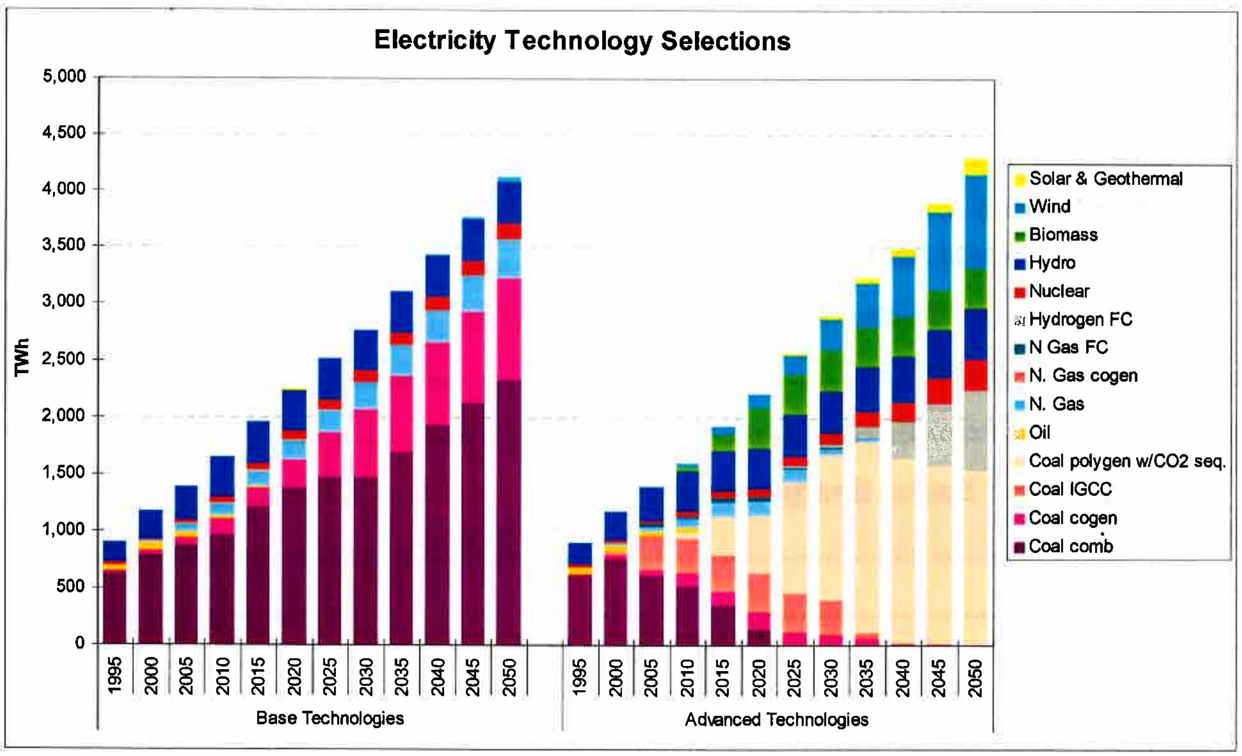
Demand Data Development
For China MARKAL Model, 1995-2050

APPENDIX A to
Future Implications of China's Energy-Technology Choices



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by
Wu Zongxin
Institute of Nuclear Energy Technology, Tsinghua University

Pat DeLaquil
Clean Energy Commercialization

Eric D. Larson
Center for Energy and Environmental Studies, Princeton University

Chen Wenying and Gao Pengfei
Global Climate Change Institute, Tsinghua University

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Introduction

The objective of this China MARKAL modeling effort is to identify potential energy futures that are supportive of socio-economic development in China and that provide national and global environmental protection through introduction of clean and renewable technologies, including advanced technologies for fossil fuel conversion. The focus of the effort is to identify sets of technologies and policies that will allow China to: 1) satisfy the energy demand requirements needed to support its economic and social development goals, 2) meet its energy security concerns, 3) have cleaner air and water, and 4) limit its contribution to global carbon emissions.

The level of future energy service demands for China is the driving function for the analysis. A single set of assumptions of future energy service demands was adopted, and all MARKAL scenarios involving various technology and policy constraints must meet these energy service demands. The assumed future levels of energy service demands are not predictions of the future, but they do fall in line with projections of future energy demand made in a number of other studies as shown in Figure 1.

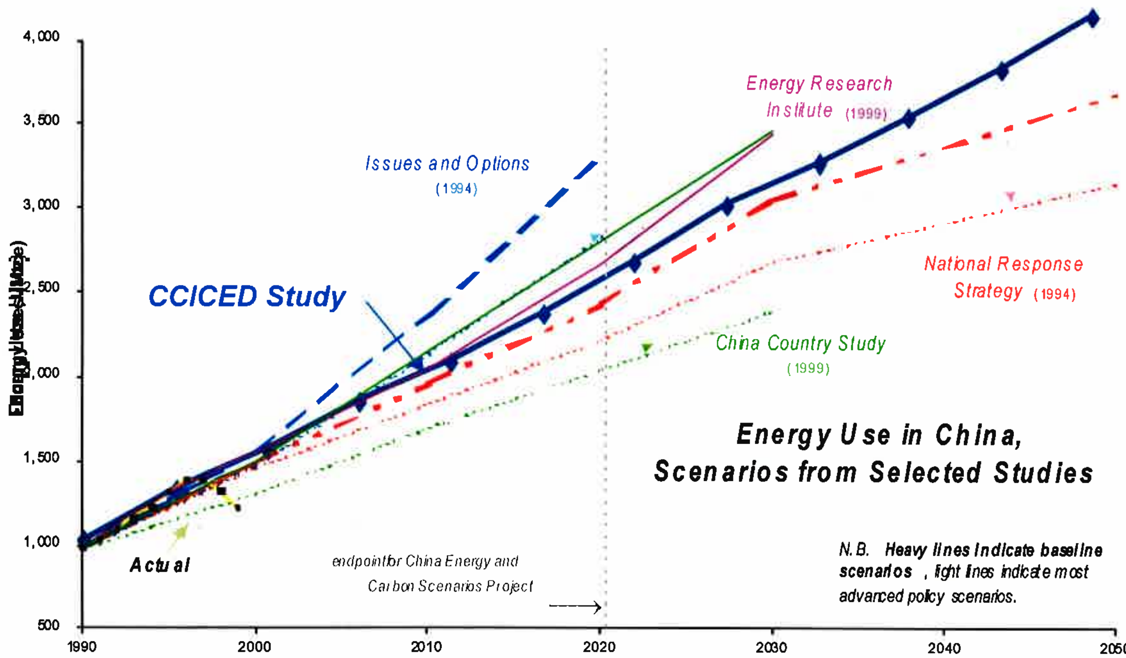

Figure 1. Comparison of Various Energy Demand Projections for China [1]

In developing the energy service demand assumptions, significant attention was paid to the fact that the Chinese economy will likely undergo significant structural changes during the time interval of the analysis. Most of the work discussed in this appendix is based on previous work by two of the co-authors, Professor Wu[2] and Professor Chen[3]. Unless otherwise noted, the basis for these projections is contained in those two references.

We developed projections of the future demands for energy services at five-year intervals to 2050, based largely on comparisons with historical data for various OECD countries at similar levels of GDP per capita. Future levels of energy demand were specified based on the assumption that by 2050 China as a whole will have developed to the levels of energy services that characterized key OECD countries in the mid-1990s. Considerable thought was given to the appropriate choice of the cross-country comparisons in order to minimize differences in economic structure, demographics, geography, culture, development path, etc. This methodology was selected because the Chinese economy is expected to undergo significant structural changes during the assessment time period,[4,5] and this approach does not presume what type of technology choices will be made to supply the projected demand. The methodology ties the projection of demands for energy services to the level of economic development toward which China aspires in the future.

The energy service demands have been developed according to the following sectors:

1. Industrial
2. Urban residential
3. Rural residential
4. Commercial
5. Agricultural
6. Transportation

Within these sectors, major end uses have been identified and analyzed separately. This appendix describes the data used to establish the 1995 baseline data and the assumptions and methodology used to project energy service demands. Unless otherwise noted, all 1995 energy data were derived from the China Energy Statistical Yearbook.[6]

General Assumptions

Table 1 presents the general economic assumptions underlying the energy service demand projections.[7] The population projections and GDP projections are based on official data from China's State Economic Information Center and represent their baseline population projection and their lower bound GDP growth projection. The lower GDP projection was selected as being more consistent with recent trends in China's energy consumption.[8] The urbanization trend shown in Table 1 should be understood in the Chinese context, where it does not mean that a person migrates to a city. Instead, it means that the person transitions from some form of land-based employment and non-commercial energy use to some form of industrial or service-based employment and that they make commercial purchases for energy and other services.

Table 1. General Economic Assumptions

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Population (billion)[a]	1.211	1.294	1.340	1.386	1.441	1.495	1.528	1.560	1.575	1.590	1.583	1.575
Population GR (%/yr)	1.3%	0.7%	0.7%	0.8%	0.8%	0.43%	0.43%	0.2%	0.2%	-0.1%	-0.1%	
Urbanization (%)[b]	31.4%	34.4%	38.4%	42.4%	46.9%	51.4%	54.9%	58.4%	61.7%	65.0%	67.5%	70.0%
Urbanization GR (%/yr)	1.8%	2.2%	2.0%	2.0%	1.8%	1.3%	1.2%	1.1%	1.0%	0.8%	0.7%	
GDP (billion US$)	709	1,104	1,549	2,172	2,839	3,710	4,849	6,338	7,711	9,382	11,414	13,887
GDP GR (%/yr)[c]	9.3%	7.0%	7.0%	5.5%	5.5%	5.5%	5.5%	4.0%	4.0%	4.0%	4.0%	
Per capita GDP (US$)	585	853	1,156	1,567	1,971	2,482	3,175	4,063	4,896	5,901	7,213	8,817
Per capita GDP GR (%/yr)	7.8%	6.3%	6.3%	4.7%	4.7%	5.0%	5.1%	3.8%	3.8%	4.1%	4.1%	
ppp factor	5.005	4.430	3.930	3.460	3.080	2.730	2.380	2.055	1.830	1.625	1.415	1.230
Per capita ppp GDP (US$)[d]	2,930	3,780	4,542	5,422	6,069	6,775	7,555	8,347	8,958	9,586	10,203	10,845
pppGDP/cap growth (%/yr)	5.2%	3.7%	3.6%	2.3%	2.2%	2.2%	2.0%	1.4%	1.4%	1.3%	1.2%	

(a) State Economic Information Center internal report.
(b) IEA: Link Between Energy and Human Activity, ISBN 92-64-15690-9.

(c) Chinese government social development goal from State Economic Information Center internal report.
(d) World Bank: Key World Energy Statistics.

The breakdown of GDP shares by major economic sectors is shown in Table 2. The industrial share of GDP is assumed to decrease slightly over the next 50 years even though industrial growth must remain strong to meet the growing demand for manufactured goods. The agricultural share of GDP decreases significantly because this sector is assumed to grow rather slowly due to the declining potential for future agricultural productivity gains. The services sector is expected to grow quite rapidly, and its share of GDP also increases significantly.

The GDP breakdown by 2050 was projected to approach that prevailing at present in the OECD countries. For comparison, the industry share of GDP today is approximately 38%, 26% and 33% for Japan, France and the USA, respectively.

Table 2. GDP Share by Sector

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Industry	48.8%	47.5%	46.3%	45.0%	44.3%	43.5%	42.8%	42.0%	41.3%	40.5%	39.8%	39.0%
Service & Transport	30.7%	33.8%	36.9%	40.0%	42.0%	44.0%	46.0%	48.0%	49.8%	51.5%	53.3%	55.0%
Agriculture	20.5%	18.7%	16.8%	15.0%	13.8%	12.5%	11.3%	10.0%	9.0%	8.0%	7.0%	6.0%

Industry Sector

China has a large industrial base with an energy intensity that is several times higher than that of most other countries. The principal reason for the high energy intensity is that the product mix is weighted towards relatively low-value goods, which are relatively energy-intensive to produce. In addition, out-dated and low-efficiency process technologies are widely used, which leads to higher energy use per output relative to other countries. Finally, many industrial plants are small and fail to achieve critical economies of scale.[9] The structure of China's industrial sector is expected to change significantly over the next 50 years. Greater diversity in the output of industrial goods, improvements in product quality and value, industrial modernization and restructuring, and classical industrial efficiency improvements will all lead to a significant improvement in the industrial sector energy intensity. We assume that the overall level of industrial energy intensity per unit of industrialGDP decreases from the 1995 value of 1.99 kilograms of coal equivalent per US$ (kgce/US$) to a value in 2050 of 0.25 kgce/US$. The latter value is equivalent to the 1995 industrial energy intensity in the USA and South Korea, but it is higher than the 1995 values in Western Europe and Japan. A few relevant comparisons are provided in Table 3.

Table 3. Industry Sector Energy Intensity in Some Countries in 1995

	Japan	France	Germany	US	UK	S. Korea
Industry Energy Intensity, kgce/US$	0.17	0.2	0.16	0.25	0.17	0.24

Based on the projected 2050 value for industrial energy intensity of 0.25 kgce/US$, an overall projection for industrial final energy demand was developed as shown in Table 4.

Table 4. Industry Sector Energy Intensity Projection

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
GDP Share (billion US$)	346	525	717	978	1,256	1,614	2,073	2,662	3,181	3,800	4,537	5,416
GDP Share GR (%/yr)	8.7%	6.4%	6.4%	5.1%	5.1%	5.1%	5.1%	3.6%	3.6%	3.6%	3.6%	
Energy Intensity (kgce/US$)	1.99	1.61	1.31	1.06	0.87	0.72	0.59	0.49	0.41	0.35	0.30	0.25
Energy Intensity GR (%/yr)	-4.1%			-3.8%				-3.3%				
Final Energy Demand (Mtce)	688	846	937	1,036	1,098	1,163	1,232	1,304	1,317	1,330	1,342	1,354
Final Energy Demand (PJ)	20,131	24,762	27,410	30,318	32,128	34,037	36,048	38,166	38,544	38,912	39,271	39,619

To develop energy service demand projections by industrial sub-sectors, a combination of two methods was used. Industrial output for five major energy consuming industries (steel, paper, cement, ammonia, and aluminum) was projected, and a variety of demand technologies providing different levels of output per unit of energy input were available for MARKAL to select from. An "Other Industries" sector – comprised of light manufacturing, machinery, electronics, building products, and other industries – was modeled as a single entity with final energy demands for three energy carriers (electricity, process heat and non-energy feedstocks.)

The projected output of the five major industries is given in Table 5. The output from each sub-sector is projected to increase, but the output growth-rates decrease over time and are all significantly lower than the GDP growth rate.

Table 5. Industrial Activity by Sub-sector (million tons per year)

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Aluminum	1.9	2.2	2.5	2.8	3.2	3.5	3.8	4.2	4.6	5.0	5.4	5.8
Ammonia	27.7	35.9	44.1	52.3	60.6	68.8	77.0	85.2	93.4	101.7	109.9	118.1
Cement	476.0	530.0	584.0	638.0	692.0	746.0	800.0	854.0	908.0	962.0	1,016.0	1,070.0
Paper	28.0	36.8	45.4	54.1	62.7	71.4	80.0	88.6	97.3	105.9	114.6	123.2
Steel	94.5	107.6	119.9	132.2	144.5	156.7	169.0	181.3	193.5	205.8	218.1	230.4

Steel

Increasing steel output has been a top priority in China's industrial development strategy for decades, and China is now the world leader in steel production. Between 1971 and 1999, steel production grew at an average annual rate of 6.5%. However, this historical trend is expected to decline,[10] and the production of steel is expected to increase by a factor of about 2.4 over the next 50 years. The growth rate is 2.5%/yr initially, but decreases to 1.6%/yr after 2010 and to 1.2%/yr after 2030. In 1995, the steel industry consumed 125.7 Mtce, and had an average energy intensity of 1,330 kgce/ton, which is double that of Japan, Germany and the USA. Almost 70% of current output is from large plants, with small plants comprising less than 10% of output. The percentage output of large plants is assumed to remain constant, but the percentage of small plants is assumed to decrease to about 5%. Energy intensity in the conventional steel technologies (blast furnace and electric arc) is expected to decrease by about 25% by 2050. This was considered reasonable given that the World Bank[5] estimates a 15% improvement by 2020.

Paper
Consumption of paper products is expected to grow rapidly in China in the future, and the production of paper is assumed to increase by a factor of about 4.4 over the next 50 years. The growth rate is 5.6%/yr initially, but decreases to 3%/yr after 2010 and to almost 2%/yr after 2030. In 1995, the paper industry consumed 44.8 Mtce, and had an average energy intensity of 1,600 kgce/ton, which is very high because of the use of low-grade raw materials and outdated technology. By comparison, energy use per ton of paper is only about 200 kgce in Finland. Energy use from conventional plants can decrease through the use of imported pulp to about 900 kgce/ton. Modern paper plants in China have an energy intensity of about 600 kgce/ton. Because China has a limited supply of raw materials for making paper, the proportion of imported pulp is expected to grow to at least 50% by 2020.[5]

Cement
The size of the cement industry is expected to more than double over the next 50 years. It grows at about 2%/yr initially, but that decreases beyond 2010 to about 1.5%/yr and to about 1.2%/yr after 2030. In 1995, the cement industry consumed 90 Mtce, and had an energy intensity of 189 kgce/ton, which is a composite of the current mix of cement manufacturing plants, characterized as small, wet, and dry processes with energy intensities of 0.2, 0.17, and 0.11 kgce/ton, respectively. These energy intensities are not expected to improve much, but the energy intensity of the cement industry is expected to improve as small plants, which dominate the market in 1995, are consolidated and/or switch to more efficient processes.

Ammonia
The use of chemical and nitrogen fertilizers in China is much higher than world average levels. Therefore, the production of ammonia, the main ingredient in nitrogen fertilizer, is expected to more than quadruple over the next 50 years. The growth rate is about 5%/yr initially, but decreases to about 3%/yr after 2010 and to less than 2%/yr after 2030. In 1995, the ammonia industry consumed 57.1 Mtce, and had an energy intensity of 2,066 kgce/ton, which is a composite of the current mix of large, medium and small manufacturing plants.

Aluminum
The production of aluminum is expected to triple over the next 50 years. The growth rate is 3%/yr initially, but decreases to 2%/yr after 2010 and to 1.5%/yr after 2030. In 1995, the aluminum industry consumed 11.2 Mtce, and had an average energy intensity of about 6,000 kgce/ton. Current Chinese plants require about 17,000 kWh/ton, or 6,270 kgce/ton, based on the primary energy content of the fuel required to produce the electricity. Modern plants can reduce energy consumption to about 13,000 kWh/ton.

Other Industry
The other industry sub-sector is largely comprised of light manufacturing, machinery, electronics, building products, etc. This sub-sector is assumed to significantly increase overall energy consumption over the next 50 years. The 1995 growth rate was about 4.2%/yr. That is expected to decrease to 3% in 2000, 2% in 2005 and to 1.5%/yr after 2020. The final energy projections for this sub-sector are shown in Table 6. Note that by 2050, the other industry category accounts for almost 80% of all industry sector demand

Table 6. Other Industry Overall Energy Demand (petajoules)

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Other Industry	10,493	12,907	14,963	16,550	18,272	20,174	21,733	23,413	25,223	27,172	29,272	31,534

This overall sub-sector demand was divided into three demand categories of electricity, process heat and non-energy feedstock. In 1995, the energy carrier constituents of the other industry category consisted of electricity, coal, coke, fuel oil, oil feedstock, natural gas and steam heat. The proportion of electricity and gas use is expected to increase in the future while the proportion of coal is expected to decrease. Table 7 shows how the mix of energy carriers was projected to change, and Table 8 provides the projection of final energy demand for the three categories of electricity, process heat (which combines coal, coke, fuel oil, natural gas and steam heat) and non-energy feedstock.

Table 7. Other Industry Sector Fuel Composition

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Electric	14.8%	16.4%	17.9%	19.5%	21.1%	22.6%	24.2%	25.8%	27.3%	28.9%	30.4%	32.0%
Coal	44.8%	43.5%	42.2%	40.8%	39.5%	38.2%	36.9%	35.5%	34.2%	32.9%	31.6%	30.2%
Fuel oil	10.7%	10.1%	9.6%	9.1%	8.6%	8.1%	7.6%	7.1%	6.5%	6.0%	5.5%	5.0%
Gas	7.0%	7.2%	7.4%	7.5%	7.7%	7.9%	8.1%	8.3%	8.5%	8.6%	8.8%	9.0%
Steam heat	6.0%	6.1%	6.2%	6.3%	6.4%	6.5%	6.5%	6.6%	6.7%	6.8%	6.9%	7.0%
Non-energy feedstocks	16.8%	16.8%	16.8%	16.8%	16.8%	16.8%	16.8%	16.8%	16.8%	16.8%	16.8%	16.8%

Table 8. Other Industry Final Demand Projections (petajoules)

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Electricity	1,555	2,114	2,685	3,228	3,850	4,565	5,258	6,030	6,889	7,846	8,910	10,091
Process heat	7,180	8,633	9,774	10,552	11,364	12,232	12,837	13,463	14,109	14,774	15,458	16,160
Non-energy feedstock	1,758	2,162	2,507	2,773	3,061	3,380	3,641	3,923	4,226	4,552	4,904	5,283

Urban Residential Sector

The urban and rural residential sectors were projected separately in order to account for their significantly different energy service demands, and to allow for the trend of urbanization to be included in the model. We divided urban residential sector energy demands into four categories: space heating, cooking & water heating, lighting & electric appliances, and air conditioning, which were projected independently.

The urban residential space heating demands were determined from projections of the urban population and the per capita floor area, assuming that 51.1% of urban floor space requires heating. The per capita floor area was projected to increase to a value of 35 m^2 in 2050, which compares to 1995 levels of 36 for Japan, 40 for Europe, and 58 for the USA. The percentage of urban residential floor space requiring heating was based on the current geographic distribution of urban centers and was assumed to remain the same into the future. Because the current overall level of space heating per unit floor area in China is modest, the space heating energy intensity was projected to grow slowly from 9.4 kgce/m^2 in 1995 to 11.3 kgce/m^2 in 2050 in spite of building and heating efficiency improvements. As a result of the projected increase in space heating energy intensity, urban space heating per capita energy increases from 111 kgce/person in 1995 to 404 kgce/person in 2050. This compares to 1995 values of 168 kgce/person for Japan, 583 for Europe, and 644 for the USA.

Table 9 shows the development of the energy service demand for the urban residential sector. The demand for energy services was determined from final energy demands by assuming an average conversion of final energy to energy service of 74% in 1995, increasing to 80% in 2050.

Table 9. Urban Residential Space Heating Energy Demand

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Urban population (billion)	0.380	0.445	0.515	0.588	0.676	0.768	0.839	0.911	0.972	1.034	1.068	1.103
Per capita floor area (m2/person)	11.8	14.1	16.8	20.0	21.8	23.7	25.7	28.0	29.6	31.3	33.1	35.0
Total floor area (billion m2)	4.49	6.26	8.63	11.75	14.70	18.18	21.59	25.51	28.77	32.35	35.36	38.59
Energy demand Intensity (kgce/m2)	9.4	9.6	9.8	10.0	10.2	10.4	10.6	10.8	11.0	11.1	11.3	11.53
Per capita energy use (kgce/person)	111	135	164	200	221	245	272	301	324	349	375	404
Final energy demand (Mtce)	42.2	60.1	84.5	117.4	149.6	188.6	228.1	274.5	315.2	360.7	401.0	445.1
Heating efficiency	74%	74.5%	75.1%	75.6%	76.2%	76.7%	77.3%	77.8%	78.4%	78.9%	79.5%	80%
Useful energy demand (Mtce)	31.2	44.8	63.5	88.8	114.0	144.7	176.3	213.6	247.0	284.6	318.6	356.1
Useful energy demand (PJ)	914	1,311	1,857	2,597	3,335	4,235	5,157	6,250	7,226	8,327	9,322	10,419

The urban cooking and water heating energy service demands were projected from the per capita energy demand, which in 1995 was 52 kgce/person. This value was assumed to increase at a constant annual rate of 1.5% to a value of 118 kgce/person in 2050. This compares to today's values of 138 for Japan, 140 for Europe, and 245 for the USA. Table 10 presents these projections. To allow Markal to select between various end-use technologies for this sector, the useful energy demand was calculated from the assumed final energy demands using end-use efficiency estimates of 35% for 1995, increasing to about 55% in 2050.

Table 10. Urban Residential Cooking & Water Heating Energy Demand

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Urban population (billion)	0.380	0.445	0.515	0.588	0.676	0.768	0.839	0.911	0.972	1.034	1.068	1.103
Per capita final energy, kgce/person	52.0	56.0	60.3	65.0	70.0	75.4	81.3	88.0	94.8	102.1	110.0	118.0
Cooking & HW end-use efficiency	35.0%	36.8%	38.6%	40.5%	42.3%	44.1%	45.9%	47.7%	49.5%	51.4%	53.2%	55%
Per capita energy service demand, kgce	18.2	20.6	23.3	26.3	29.6	33.3	37.3	42.0	47.0	52.4	58.5	64.9

Energy service demand, Mtce	6.9	9.2	12.0	15.5	20.0	25.6	31.3	38.3	45.6	54.2	62.5	71.6
Energy service demand, PJ	202	270	353	452	591	758	927	1,120	1,345	1,600	1,837	2,094

The urban electricity demand for lighting and appliances was 350 kWh per household in 1995. This demand was assumed to grow at a constant 2.7% per year to reach a level of 1,515 kWh per household in 2050. This value is equivalent to Japan in 1995 (1,500 kWh per household), but low relative to other OECD countries, where it ranges from 2,500 to 6,500 kWh per household. These energy service demand projections are given in Table 11.

Table 11. Urban Residential Lighting and Appliance Demand

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Population per household	3.22	3.12	3.08	3.06	3.02	3.01	2.92	2.86	2.85	2.84	2.77	2.70
Number of households (billion)	0.118	0.143	0.167	0.192	0.224	0.256	0.287	0.319	0.341	0.364	0.386	0.408
Electric demand per HH, kWh	350	400	457	522	596	681	778	889	1016	1160	1326	1515
Electric demand, TWh	41	57	76	100	133	174	224	284	347	422	511	618
Electric demand, PJ	149	205	275	361	480	626	805	1021	1248	1519	1841	2225

The energy demand for urban air conditioning in 1995 was about 1 kgce/person. This energy demand is assumed to grow at about 4.1% per year until 2010, at 3.5% from 2010 to 2030, and at 2.0% per year after 2030 to reach 9 kgce/person in 2050. These energy demands are shown in Table 12.

Table 12. Urban Air Conditioning Energy Demand

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Urban population (billion)	0.380	0.445	0.515	0.588	0.676	0.768	0.839	0.911	0.972	1.034	1.068	1.103
Electric demand (kgce/person)	1.0	1.7	2.3	3.0	3.8	4.5	5.3	6.0	6.8	7.5	8.3	9.0
Cooling, Mtce	0.4	0.7	1.2	1.8	2.5	3.5	4.4	5.5	6.6	7.8	8.8	9.9
Energy demand (PJ)	11.1	21.7	35.1	51.6	74.1	101.2	128.8	159.9	191.9	226.8	257.9	290.3

Rural Residential Sector

We divided rural residential sector energy demands into three categories: cooking & water heating, lighting & electric appliances and space heating. The expected growth in air conditioning use in the rural sector was included in the lighting & electric appliance category assuming it will all be electrically powered. In 1995, this sector consumed 61.8 Mtce of commercial final energy, which included 43 TWh of electricity. Use of traditional, non-commercial biomass-based fuels is not included in this figure. Although these energy sources are important to rural China, they were not explicitly included in the assessment because MARKAL will always select a free non-commercial resource over a commercial resource. However, the transition of the rural population from traditional to modern energy carriers was included in the model through both the projection of rural residential energy use and in the urbanization trend that shifts population from the rural energy sector to the urban energy sector.

The total per capita use of commercial energy in the rural residential sector was assumed to grow in proportion to the GDP growth rate according to an historical elasticity of about 0.6. Similarly, the per capita electric energy consumption was projected based on a demand elasticity of about 0.8. The development of the rural residential sector final energy demand is shown in Table 13.

Table 13. Rural Residential Sector Final Energy Demand

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Rural Population (billion)	0.831	0.849	0.825	0.798	0.765	0.727	0.689	0.649	0.603	0.557	0.514	0.473
Persons per household	4.3	4.4	4.2	4.1	4.0	3.9	3.8	3.7	3.7	3.6	3.5	3.5
Number of households (billions)	0.192	0.194	0.195	0.197	0.192	0.186	0.181	0.175	0.165	0.155	0.145	0.135
Com'l energy per capita (kgce/person)	74.4	86.0	99.5	115.0	134.3	156.9	183.2	214.0	250.2	292.6	342.1	400.0
Electricity per capita (kWh/person)	51.8	71.8	91.9	112.0	146.5	181.0	215.5	250.0	309.0	368.0	427.0	486.0
Final energy demand (Mtce)	61.8	73.0	82.1	91.8	102.7	114.0	126.2	138.9	150.9	162.8	175.9	189.0
Electric energy demand (TWh)	43.0	61.0	75.9	89.4	112.1	131.5	148.5	162.2	186.4	204.8	219.6	229.6
Final energy demand (PJ)	1,808	2,136	2,402	2,686	3,006	3,335	3,693	4,064	4,417	4,764	5,148	5,530

In 1995, 8.6% of the final energy demand was used for lighting and electric appliances, and the remaining final energy was evenly split between space heating and cooking and water heating. In 2050, the final energy proportion for lighting and electric appliances is 15%, based on the projection for rural residential electricity use. The proportion of rural residential energy use for space heating was projected to increase to 50% while the share for cooking and water heating decreased to 35%.

To allow the model to select between various end-use technologies for this sector, the useful energy demand was calculated. The current average end-use efficiency of 30% for rural cooking and water heating was projected to increase to 45% by 2050, and an average end-use efficiency of 80% was used for rural space heating. Table 14 provides the useful energy demands for this sector.

Table 14. Rural Residential Useful Energy Demands

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Cooking and Water Heating	227	297	338	382	433	487	546	609	670	732	801	871
Lighting and Electric Appliance	155	220	273	322	403	473	534	584	671	737	791	827
Space Heating	718	775	876	995	1,109	1,243	1,405	1,590	1,742	1,914	2,123	2,353

Commercial Sector

Energy demand in the commercial sector is expected to grow quite rapidly in China over the next several decades. We projected commercial sector floor area requirements according to the ratio of commercial sector floor area to urban residential floor area. Typical ratios for developed countries today include 0.31 for Japan and 0.41 for the USA. China was projected to reach 0.40 by 2015 and then remain constant. As a check, the ratio of commercial floor area to commercial GDP share decreases from a 1995 value of 9.65 m^2/1000$US to a value of about 2.0 m^2/1000$US in 2050. Values for this ratio today in other countries include 1.5 for Japan, 1.2 for Italy and 2.8 for the USA. Thus, commercial sector floor area grows at about 6% per year until 2010, at 3.5% from 2010 to 2030, and at 2.2% per year after 2030.

In 1995, the commercial sector energy use was 29 Mtce, resulting in a commercial sector energy intensity of 13.8 kgce/m^2. We projected commercial sector energy intensity to grow to a value of 20 kgce/m^2 in 2050, based on an assumed increase in energy service demands as this sector develops. The overall final energy demand for the commercial sector is shown in Table 15.

Table 15. Commercial Sector Energy Demand

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Urban Res. floor area (billion m2)	4.49	6.26	8.63	11.75	14.70	18.18	21.59	25.51	28.77	32.35	35.36	38.59
Commercial to residential ratio	0.47	0.45	0.43	0.43	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Commercial floor area (billion m2)	2.1	2.8	3.7	5.0	5.9	7.1	8.4	10.0	11.1	12.4	13.8	15.4
Commercial energy intensity (kgce/m2)	13.8	14.5	15.2	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0
Final energy demand (Mtce)	29.0	40.7	57.0	80.0	98.0	120.0	147.0	180.0	205.9	235.5	269.3	308.0
Final energy demand (PJ)	848	1,190	1,669	2,341	2,867	3,511	4,300	5,267	6,024	6,889	7,880	9,012
GDP Share (billion US$)	218	373	571	869	1,192	1,633	2,231	3,042	3,836	4,832	6,078	7,638
Commercial floor per GDP share (m2/1000US$)	9.65	7.51	6.55	5.75	4.99	4.33	3.77	3.29	2.90	2.57	2.27	2.02

We characterized commercial sector energy demands according to three categories: space heat and water heating, air conditioning, and lighting and appliances. In 1995, the split of the total final energy demand was approximately 6% air conditioning, 12% lighting and appliances, and 82% space heating and water heating. The proportion of final energy used for air conditioning was projected to increase to 16% by assuming that the proportion of air-conditioned commercial floor space would increase from 30% in 1995 to 80% in 2050 and that air conditioning energy intensity (kgce/m2) would increase slightly over the period. Similarly, the proportion of final energy devoted to space heating and water heating was projected based on a slight increase in its energy intensity over the period, and its proportion decreases to about 66%. Thus, the proportion devoted to lighting and appliances increases to 18%. The breakdown of the commercial sector final energy demands is shown in Table 16.

Table 16. Breakdown of Commercial Sector Energy Demands (petajoules)

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Air conditioning	52	84	135	218	285	373	489	640	783	959	1,174	1,437
Lighting and appliances	103	200	300	443	545	670	822	1,006	1,134	1,276	1,430	1,598
Space Heating & Water heating	693	906	1,234	1,680	2,037	2,468	2,990	3,621	4,106	4,655	5,275	5,977

Agricultural Sector Energy Demands

In 1995, the agricultural sector consumed 39.4 Mtce. Future final energy demands for this sector were projected from historical data that indicates an energy-demand elasticity of 0.5 to the agricultural share of GDP growth. Table 17 shows the development of the projection for this sector. The overall energy intensity decreases. Most arable land in China is already under cultivation and future increases in production of food and other agricultural goods must come through productivity and efficiency improvements. This fact and the expected increases in the value of agricultural products are consistent with the decline of energy intensity in this sector.

Table 17. Total Agricultural Sector Energy Demand (petajoules)

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
GDP Share (billion US$)	145	206	261	326	390	464	546	634	694	751	799	833
GDP Share GR (%/yr)	7.2%	4.8%	4.6%	3.7%	3.5%	3.3%	3.0%	1.8%	1.6%	1.3%	0.8%	
Total Energy Demand GR (%/yr)	3.6%	2.4%	2.3%	1.8%	1.8%	1.7%	1.5%	0.9%	0.8%	0.6%	0.4%	
Total Energy Demand (Mtce)	39.1	46.8	52.7	58.9	64.6	70.4	76.4	82.4	86.3	89.7	92.6	94.6
Total Energy Demand (PJ)	1,145	1,368	1,541	1,724	1,889	2,061	2,236	2,412	2,524	2,626	2,709	2,767
Energy intensity (kgce/US$)	0.27	0.23	0.20	0.18	0.17	0.15	0.14	0.13	0.12	0.12	0.12	0.11

Agricultural sector energy demand projections were divided into four categories: electric motors, agro-processing (heat), irrigation, and farm machines. In 1995, the proportions of final energy carriers in this sector were: 37% coal, 45% fuel oil and 18% electricity. In 2050, the proportion of liquid fuels (conventional or synthetic) was projected to remain the same, while the proportion of coal was projected to decrease to 27%, and the percentage of electricity to increase to 28%. The final energy demand projections are shown in Table 18. For this sector, the energy service demands were assumed to be equal to the final energy demands.

Table 18. Agricultural Sector Energy Demand Breakdown (petajoules)

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Electric Motors	209	264	312	366	419	477	540	605	658	710	759	802
Agro-Processing	424	494	543	592	631	669	706	739	751	757	756	747
Irrigation	128	153	172	192	210	229	248	267	279	290	298	304
Farming Machines	384	458	515	575	629	686	743	800	836	869	895	913

Transportation Sector Energy Demands

Energy use in China's transportation sector is expected to increase significantly in the future as improvements in living standards increase the demand for goods that must be transported to market, and as the increasing population requires more and better quality passenger transportation. In this sector, as in the industry sector, we projected the activity rather than final energy to allow better comparison of different end-use technologies. For the transport sector we projected activity levels for both freight and passengers. These were developed from the projections of GDP growth, population growth, and expected changes in transport modes.

In 1995, freight transport intensity for China was 1.01 t-km/US$ ppp, and we assumed this value decreases to 0.7 t-km/US$ ppp in 2050, which compares to 1995 values of 0.8 for the USA and 0.75 for Australia. The ppp-normalized GDP is used to project freight transport because it gives a better measure of the overall demand for goods. Thus, the total freight activity increases from 3,573 billion t-km in 1995 to almost 12,000 billion t-km in 2050. The growth rate in freight activity is 4.3% per year through 2010, 2.2% per year from 2010 to 2030, and 0.7% after 2030. This projection is shown in Table 19. The table also shows an overall energy demand projection for freight transport, which was made for comparison purposes only. Even though energy efficiency will improve in each transportation mode, the overall freight energy intensity was projected to increase because of the shift to more energy-intensive road and air transport modes. The freight energy intensity in 2050 of 3.0 kgoe/100t-km compares to 5.8 for Japan, 5.2 for Italy and 3.2 for the USA.

Table 19. Freight Activity and Energy Demand Projections

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
GDP (billion US$)	709	1,104	1,549	2,172	2,839	3,710	4,849	6,338	7,711	9,382	11,414	13,887
ppp GDP (billion US$)	3,548	4,891	6,086	7,515	8,743	10,128	11,540	13,022	14,108	15,241	16,146	17,081
Freight Intensity (t-km/US$ ppp)	1.01	0.97	0.94	0.90	0.88	0.85	0.83	0.80	0.78	0.75	0.73	0.70
Freight Activity (10^9 t-km)	3,573	4,751	5,694	6,763	7,650	8,609	9,520	10,418	10,934	11,431	11,706	11,957
Freight Energy Intensity (kgoe/100t-km)	1.45	1.55	1.65	1.76	1.88	2.01	2.15	2.30	2.46	2.63	2.81	3.00
Freight Energy Demand (Mtoe)	51.8	73.5	93.9	119.0	144.0	173.2	204.8	239.6	268.7	300.3	328.6	358.7
Freight Energy Demand (PJ)	2,166	3,071	3,927	4,976	6,017	7,240	8,560	10,015	11,234	12,551	13,736	14,994

For freight transportation, the following five categories: air, pipeline, ship, rail and truck are modeled, and in 1995 the proportion of activity for each mode is shown in Table 20. The activity in the air, truck and pipeline sub-sectors was projected to increase relative to the others.

Table 20. Freight Transportation Activity Proportions

	1995	2010	2030	2050
Air	0.05%	0.15%	0.27%	0.40%
Pipeline	1.7%	2.3%	3.1%	3.9%
Ship	49.1%	46.8%	43.8%	40.7%

Rail	36.0%	34.4%	32.2%	30.0%
Truck	13.2%	16.4%	20.7%	25.0%

Table 21 presents the freight transportation activity projections, in billion-ton-km, based upon the above proportions and the total freight transport activity shown in Table 19.

Table 21. Freight Transportation Category Activity (billion-ton-km)

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Air	2	4	6	10	14	18	23	28	33	38	43	48
Pipeline	59	88	117	153	189	230	274	321	359	398	432	466
Ship	1,754	2,296	2,709	3,166	3,523	3,898	4,238	4,559	4,701	4,828	4,855	4,867
Rail	1,286	1,684	1,988	2,324	2,587	2,864	3,116	3,353	3,459	3,554	3,576	3,587
Truck	472	678	874	1,110	1,338	1,598	1,869	2,157	2,382	2,613	2,801	2,989

Passenger transportation in China in 1995 consumed 11.2 Mtoe in providing about 900 billion-passenger-km. The per capita travel activity was 743 passenger-km/person. We projected future per capita passenger transport activity based on a demand elasticity of 0.8 between the GDP growth rate and the per-capita transport growth rate. Even with this relatively rapid increase, the projected per capita passenger travel for China in 2050 remains a factor of 2 to 3 below the current activity levels in the USA and Western Europe. This projection is shown in Table 22. As with the freight category, the table also shows an overall energy demand projection, which was made for comparison purposes only. The passenger energy intensity in 1995 was 12.4 kgoe/1000 passenger-km. As with the freight sector, the passenger transportation energy intensity is expected to increase due to shifts to more energy intensive transportation modes and is projected to reach 20.2 kgoe/1000 passenger-km in 2050, which compares to 37.3 for Europe, 40 for Japan, and 60.3 for the USA.

Table 22. Passenger Transportation Activity & Energy Demand

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Per capita GDP (billion US$)	585	853	1,156	1,567	1,971	2,482	3,175	4,063	4,896	5,901	7,213	8,817
Per capita GDP total GR	7.8%	6.3%	6.3%	4.7%	4.7%	5.0%	5.1%	3.8%	3.8%	4.1%	4.1%	
Per capita travel activity GR %	6.3%	5.0%	5.0%	3.8%	3.8%	4.0%	4.0%	3.0%	3.0%	3.3%	3.3%	
Per capita travel activity (p-km/person)	743	1,007	1,285	1,642	1,974	2,376	2,896	3,531	4,101	4,764	5,598	6,578
Travel Activity (billion-p-km)	900	1,303	1,722	2,276	2,843	3,552	4,423	5,508	6,459	7,575	8,859	10,361
Passenger energy intensity, kgoe/1000p-km	12.4	13.0	13.6	14.2	14.8	15.5	16.2	16.9	17.7	18.5	19.3	20.2
Passenger final energy, Mtoe	11.2	16.9	23.4	32.3	42.2	55.0	71.6	93.2	114.2	139.9	170.9	208.8
Passenger final energy, PJ	468	708	978	1,351	1,764	2,301	2,994	3,896	4,773	5,849	7,146	8,732

Passenger transportation activity was modeled according to the following five categories: automobile, bus, rail, air and ship. In 1995 the proportion of activity for each mode is shown in Table 23. The proportion of automobile activity was projected to increase significantly based on comparisons of per capita automobile transport to Japan, Western Europe and the USA. Given that China's per capita ppp GDP will reach US$10,000 in 2050, it was projected that the percentage of the population owning cars would reach the same level (between 10 and 15%) as countries today with the same level of GDP, e.g. South Korea. Assuming that China has 100 cars per 1000 people in 2050, there will be 157.5 million cars. The annual travel was estimated at 15,000 km (reference: Japan at 12,500 km and the USA at 18,000 km), and the occupancy was estimated at 1.5 people per car. This gives a 2050 passenger travel activity of 3,548 billion passenger–km, which is 32.4% of the total. The proportion of air transport increases slightly, while the other categories decrease.

Table 23. Passenger Transportation Sector Proportions

	1995	2010	2030	2050
Car	6.1%	11.7%	25.2%	32.4%
Bus	45.0%	42.4%	35.9%	32.6%
Rail	39.4%	36.3%	29.0%	25.0%
Air	7.6%	8.0%	8.5%	9.0%
Ship	1.9%	1.7%	1.3%	1.0%

Table 24 presents the passenger transportation activity projections by category, based upon the above proportions and the total passenger transportation activity given in Table 22.

Table 24. Passenger Transportation Activity (billion-passenger-km)

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Car	55	107	176	262	464	721	1,036	1,406	1,869	2,380	2,940	3,548
Bus	405	594	776	950	1,254	1,531	1,781	2,004	2,429	2,831	3,212	3,570
Rail	355	516	669	813	1,060	1,277	1,464	1,620	1,940	2,233	2,499	2,738
Air	68	104	141	179	249	322	397	474	597	723	852	986
Ship	17	24	31	37	48	58	67	74	86	96	104	110

Summary

Table 25, which summarizes the final energy demand projections for each sector, was prepared for illustrative purposes only. The estimates shown for the industrial and transportation sectors are based on the projected activity levels and energy intensities as discussed above. They were not used in the China MARKAL model developed for this study. For those sectors the inputs to MARKAL consist of the projected activity levels. In the MARKAL model runs, the actual final energy demand in 2050 will depend on the mix of end-use technologies selected by the model.

The table indicates that the industrial sector accounts for over two-thirds of the total energy demand in 1995, but decreases to just over one-third in 2050. The commercial sector almost triples its share of final energy, but accounts for only 9% of final energy in 2050. The most significant increases come in the urban residential and transportation sectors, which grow to 19% and 24% of final energy in 2050. Only the agricultural share decreases.

Table 25. Final Energy Demand Projections for All Sectors (petajoules)

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Industrial	20,131	24,762	27,410	30,318	32,128	34,037	36,048	38,166	38,544	38,912	39,271	39,619
Commercial	848	1,190	1,669	2,341	2,867	3,511	4,300	5,267	6,024	6,889	7,880	9,012
Urban Residential	1,973	2,615	3,382	4,281	5,546	7,033	8,509	10,191	12,324	14,692	16,914	19,290
Rural Residential	1,808	2,136	2,402	2,686	3,006	3,335	3,693	4,064	4,417	4,764	5,148	5,530
Transportation	2,634	3,884	5,049	6,522	8,087	9,998	12,210	14,827	17,051	19,578	22,193	25,164
Agriculture	1,145	1,368	1,541	1,724	1,889	2,061	2,236	2,412	2,524	2,626	2,709	2,767
Total	28,540	35,955	41,452	47,873	53,524	59,975	66,997	74,926	80,884	87,461	94,115	101,381

An indication of the changes in the sectoral proportions of final energy between 1995 and 2050 is illustrated in Figure 2.

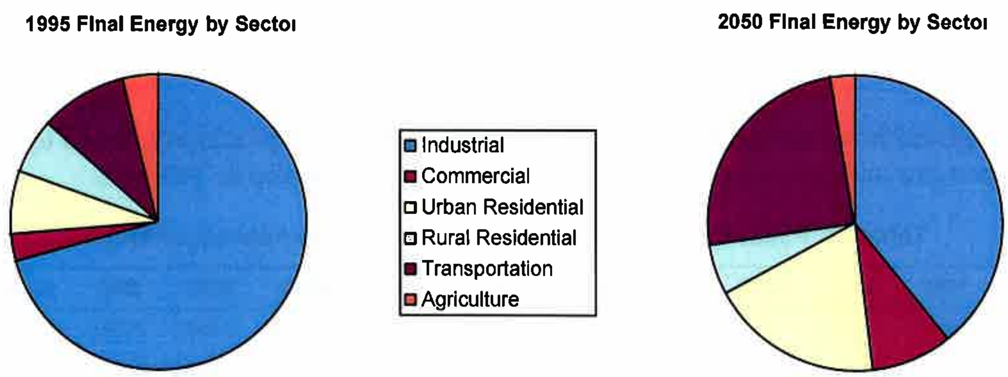

Figure 2. Illustrative Breakdown of Final Energy Demand by Sector

Table 26 shows per capita energy demand growing from 23.5 GJ per person in 1995 to reach 63.4 GJ/person in 2050. The growth rate is 2.6%/yr to 2010 and about 1.5%/yr after that. The energy intensity per unit of GDP decreases by over a factor of five, and the ppp energy intensity decreases at about 1.6%/yr to 2010, 0.5%/yr until 2030 and is essentially constant after 2030.

Table 26. Overall Energy Statistics

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Per capita GDP (US$)	585	853	1,156	1,567	1,971	2,482	3,175	4,063	4,896	5,901	7,213	8,817
Per Capita Energy Demand (GJ/person)	23.6	27.8	31.0	34.6	37.3	40.3	44.1	48.3	51.7	55.4	59.9	64.9
Energy Intensity (MJ/US$)	40.3	32.6	26.8	22.1	18.9	16.2	13.9	11.9	10.6	9.4	8.3	7.4
ppp Energy Intensity (MJ/US$ ppp)	8.1	7.4	6.8	6.4	6.1	5.9	5.8	5.8	5.8	5.8	5.8	5.8

Figure 3 provides a comparison of the projected growth in per capita energy demand for China and the historical growth in several other developing countries. The per capita energy demand growth projected for China over 50 years is similar to what smaller countries have been able to achieve in shorter periods (15 years), but this is reasonable considering China's significant population and its lower per-capita energy starting point compared to the other countries shown.

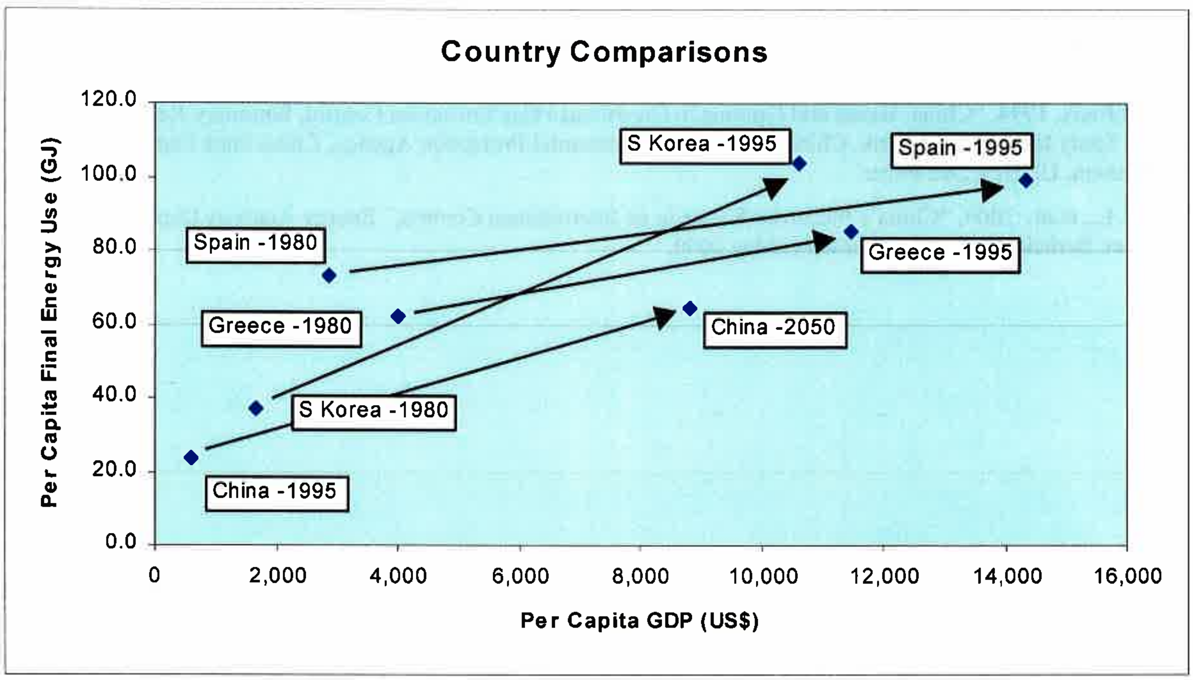

Figure 3. Comparison of Per Capita Energy Growth

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