goals.

The cumulative 2007 to 2027 emissions associated with the BAU scenario are 116,063 Mt CO_{2e} while this value is 43,523 Mt CO_{2e} in the SD scenario. By difference, the net GHG mitigations potential between 2007 and 2027 in China's power sector is 72,540 Mt CO_{2e}. The economic investment associated with this GHG mitigation potential is discussed in later sections.

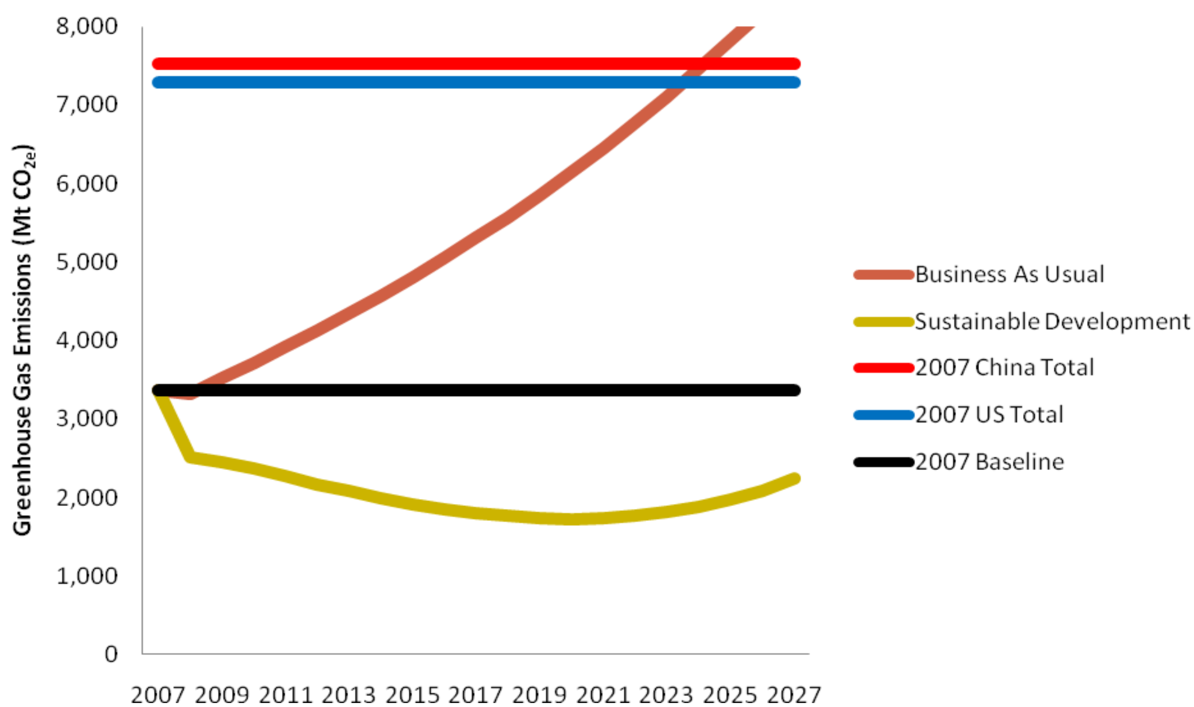

Figure 18: Power sector GHG emissions forecast comparison of BAU and SD scenarios relative to 2007 levels

DISCUSSION

With electric loads projected to increase three fold over 20 years, the implications will be drastic. The effects will be met with the need to make difficult decisions on domestic issues. This will be further complicated by the demands of the international community.

ECONOMICS

The rate at which power consumption is anticipated to grow will require substantial costs to simply meet demand. An understanding of the additional investment to implement the Sustainable Development scenario is needed to justify the expenditure. The economics of the power industry in any region is complex, but the uncertainty is escalated in a nation experiencing a transformation such as China. The sheer scale (in terms of energy demand, time period, geography, demographics, etc) required of such a study is exacerbated by the rate of development. A volatile international energy market, combined with increased domestic market deregulation, provides additional ambiguity. Thus, a detailed economic study is beyond the scope of this study.

A brief economic analysis was prepared, leveraging previous reports, only to provide a sense of magnitude, and not an accurate portrayal of financial costs. The energy cost assumptions used, are compiled in Table 4. Coal, natural gas and nuclear power generation estimates are from a China specific study. A broader price range was selected for the significant renewable energy sources to account for increased uncertainty, as the values are not directly applicable to China. A high and low cost estimate was calculated, with the range plotted in Figure 19, in US dollars.

Table 4: Energy production cost assumptions

Fuel	Low ($/kWh)	High ($/kWh)	Source
Coal	0.022	0.030	[12]
Crude Oil	0.054	0.054	[12]
Natural Gas	0.023	0.035	[12]
Hydro	0.080	0.150	[10]
Nuclear	0.047	0.081	[13]
Wind	0.060	0.120	[10]
Solar PV	0.250	0.500	[10]
Solar Thermal	0.060	0.240	[10]
Tidal Wave	0.080	0.080	[14]
Biomass	0.050	0.120	[10]

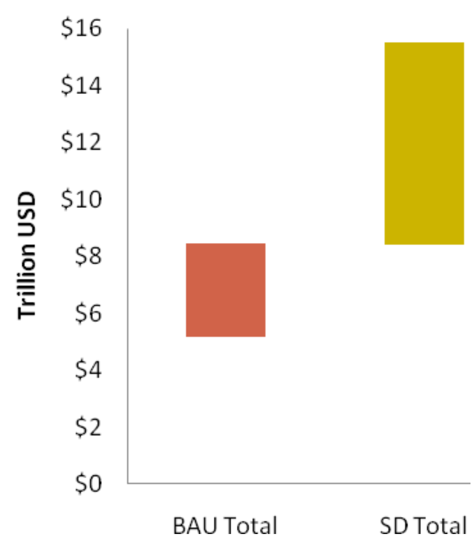

Figure 19: 20 Year cumulative scenario costs

At both extremes, the Sustainable Development scenario costs are much greater than that of the Business as Usual case. The Business as Usual case ranges from $5.1 - 8.4 trillion over 20 years, while the Sustainable Development model is from $8.4 - 15.5 trillion. This leads to a cost premium to implement the Sustainable Development supply technologies of between 65%-85%.

These overall costs were further broken down in Figure 20 and Figure 21. The average energy costs are low, in part due the lower cost of operation in China, with the upper end of the Sustainable Development scenario costs are $0.10/kWh. This is reasonable in comparison with Albertan costs, where regulated residential rates have varied from $0.07-$0.12/kWh [15], from May 2008-April 2009.

The 20 year cost premium is divided by the cumulative emissions offset, to determine the mitigation costs in Figure 21. The calculated costs of $45-$99/t CO_{2e} are compared to implemented and proposed mitigation costs in Canada. The Federal Technology Fund, a part of the Turning the Corner GHG mitigation policy is available to industries which exceed the maximum allotted GHG emissions. Industries have the option of by passing the provincial carbon trading market, by contributing to the Technology Fund at a rate of $20/t CO_{2e} by 2013, effectively placing an upper cap on the market prices [16]. During the 2008 Canadian federal election, the Liberal Party proposed in its Green Shift tax restricting policy, to gradually implement a $42/t CO_{2e} [17]. While neither of these policies (should they be implemented to China) would be sufficient to execute the Sustainable Development alternative scenario on their own, these results are within the same order of magnitude.

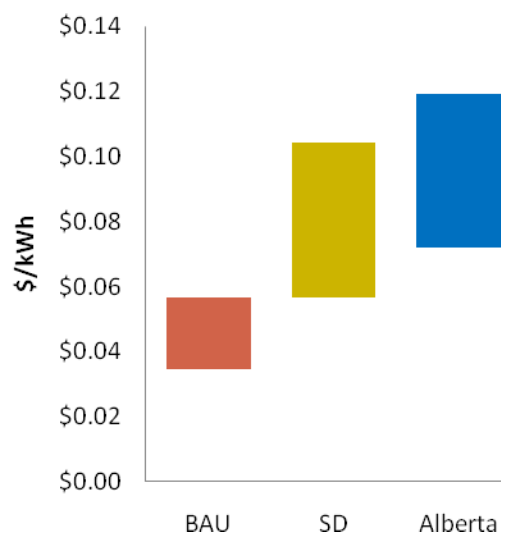

Figure 20: Scenario costs per unit energy

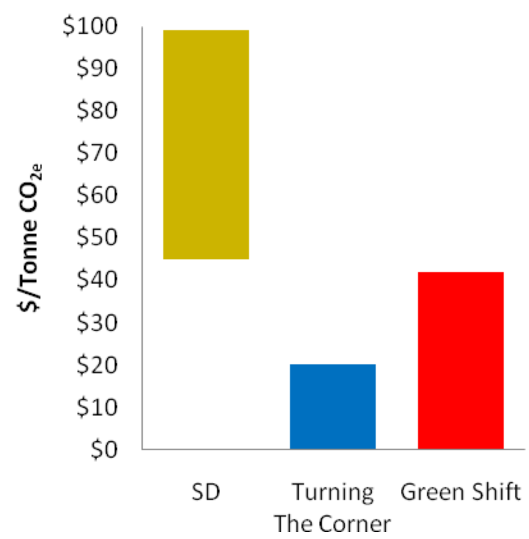

Figure 21: Mitigation costs of various plans

DEMAND SIDE MANAGEMENT

It could be argued that a demand side management (DSM) approach is a more appropriate strategy to manage greenhouse gas emissions growth. Forecasting studies utilizing the LEAP model often implement DSM in conjunction with supply side management techniques. However, in reality, it is much more difficult to predict the effect of DSM measures.

When consumers realize a financial benefit of efficiency gains, the measures are prone to a “rebound effect”. Additional disposable income can simply lead to increased activity. For example, a more fuel efficient vehicle may consume less fuel per kilometer; however the cost savings would encourage increased overall driving distances. Low incremental costs can remove a psychological barrier limiting consumption, and could result in increased overall energy use.

Other circumstances may prompt a direct compensation in energy consumption. Increased efficiencies within indoor appliances in heated environments, such as northern and western China, would reduce thermal heat losses to heated spaces. These energy savings would be met with increased space heating requirements. Although overall energy demand may be lower, it proves to complicate the estimation of efficiency gains of specific measures.

Additionally, China continues to consume energy at substantially lower rates than other developed nations. Government subsidized energy costs are actually used to promote consumption, in an effort to increase standards of living. The removal of these subsidies may be the most effective DSM technique to reduce consumption; however the overall social cost may not be justified. Environmental benefits may also not be realized as lower cost, more carbon intensive fuels may be substituted. For example, electric heating or cooking, fuelled partially from renewable resources, could be replaced with low grade fossil fuels, such as kerosene or charcoal, and without the environmental controls of a commercial power plant.

DSM can be successful and should be utilized; however it is much more nuanced than is often reported. In a national scale study, with electric loads fragmented into such diverse sectors, any efficiency gains would either be arbitrary (across the board reductions), incomplete (not considering residual effects), or justify an intensive study in and of itself. To achieve the medium term, large scale reductions greenhouse gas emissions sought in this study, supply side controls are much more effective.

OTHER IMPLICATIONS

Beyond greenhouse gas emissions, there are other serious repercussions of a dramatic rise in energy consumption in China. Regional air pollution is already at visibly high levels. Jet streams deposit mercury from coal fired plants across the Pacific Ocean, up to the Canadian arctic. The rapid hydroelectric development in either scenario presented in this study, will displace millions of people, and flood valuable agricultural land.

Compared to the political leadership of most other major industrialized nations, the Chinese government does hold greater leverage. Although Chinese citizens as a whole are relatively impoverished, the cumulative productivity has allowed the central government to amass substantial wealth. There is also greater political stability which can allow for more substantial long term investments, which may not be possible with governments democratically elected in short intervals.

However, despite the political stability, and almost certain growth, there will remain significant uncertainty. This was recently highlighted by the prolonging of a moratorium on new coal mining licenses until 2011. Lower than anticipated demand for coal has created glut in the market for coal. There can be considerable ambiguity, even in short term forecasts.

CONCLUSIONS

The Long Range Energy Alternatives Planning system - LEAP was used to forecast the increased energy generation resource capacity mix, generation mix, and resulting GHG emissions over the time period 2008 to 2027 from a baseline year of 2007 in an effort to gain insight into possible GHG mitigations potential in China's power sector. This was done via comparison of two distinct scenarios: a Business as Usual (BAU) scenario and a Sustainable Development (SD) scenario in which the increased use of renewable energy generation sources is aggressively encouraged. In each scenario, gross energy generation was forecasted such that the forecasted electric energy demand was satisfied after accounting for transmission and distribution losses.

In order to achieve energy generation forecast outputs, energy resource alternative yearly installed capacity forecasts were used to establish the energy generation potential associated with each of the considered alternatives over the 20 year period. Figure 22 shows the 2007 power capacity mix as well as the final forecasted 2027 BAU and SD capacity mixes by generation source. China's total installed generation capacity in 2007 was 701 GW being 75.4% fossil fuels; in the 2027 BAU scenario the required capacity was found to be 1,935 GW while the installed 2027 SD capacity was forecasted to be 2,518 GW. The discrepancy is simply due to the sustained reliance on fossil fuel sources in the BAU scenario and the increased installation of renewable generation capacity in the SD scenario. In the BAU scenario, fossil fuels constitute 74% of capacity while renewables make up the remaining 26% in 2027. The SD scenario reflects the increased use of renewable source capacities at 44% of the 2027 mix.

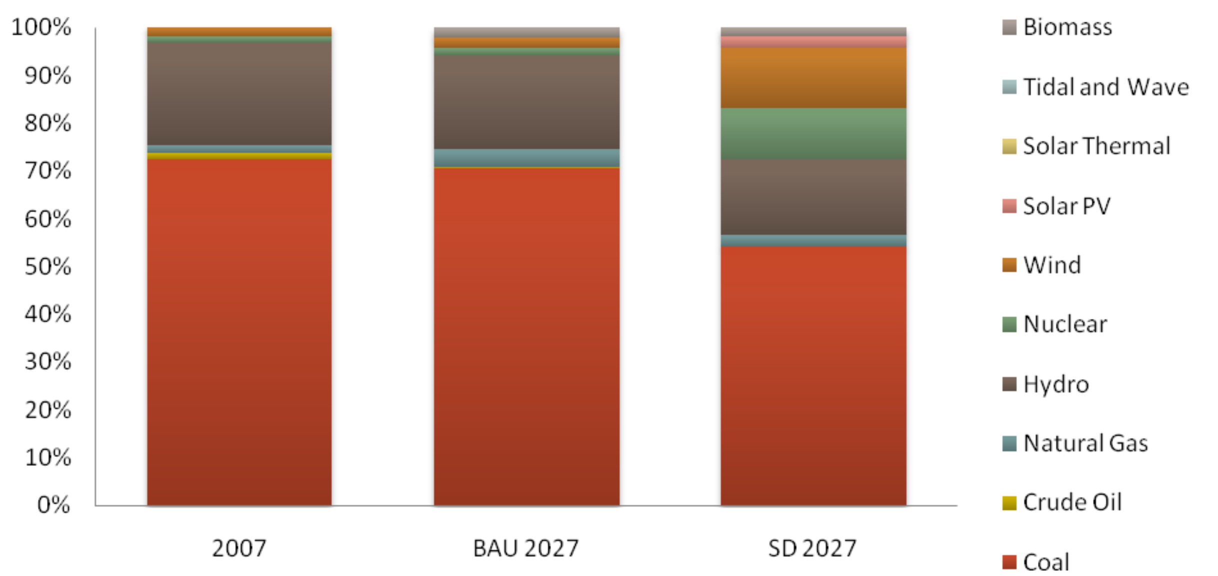

Figure 22: Variation of installed power capacity mix in 2027 BAU and SD scenarios relative to 2007

The resulting electric energy generation required to meet forecasted demand in 2027 was found to be 11,070TWh; a threefold increase from the 2007 net generation of 3,976TWh. The 2027 BAU and SD energy generation mixes are shown relative to the 2007 mix in Figure 23. We note that in the BAU scenario, coal fired energy decreases from 82.5% in 2007 to 76.4% in 2027 with renewable energy sources eventually constituting 24% of energy generation in 2027. In the SD scenario, coal fired power is substantially decreased to 18.5% while renewable energy make up 78.8% of the 2027 energy mix, mainly due to the increased use of hydro, nuclear, wind and, to a lesser extent, solar PV energy.

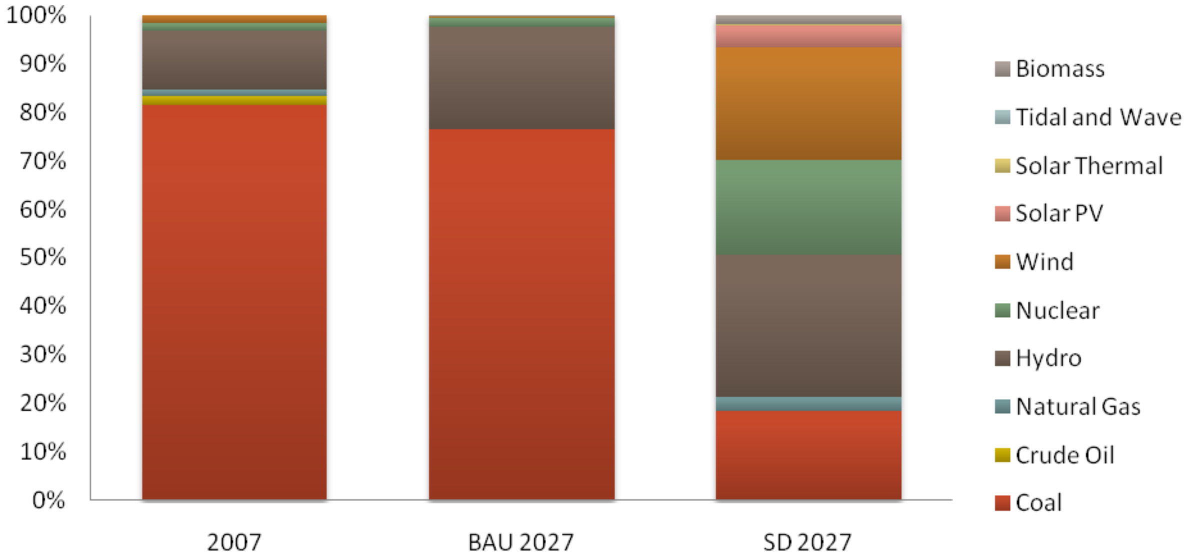

Figure 23: Variation of power generation technologies in 2027 BAU and SD scenarios relative to 2007

The paramount objective of this work was to study GHG mitigations potential in China's power sector. Based on the forecasted energy demand and resulting energy generation mix in both the BAU and SD scenarios we make the following conclusions relative to 2007 Chinese power sector emissions levels of 3,374 Mt CO_{2e}:

- Due to the increased use of coal fired energy generation in the BAU scenario, emissions levels of 8,591 Mt CO_{2e} are realized in the year 2027. This represents an increase of 155% relative to 2007 levels.

- The SD scenario exploits renewable energy potential in China's power sector to a large degree, thus decreasing the use of fossil fuels significantly; this results in 2027 emissions levels of 2,241 Mt CO_{2e}, a decrease of 34% relative to 2007 levels.

- Over the 20 year forecast period, the BAU and SD scenarios deliver net cumulative GHG emissions of 116,062 and 43,523 Mt CO_{2e}, respectively. Therefore, the resulting GHG mitigations potential in China's power sector is 72,539 Mt CO_{2e} during the 2007 to 2027 period of study. This is depicted in Figure 24 below.

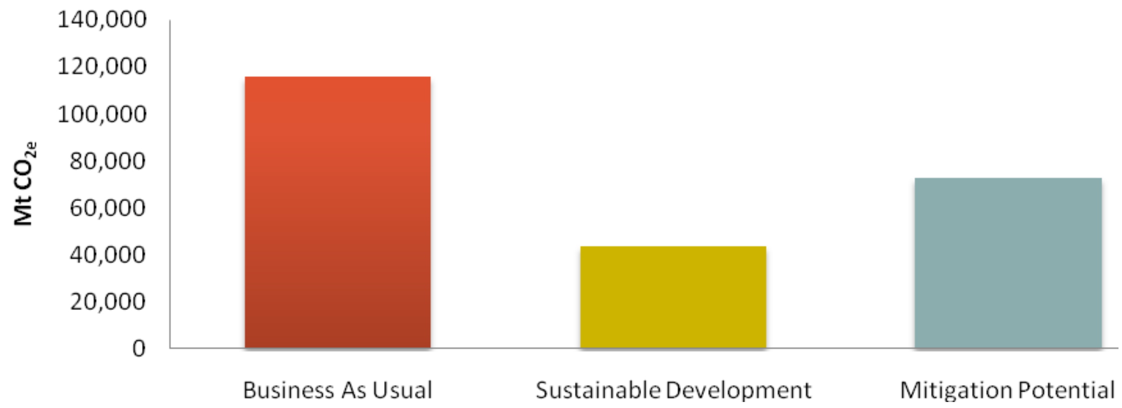

Figure 24: Cumulative GHG emissions levels in the BAU and SD scenarios over 20 years

The aggressive proposal in the SD scenario requires significant financial investment. While the 20 year costs are likely to be measured in the trillions of USD in either scenario, the premium required to achieve these mitigation potentials may be in the range of 65%-85%. This is projected to be higher than what would be economically justified by current policies. However, as the mitigation costs are in the same order of magnitude as those established by Canadian GHG policies, implementation of the SD scenario may be achievable in the near future, as the international urgency to manage the effects of climate change increases.

TECHNICAL RECOMMENDATIONS

Energy sector forecasting could continually be improved upon. Over the 20 year forecast period, it is almost certain that technological gains will be made regarding the power generation industry. Supply side technologies, such as large scale carbon sequestration, or demand side effects from wide spread use of electric vehicles could potentially reverberate throughout the industry. Currently non-commercial technologies should be considered in long term forecasts.

Specific resource capacities and anticipated demand studies could be incorporated. The current demand side model does not include provisions for exhaustion of resources (ie. minerals). Individual analyst reports on each activity could be utilized rather than simply extrapolating historical trends.

Time permitting, cited data should be further investigated. Particularly due to the fact that much official data available has been translated, or recited by third party sources, it is difficult to fully understand the methodology in obtaining the values. Factors such as reserve margins, thermal efficiencies, transmission losses, capacity factors, and onsite consumption are often difficult to obtain. While a language barrier may play a role, documentation is also not as thorough as other official data sources, such as Statistics Canada.

Further perspective could also be provided in interpreting these results. A thorough economic analysis could provide greater accuracy in estimating GHG mitigation costs. The magnitude of GHG's could also be framed in a manner which relates to realized environmental damage. This could be in the form of potential sea level rise or temperature increases.

REFFERENCES

[1] Beauregard-Tellier F. Electricity Production in China: Prospects and Global Environmental Effects. Government of Canada, Library of Parliament 2007. PRB 07-04E.

[2] Leggett J, Logan J, Mackey A. China's Greenhouse Gas Emissions and Mitigation Policies. United States CRS Report for Congress 2008. RJ34659.

[3] China Statistical Yearbook 2008. Government of the People's Republic of China - All China Data Center. Available from: http://chinadataonline.org/ (accessed April 08, 2009)

[4] China Energy Statistical Yearbook 2007. Government of the People's Republic of China - All China Data Center. Available from: http://chinadataonline.org/ (accessed April 08, 2009)

[5] An Introduction to LEAP. COMMEND: Community for energy, environment and development. Available from: http://www.energycommunity.org/default.asp?action=47 (accessed April 08, 2009)

[6] Junfeng L, Sicheng W. WWF-Greenpeace China Solar PV Report. China Environmental Science Press 2007.

[7] China Holdings. Project (Power Capacity: 50 MW); Total Potential: 100 MW in Biomass Energy Pipeline. November 5, 2007. Available from: http://www.chinaholding.net/Press_Releases.php (Accessed April 08, 2009)

[8] China Sustainable Energy Program. Fact Sheet: China Emerging as New Leader in Clean Energy Policies. Available from: http://www.efchina.org/FNewsroom.do?act=detail&newsTypeId=1&id=107 (Accessed April 8, 2009).

[9] Ni C.C. China's Natural Gas Industry and Gas to Power Generation. Institute of Energy Economics, Japan. Electric Power & Gas Industry Group, Strategy and Industry Research Unit 2007.

[10] European Renewable Energy Council & Greenpeace. Energy Revolution: A Sustainable China Energy Outlook. Available from: http://www.greenpeace.org/china/en/press/reports/energy-revolution (Accessed April 8, 2009).

[11] IEA Energy Technology Essentials. Nuclear Power: World Nuclear Energy Report. March 2007.

[12] Skeer J, Wang Y. Carbon Charges and Natural Gas Use in China. Energy Policy 2006. 34(2006): 2251-2262.

[13] IEA. IEA Energy Technology Essentials. Available from: http://www.iea.org/Textbase/techno/essentials.htm (Accessed April 8, 2009).

[14] ECOWORLD: Nature and Technology in Harmony. Winds, Waves, Tides-Ocean Energy. Available from: www.ecoworld.com/futures/2008/08/09/winds-waves-tides-ocean-energy/. (Accessed April 8, 2009).

[15] EPCOR. RRO Energy Rates. Available from: http://www.epcor.ca/en-ca/Customers/electricity-customers/electricity-rates/RRO-energy-rates/Pages/default.aspx (Accessed April 8, 2009).

[16] Environment Canada. Technology Fund Backgrounder. Available from: http://www.ec.gc.ca/default.asp?lang=En&n=714D9AAE-1&news=EADA9B4C-9C01-4621-9A00-BF1B2DBA11E5 (Accessed April 8, 2009).

[17] Malhi G. Issues: Gasoline Price Rise is Long-Term Challenge. Available from: http://gurbaxsinghmalhi.liberal.ca/p2665_e.aspx (Accessed April 8, 2009).

APPENDIX A: RESULTS

(TWh) Energy Resource	Base 2007	BAU 2027	BAU 2027 Energy Mix (%)	SD 2027	SD 2027 Energy Mix (%)
Coal	3,244.20	8,459.50	76.42%	2,046.20	18.48%
Crude Oil	66.80	0.00	0.00%	0.00	0.00%
Natural Gas	56.30	0.00	0.00%	300.00	2.71%
Fossil Fuels	3,367.30	8,459.50	**76.42%**	2,346.20	**21.19%**
Hydro	486.10	2,351.60	21.24%	3,244.40	29.31%
Nuclear	62.20	199.10	1.80%	2,190.00	19.78%
Wind	58.90	40.00	0.36%	2,555.00	23.08%
Solar PV	0.60	0.30	0.00%	494.50	4.47%
Solar Thermal	0.00	0.00	0.00%	24.30	0.22%
Tidal and Wave	0.00	0.00	0.00%	0.30	0.00%
Biomass	1.20	19.30	0.17%	215.00	1.94%
Renewables	609.00	2,610.30	**23.58%**	8,723.50	**78.81%**
Total	3,976.30	11,069.80	100.00%	11,069.70	100.00%

(GW) Energy Resource	Base 2007	BAU 2027	BAU 2027 Energy Mix (%)	SD 2027	SD 2027 Energy Mix (%)
Coal	506.80	1363.40	70.48%	1363.40	54.14%
Crude Oil	10.40	7.90	0.41%	3.00	0.12%
Natural Gas	11.60	68.80	3.56%	60.00	2.38%
Fossil Fuels	528.80	1,440.10	**74.44%**	1,426.40	**56.64%**
Hydro	149.70	379.00	19.59%	400.00	15.88%
Nuclear	10.10	32.10	1.66%	270.00	10.72%
Wind	12.10	40.00	2.07%	315.00	12.51%
Solar PV	0.10	0.30	0.02%	61.00	2.42%
Solar Thermal	0.00	0.00	0.00%	3.00	0.12%
Tidal and Wave	0.00	0.00	0.00%	0.00	0.00%
Biomass	0.10	43.00	2.22%	43.00	1.71%
Renewables	172.10	494.40	**25.56%**	1,092.00	**43.36%**
Total	700.90	1,934.50	100.00%	2,518.40	100.00%

(Mt CO2e) Energy Resource	Base 2007	BAU 2027	BAU 2027 Mix (%)	SD 2027	SD 2027 Mix (%)
Coal	3,294.20	8,590.10	100.00%	2,077.80	92.73%
Crude Oil	50	0	0.00%	0	0.00%
Natural Gas	29.8	0	0.00%	158.7	7.08%
Biomass	0	0.4	0.00%	4.1	0.18%
Total	**3,374.00**	**8,590.50**	100.00%	**2,240.60**	100.00%
% Change		**154.61%**		**-33.59%**	
Cumulative		**116,062.60**		**43,523.00**	
Net Mitigation			***72,539.60***		

APPENDIX B: DEMAND FORECAST INPUTS

	Industry					
	Mining					
	Petroleum And Natural Gas			Coal		
	Production	Electricity	EUI	Production	Electricity	EUI
	Megatonne	GWh	kWh/tonne	Megatonne	GWh	kWh/tonne
1997	160.7	31,468	195.8	1373	38,097	27.75
1999	160.0	29,986	187.4	1045	39,524	37.82
2001	164.0	30,919	188.6	1161	40,101	34.54
2003	169.6	34,951	206.1	1667	49,882	29.92
2004	175.9	35,895	204.1	1992	57,615	28.92
2005	181.4	38,443	212.0	2205	58,812	26.67
2006	184.8	31,599	171.0	2373	57,985	24.44
2007	186.3	31,546	169.3	2526	60,946	24.13

	Industry					
	Mining					
	Ferrous Metal			Nonferrous Metal		
	Production	Electricity	EUI	Production	Electricity	EUI
	Megatonne	GWh	kWh/tonne	Megatonne	GWh	kWh/tonne
1997	109	4,931	45.26			
1999	124	5,886	47.37			
2001	152	6,100	40.23			
2003	222	7,555	33.98			
2004	283	14,004	49.50	14.41	29,623	2,056
2005	353	20,514	58.07	16.35	29,912	1,829
2006	419	24,859	59.31	19.16	33,332	1,739
2007	489	30,922	63.20	23.79	37,996	1,597

	Industry					
	Manufacturing					
	Processing Food from Agricultural Products			Food		
	Production	Electricity	EUI	Production	Electricity	EUI
	Megatonne	GWh	kWh/tonne	Megatonne	GWh	kWh/tonne
1997	46.8	16,263	348	2.546	6,859	2,694
1999	44.1	15,090	342	1.691	9,631	5,696
2001	54.5	15,500	285	2.904	9,500	3,272
2003	61.1	19,519	320	4.364	11,369	2,605
2004	67.6	20,203	299	5.336	10,005	1,875
2005	76.4	25,275	331	5.003	11,454	2,289
2006	89.5	29,572	331	5.139	13,401	2,608
2007	100.8	34,008	338	6.036	15,411	2,553

	Industry					
	Manufacturing					
	Beverages			Tobacco		
	Production	Electricity	EUI	Production	Electricity	EUI
	Megatonne	GWh	kWh/tonne	m units	GWh	kWh/unit
1997	18.89	4,853	257	337,742	1,909	0.005652
1999	20.99	5,542	264	334,000	2,972	.008898
2001	22.89	5,670	248	340,210	3,158	.009283
2003	25.40	6,781	267	358,086	3,123	0.00721
2004	29.49	6,671	226	1,873,635	3,125	.001668
2005	31.26	7,637	244	1,938,908	3,578	.001845
2006	35.44	8,935	252	2,021,813	3,438	.001700
2007	39.54	10,275	260	2,143,884	3,713	.001732

	Industry					
	Manufacturing					
	Textile and Apparel			Timber and Lumber		
	Production	Electricity	EUI	Production	Electricity	EUI
	m m	GWh	kWh/m	m cu.m	GWh	kWh/cu.m
1997	24,879	39,807	.600	6.395	2,840	444.1
1999	25,000	37,369	1.495	5.237	2,790	532.8
2001	29,000	42,932	1.480	4.552	3,099	680.8
2003	35,352	54,878	1.552	4.759	3,759	789.9
2004	48,210	83,733	1.737			
2005	48,439	96,373	1.990			
2006	59,855	120,416	2.012			
2007	67,526	134,279	1.989			

	Industry					
	Manufacturing					
	Paper			Fuel		
	Production	Electricity	EUI	Production	Electricity	EUI
	Megatonne	GWh	kWh/tonne	Megatonne	GWh	kWh/tonne
1997	27.33	16,770	613.6	160.7	18,241	113.5
1999	21.59	19,288	893.3	160.0	20,746	567.7
2001	37.77	22,822	604.2	164.0	23,609	144.0
2003	48.49	28,497	587.6	169.6	33,062	194.9
2004	54.13	35,933	663.8	175.9	41,285	234.7
2005	62.05	40,676	655.5	181.4	31,274	172.4
2006	68.63	44,730	651.8	184.8	35,699	193.2
2007	77.92	44,235	567.7	186.3	41,589	223.2

Industry						
Manufacturing						
	Chemicals			Medicine		
	Production	Electricity	EUI	Production	Electricity	EUI
	Megatonne	GWh	kWh/tonne	Megatonne	GWh	kWh/tonne
1997	28.74	114,776	3,994	0.922	7,983	8,657
1999	33.14	105,815	3,193	0.779	7,688	9,872
2001	34.62	110,908	3,204	1.418	8,494	5,990
2003	39.58	135,556	3,425	1.703	9,793	5,749
2004	48.87	184,920	3,784	2.493	13,092	5,252
2005	52.93	212,470	4,014	2.332	15,285	6,555
2006	54.84	243,682	4,444	2.875	15,944	5,545
2007	60.01	282,184	4,702	3.180	17,332	5,451

Industry						
Manufacturing						
	Chemical Fibres			Rubber		
	Production	Electricity	EUI	Production	Electricity	EUI
	Megatonne	GWh	kWh/tonne	Megatonne	GWh	kWh/tonne
1997	4.72	11,138	2,362	0.0642	7,054	109,824
1999	6.00	15,875	2,646	0.0733	7,676	104,749
2001	8.41	18,725	2,226	0.1220	9,492	77,816
2003	11.81	20,646	1,748	0.1348	10,887	80,746
2004	17.00	22,533	1,326	0.1840	14,941	81,183
2005	16.65	23,265	1,397	0.2051	20,880	101,789
2006	20.73	24,455	1,180	0.1998	23,701	118,618
2007	24.14	28,116	1,165	0.2289	26,711	116,683

Industry						
Manufacturing						
	Plastics			Non-Metallic Minerals		
	Production	Electricity	EUI	Production	Electricity	EUI
	Megatonne	GWh	kWh/tonne	Megatonne	GWh	kWh/tonne
1997	0.686	9,732	14,192	63.4	60,808	960
1999	0.871	9,390	10,779	71.3	66,071	926
2001	1.289	11,614	9,012	78.3	73,418	938
2003	1.652	14,353	8,688	92.7	87,964	949
2004	2.367	23,016	9,726	111.4	120,925	1,086
2005	2.309	32,165	13,931	126.6	141,613	1,118
2006	2.603	35,478	13,632	143.7	167,375	1,165
2007	3.185	38,687	12,148	160.5	188,431	1,174

	Industry					
	Manufacturing					
	Ferrous Metals			Non-Ferrous Metals		
	Production	Electricity	EUI	Production	Electricity	EUI
	Megatonne	GWh	kWh/tonne	Megatonne	GWh	kWh/tonne
1997	224.1	93,416	416.9			
1999	249.7	100,472	402.4			
2001	307.2	107,769	350.8			
2003	436.0	132,310	303.5			
2004	551.2	206,363	374.4	14.41	125,793	8,729
2005	697.0	254,440	365.1	16.35	146,960	8,988
2006	831.6	303,587	365.1	19.16	182,762	9,537
2007	965.8	371,770	384.9	23.79	243,512	10,235

	Industry					
	Manufacturing					
	Metal Products			General Purpose Machinery		
	Production	Electricity	EUI	Production	Electricity	EUI
	Megatonne	GWh	kWh/tonne	m kW	GWh	kWh/kW
1997	99.8	14,098	141.3	24.1	14,974	622.6
1999	121.1	16,061	132.6	13.7	13,727	1,002.7
2001	160.7	18,870	117.4	13.4	15,455	1,153.2
2003	241.1	28,210	117.0	37.0	20,152	544.6
2004	319.8	43,279	135.3	71.4	27,978	392.0
2005	377.7	50,604	134.0	92.0	34,395	373.9
2006	468.9	60,515	129.0	116.9	38,890	332.6
2007	565.6	68,745	121.5	129.9	45,462	350.0

	Industry					
	Manufacturing					
	Special Purpose Machinery			Transport Machinery		
	Production	Electricity	EUI	Production	Electricity	EUI
	Megatonne	GWh	kWh/tonne	m units	GWh	kWh/unit
1997	0.837	7,393	8,830	1.583	20,123	12,716
1999	0.478	8,067	16,887	1.832	17,074	9,320
2001	0.917	9,083	9,911	2.342	19,555	8,351
2003	1.084	10,286	9,492	4.444	25,858	5,819
2004	2.576	15,231	5,912	5.091	35,767	7,025
2005	2.250	18,247	8,110	5.705	30,000	5,259
2006	2.357	20,702	8,783	7.279	34,506	4,741
2007	2.909	23,267	7,997	8.889	42,408	4,771

	Industry					
	Manufacturing			Manufacturing		
	Communication and Computer Equipment			Heat and Power		
	Production	Electricity	EUI	Production	Electricity	EUI
	m units	GWh	kWh/unit	Megatonnes	GWh	kWh/tonne
1997	129	14,427	111.78	27.58	176000	6,380
1999	191	18,376	96.17	25.93	187400	7,226
2001	290	20,818	71.76	67.11	204900	3,053
2003	860	28,013	32.56	49.13	247690	5,042
2004	679	50,013	73.69	82.99	337046	4,061
2005	781	57,232	73.26	94.23	369354	3,920
2006	968	68,360	70.62	95.15	416300	4,375
2007	1,074	83,386	77.61	97.88	464181	4,743

	Industry					
	Utilities					
	Gas			Water		
	Production	Electricity	EUI	Production	Electricity	EUI
	m cu.m	GWh	kWh/cu.m	Megatonnes	GWh	kWh/tonne
1997	77179	1300	0.01684	75065	13000	0.1732
1999	97342	2800	0.02876	78665	14200	0.1805
2001	121826	3300	0.02709	83585	14500	0.1735
2003	146999	3600	0.02449	87480	13900	0.1589
2004	150972	3400	0.02252	90349	17500	0.1937
2005	168834	2900	0.01718	90227	18600	0.2061
2006	180488	3100	0.01718	98410	20400	0.2073
2007	209776	4500	0.02145	93836	22300	0.2376

	Agriculture			Construction		
	Production	Electricity	EUI	Production	Electricity	EUI
	Megatonnes	GWh	kWh/tonne	m sq.m	GWh	kWh/sq.m
1997	1,625	63,977	39.36	622	1,128,440	1,813
1999	1,724	66,035	38.30	739	1,230,523	1,665
2001	1,661	67,296	40.51	977	1,347,138	1,379
2003	1,745	77,623	44.49	1228	1,633,145	1,330
2004	1,817	80,887	44.51	1474	2,197,137	1,491
2005	1,851	87,640	47.35	1594	2,494,039	1,565
2006	1,858	94,704	50.98	1797	2,858,797	1,591

2007	1,894	97,896	51.70	2040	3,271,180	1,604

	Transport			Commercial		
	Production	Electricity	EUI	Production	Electricity	EUI
	m ton-km	GWh	kWh/tonne-km	m yuan	GWh	kWh/yuan
1997				3125290	26513	0.00848
1999				3564790	34282	0.00962
2001				4305540	39368	0.00914
2003	5593058	33800	0.006043	5251630	50000	0.00952
2004	7189137	44965	0.006255	5950100	73535	0.01236
2005	8287801	43034	0.005192	6717660	75231	0.01120
2006	9171958	46737	0.005096	7641000	84725	0.01109
2007	10465789	53191	0.005082	8921000	92982	0.01042

	Other			Household		
	Production	Electricity	EUI	Production	Electricity	EUI
	m yuan	GWh	kWh/yuan	m person	GWh	kWh/person
1997	7806083	35,740	0.004578	1236	1253	1.014
1999	8847915	59,142	0.006684	1225	1481	1.209
2001	10806822	64,320	0.005952	1244	1672	1.344
2003	13517398	75,850	0.005611	1260	2001	1.588
2004	15958675	103,658	0.006495	1270	2464	1.940
2005	18408860	134,091	0.007284	1278	2825	2.210
2006	21313170	155,594	0.007300	1293	3252	2.514
2007	25148322	170,860	0.006794	1308	3623	2.769