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Impacts of Main Economic Sectors on Energy Efficiency in the period 2015–2030 in China

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Executive summary

The purpose of this deliverable is to get an understanding of the energy efficiency development in China in relation to the official targets and to measure the improvement in energy efficiency performance of the different economic sectors in China.

This has been done by first decomposing the final energy consumption into an activity, intensity and structural effects at two different levels of aggregation. The used decomposition method is the Sun-Shapley method, which provides a perfect decomposition by allocating the residual to the three effects under the principle “jointly created, equally distributed”.

From the decomposition results, the sectoral intensity effects have been used as input in the ChinaLINDA model. The modelling is used for constructing a future projection of a possible development of energy use and carbon dioxide (CO_2) emissions in China, a baseline scenario. This scenario is compared to another projection, where the aspired energy efficiency targets of the Chinese 13th five-year plan are reached.

The ChinaLINDA model used is based on an extended Kaya identity, and it includes different economic sectors and mixes of primary energy sources and different energy carriers:

$$CO2 = \frac{CO2}{TPES} \times \frac{TPES}{FEC} \times \frac{FEC}{GDP} \times \frac{GDP}{POP} \times POP$$

The decomposition analysis of final energy consumption of the Chinese economy uses data from National Bureau of Statistics of China and the World Input-Output Database. The sectoral final energy consumption data has been extracted from the National Bureau of Statistics of China database. The sectoral value added data is sourced from the World Input-Output Database. The other data used in the ChinaLINDA model, including primary energy data, economic data and population data, is taken from the National Bureau of Statistics database.

The analysis of energy intensity development in China shows the following results. Manufacture of motor vehicles, trailers and semi-trailers, manufacture of food, beverages and tobacco products, mining and quarrying, manufacture of coke and refined petroleum products, and manufacture of other non-metallic mineral products are the most interesting economic sectors in terms of a good performance and development towards a less energy intensive production in the future. On the other hand, the printing and reproduction of recorded media, the transport sector, the manufacture of rubber and plastic products, and the manufacturing of furniture and wood products show a negative development or a relatively slow positive development in terms of energy intensity, hinting at a possible energy savings potential within the activities carried out in these sectors.

The mining sector has overall contributed the most significantly to energy savings through energy efficiency improvements, and nearly as important is the manufacture of non-metallic mineral products sector. A third very significant sector in terms of absolute energy savings through efficiency gains is the manufacture of coke and refined petroleum products sector. Problematic sectors with large quantity effects but negative energy efficiency development are especially the manufacture of basic metals sector and the transport sector. Poor efficiency development and high volume of economic activity in these sectors hint at a significant potential for efficiency gains that might possibly be achieved by well focused policy interventions.

The Chinese policy targets for energy efficiency appear to be stringent in the light of observed development in energy efficiency. However, if the energy efficiency policies are successfully implemented and the aspired energy intensity goals are met, the energy saved and the avoided CO_2 emissions are decisively lower than in the business-as-usual case of continuing the development along the observed trend of energy intensity in China. The tables below show the differences in CO_2 emission development in these two scenarios:

Projection of CO_2 emissions and final energy consumption (FEC) under the policy scenario:

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
CO2 (Mtons)	8401	8630	8873	9131	9353	9557	9780	10023	10287	10506	10752	11026	11329	11662
FEC (Mtoe)	2594	2629	2667	2709	2741	2736	2736	2743	2756	2735	2724	2723	2731	2750

Projection of CO_2 emissions and final energy consumption (FEC) under the trend continuation scenario:

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
CO2 (Mtons)	9037	9499	9987	10502	11026	11521	12042	12588	13161	13683	14230	14803	15404	16032
FEC (Mtoe)	2970	3143	3327	3523	3693	3862	4039	4226	4423	4585	4754	4932	5119	5316

The results and analysis of this deliverable are useful for the researchers in the field and other stakeholder groups interested in Chinese energy performance and energy policies. The analysis and results are especially useful for the researchers and interest groups interested in decomposition analysis of energy and CO_2 emissions, and constructing alternative future scenarios for China.

Table of contents

Introduction

Chinese economy is growing fast and the rapidly expanding volume of economic activity drives the increasing energy use. This is illustrated in Figure 1. It is easy to observe that the energy intensity of GDP is decreasing, but it is difficult to clearly observe energy efficiency trends from simply looking at the final energy consumption and gross domestic product.

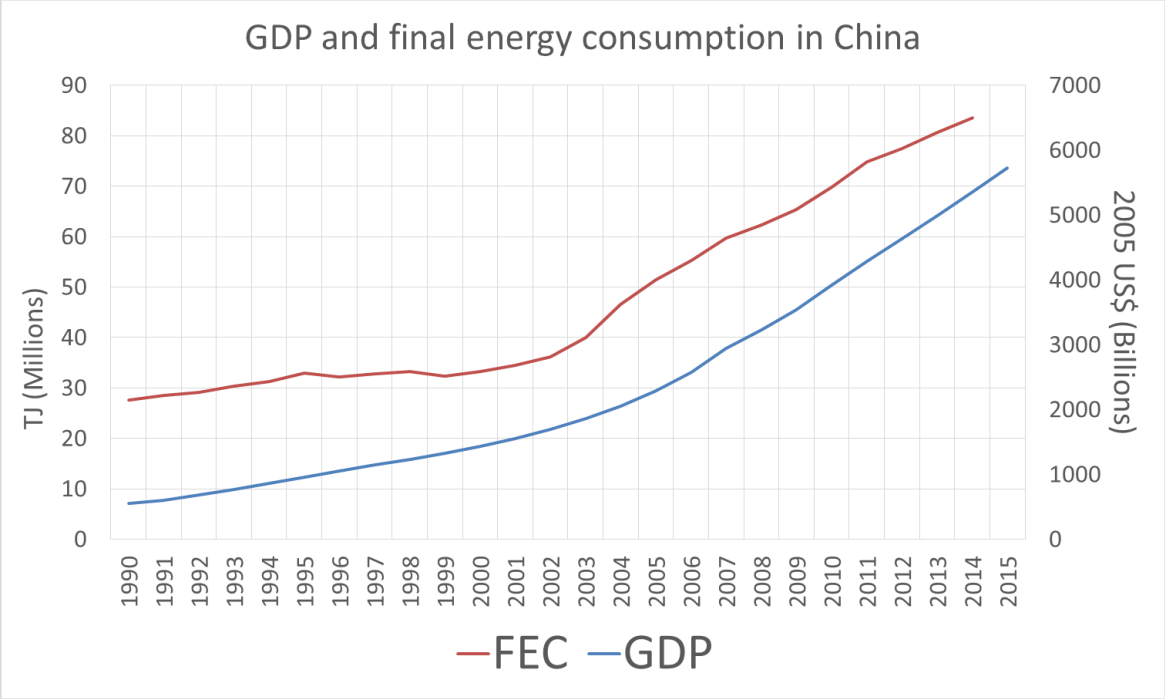

Figure 1. Gross domestic product and final energy consumption at national level in China. (World Bank: World Development Indicators [3]; International Energy Agency: Energy Balances [5])

Concurrently, a structural shift is taking place in the Chinese economy, as the service sector activities increase in their relative volume as measured by GDP. The service sector activities tend to be less energy-intensive as the industrial sector activities, so this structural shift, on the level of the whole economy, normally reduces energy consumption. The development of the sectoral value added is illustrated in Figure 2.

To quantify the energy efficiency improvements and to analyse their impact on energy use, it is necessary to isolate the effect of the economic growth and the effect of the structural shift towards less energy-intensive activities from the effect of energy efficiency improvements. This can be accomplished with structural decomposition analysis. In this report we analyse the energy efficiency trends in China in two levels: the more aggregated

level with a five-sector division, all industry subsectors treated as one single sector, and a more disaggregated level with 24 economic sectors. The aggregated level analysis provides an overview to the energy efficiency trends in China and an understanding of the phase of the structural shift towards service-oriented economy. The 24-sector structural decomposition analysis gives more detailed information on the energy intensity developments and efficiency potential especially on different industrial sectors.

Structural decomposition analysis background

Decomposition analysis is used to divide the change of an explained variable to several factors that jointly contribute to its change. The change in the energy use in a sector of an economy can be caused by general growth of economic activity in the whole economy, shifts in the shares of activity between the economic sectors and changes in the energy intensity. Structural decomposition analysis used here to investigate the energy intensity trends of Chinese economy aims to clearly show the effect of energy efficiency changes in the different sectors on the total energy use, by quantifying the effects of increased general economic activity and the shift of activity between the sectors with different energy intensity and isolating them from the impacts of changing energy efficiency.

The decomposition technique used for the decomposition analyses in this report is based on the Sun-Shapley method [8]. This technique is used to divide the change in FEC to three components: the *activity* or *quantity* effect, the *structural* effect and the *intensity* effect.

- The activity/quantity effect is the measure of the change of volume of activity that drives the energy use. In this analysis, it is measured as sectoral value added.
- The structural effect represents the impact of change of shift of activity between the different sectors. This is measured by the share of value added in the different sectors.
- The intensity effect is the measure of the impact of energy efficiency, measured as unit of energy over unit of value, i.e. FEC/GDP.

The decomposition technique used here divides the change in the explained variable so that the sum of all effects in all sectors is equal to the total change in the explained variable, and also so that the sum of all effects in a single sector sum to be the change in the energy consumption in the sector in question. It is noteworthy that the technique results in a decomposition where structural effects do not sum to be zero, but the sum of structural effects reflects the effect of structural shift in the whole economy.

Data sources and data transformations for the decomposition analyses

The following structural decomposition analysis of Chinese economy uses data from National Bureau of Statistics of China and the World Input-Output Database. The sectoral final energy consumption data has been extracted from National Bureau of Statistics of China database [7]. The sectoral value added data is sourced from the World Input-Output Database [6].

The used databases do not have a fully matching sectoral division. Some economic subsectors have been combined in both databases to match the statistical items so that the structural decomposition analysis would be possible. Table 1 details how the statistical items have been matched between the two datasets. The "Matching row(s)" column indicates which row or rows in the final energy consumption data the value added data corresponds to. In a case where several rows in the VA data correspond to a single row in the FEC data, the VA data rows have been summed to create an aggregate sector value from several value added sectors present in the World Input-Output Database. In cases where a single row in the VA data corresponds to more than one row in the FEC data, the FEC data rows have been summed to create an aggregate sector value from several sectors present in the energy consumption statistics provided by the National Bureau of Statistics of China. This process results in a dataset containing final energy consumption data and value added data for 26 economic sectors. For two of these sectors (Manufacture of other transport equipment; Repair and installation of machinery and equipment), there are significant data gaps in one or both of the combined datasets and these sectors have been left out of the analysis, resulting in a dataset with data for 24 sectors used in the decomposition analysis.

The value added data, which is reported as current US dollars in the World Input-Output Database, has additionally been converted into constant 2010 US dollars by computing the yearly shares of value added of each sector in the analysis and multiplying that share by the total GDP for that year reported as constant 2010 US dollars, as provided by the World Bank World Development Indicators database. This transformation is important as the decomposition analysis would display false energy efficiency improvements as a result of inflation.

The actual data which the decomposition has been performed with has further been transformed so that a 3-year moving average has been used to substitute the original values. This transformation is usually beneficial in decomposition analysis. The aim is to reduce the impact of possibly unusual or outlier-type values for the base year and comparison year.

Row	FEC data, National Bureau of Statistics of China	VA data, World Input-Output Database	Matching row(s)
1	Total Energy Consumption	Crop and animal production, hunting and related service activities	2
2	Farming, Forestry, Animal Husbandry, Fishery and Water Conservancy	Forestry and logging	2
3	Industry	Fishing and aquaculture	2
4	Mining	Mining and quarrying	4
5	Mining and Washing of Coal	Manufacture of food products, beverages and tobacco products	13,14,15,16
6	Extraction of Petroleum and Natural Gas	Manufacture of textiles, wearing apparel and leather products	17,18,19
7	Mining and Processing of Ferrous Metal Ores	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	20
8	Mining and Processing of Non-Ferrous Metal Ores	Manufacture of paper and paper products	22
9	Mining and Processing of Non-Metal Ores	Printing and reproduction of recorded media	23
10	Support Activities of Mining	Manufacture of coke and refined petroleum products	25
11	Mining of Other Ores	Manufacture of chemicals and chemical products	26,28
12	Manufacturing	Manufacture of basic pharmaceutical products and pharmaceutical preparations	27
13	Processing of Food from Agricultural Products	Manufacture of rubber and plastic products	30,31
14	Manufacture of Foods	Manufacture of other non-metallic mineral products	32
15	Manufacture of Beverages	Manufacture of basic metals	33,34
16	Manufacture of Tobacco	Manufacture of fabricated metal products, except machinery and equipment	35
17	Manufacture of Textile	Manufacture of computer, electronic and optical products	41
18	Manufacture of Textile Wearing Apparel, Footware, and Caps	Manufacture of electrical equipment	40
19	Manufacture of Leather, Fur, Feather and Related Products	Manufacture of machinery and equipment n.e.c.	36,37
20	Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm and Straw Products	Manufacture of motor vehicles, trailers and semi-trailers	38
21	Manufacture of Furniture	Manufacture of other transport equipment	39
22	Manufacture of Paper and Paper Products	Manufacture of furniture; other manufacturing	21,24,42,43
23	Printing, Reproduction of Recording Media	Repair and installation of machinery and equipment	45
24	Manufacture of Articles For Culture, Education and Sport Activity	Electricity, gas, steam and air conditioning supply	44,46
25	Processing of Petroleum, Coking, Processing of Nuclear Fuel	Water collection, treatment and supply	44,46
26	Manufacture of Raw Chemical Materials and Chemical Products	Sewerage; waste collection, treatment and disposal activities; materials recovery	44,46
27	Manufacture of Medicines	Construction	50
28	Manufacture of Chemical Fibers	Wholesale and retail trade and repair of motor vehicles and motorcycles	52
29	Manufacture of Rubber and Plastics	Wholesale trade, except of motor vehicles and motorcycles	52
30	Manufacture of Rubber	Retail trade, except of motor vehicles and motorcycles	52
31	Manufacture of Plastics	Land transport and transport via pipelines	51
32	Manufacture of Non-Metallic Mineral Products	Water transport	51
33	Smelting and Pressing of Ferrous Metals	Air transport	51
34	Smelting and Pressing of Non-Ferrous Metals	Warehousing and support activities for transportation	51
35	Manufacture of Metal Products	Postal and courier activities	51
36	Manufacture of General Purpose Machinery	Accommodation and food service activities	52
37	Manufacture of Special Purpose Machinery	Publishing activities	53
38	Manufacture of Transport Equipment	Motion picture, video and television programme production, sound recording and music publishing activities	53
39	Manufacture of Railway, Shipping, Aerospace and Other Transport Equipments	Telecommunications	53
40	Manufacture of Electrical Machinery and Equipment	Computer programming, consultancy and related activities; information service activities	53
41	Manufacture of Communication Equipment, Computers and Other Electronic Equipment	Financial service activities, except insurance and pension funding	53
42	Manufacture of Measuring Instruments and Machinery for Cultural Activity and Office Work	Insurance, reinsurance and pension funding, except compulsory social security	53
43	Manufacture of Artwork and Other Manufacturing	Activities auxiliary to financial services and insurance activities	53
44	Recycling and Disposal of Waste	Real estate activities	53
45	Repair of Metal Products, Machinery and Equipment	Legal and accounting activities; activities of head offices; management consultancy activities	53
46	Electric Power, Gas and Water Production and Supply	Architectural and engineering activities; technical testing and analysis	53
47	Production and Distribution of Electric Power and Heat Power	Scientific research and development	53
48	Production and Distribution of Gas	Advertising and market research	53
49	Production and Distribution of Water	Other professional, scientific and technical activities; veterinary activities	53
50	Construction	Administrative and support service activities	53
51	Transport, Storage and Post	Public administration and defence; compulsory social security	53
52	Wholesale, Retail Trade and Hotel, Restaurants	Education	53
53	Others	Human health and social work activities	53
54	Household	Other service activities	53
55		Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	54
56		Activities of extraterritorial organizations and bodies	53
57		Final consumption expenditure by households	54

Table 1. Matching of the statistical items in the FEC and VA data.

Energy efficiency trends on the national level

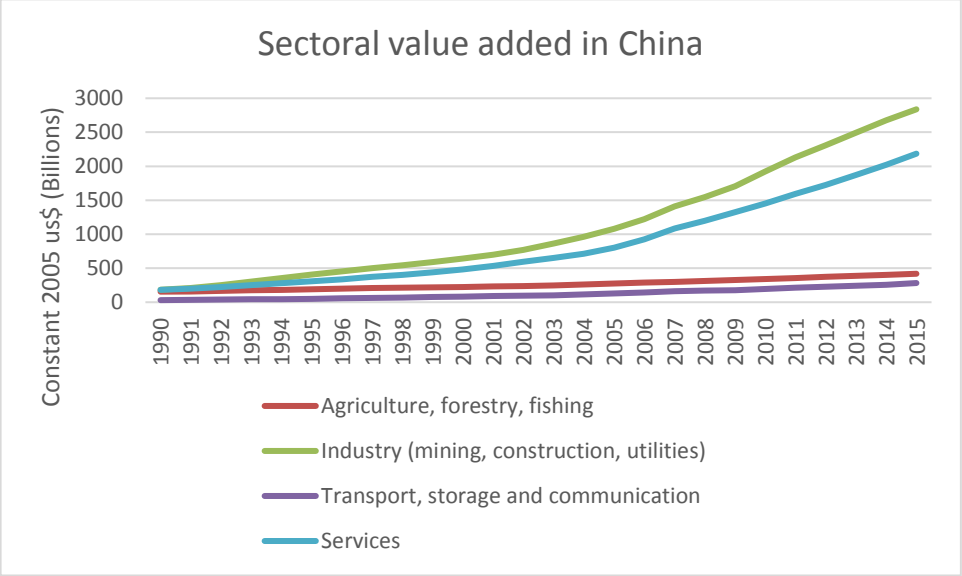

Figure 2. Sectoral value added in China 1990-2015. (World Bank: World Development Indicators; International Energy Agency: Energy Balances)

Figure 2 shows the development of the sectoral value added in China. The growth of value added in the agricultural sector and the transport sector is slow compared to the growth of value added in the industrial and service sector. It is noteworthy that the service sector value added remains smaller than in the industrial sector. In China, the next ten years might bring about significant shift in the focus in economic activity to service sector, which likely will contribute to reducing energy consumption.

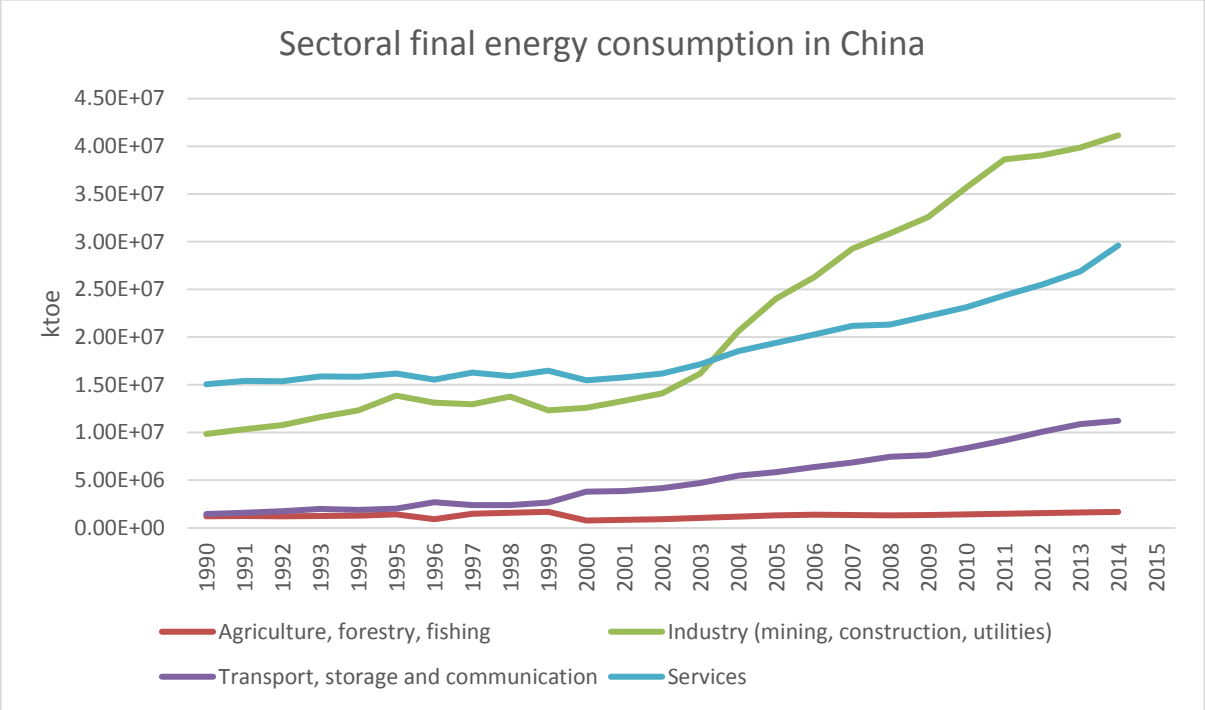

Figure 3. Sectoral final energy consumption in China (World Bank: World Development Indicators; International Energy Agency: Energy Balances)

Figure 3 shows the development of the sectoral final energy consumption, using the 4-sector division of the economy. The growth in energy consumption has been very fast in the period 2000-2010. The overall trend seems to be, however, a slow-down in the growth in energy use. Even when the energy intensity of the service sector activities is low, the high total energy consumption in service sector hints that significant energy efficiency gains can be made by improving efficiencies in service activities.

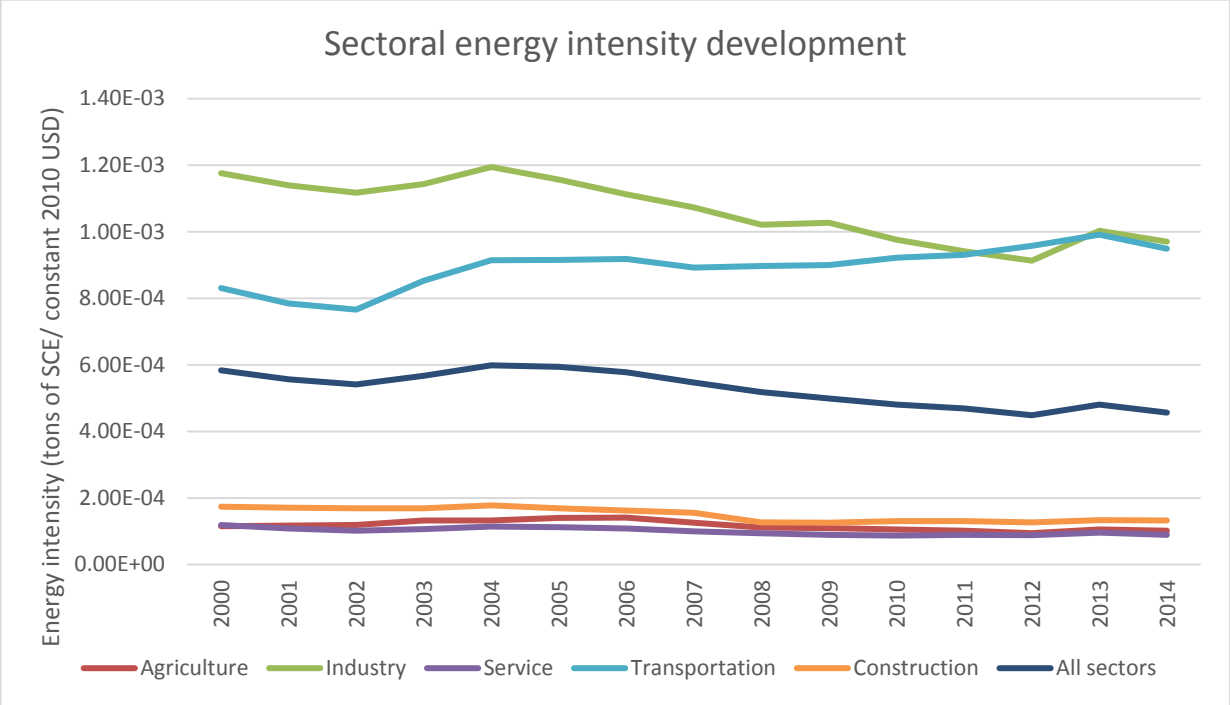

Figure 2. Development of energy intensity in China, using a 5-sector division.

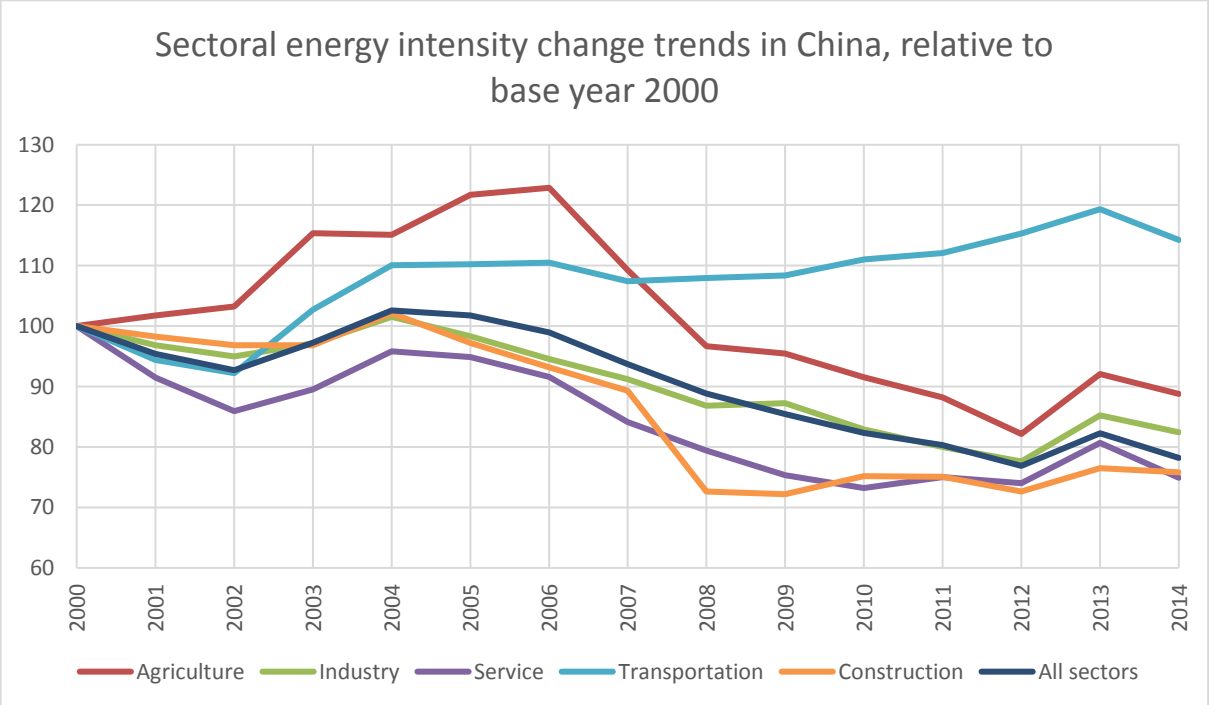

Figure 4. Sectoral energy intensity change trends in 5 sectors. Values for each sector are relative to base year 1990 value for the sector in question.

Figure 4 shows the development of energy intensity (FEC/GDP) in the different economic sectors in China. The yearly energy intensity values for each sector are compared to the energy intensities of base year 2000. The transport sector shows negative energy intensity improvement measured as value over energy used, and the transport sector is getting more energy intensive. Oher sectors show significant energy intensity improvement over the period 2000—2014. The construction and service sectors have seen the greatest improvements in energy intensity, and the decrease of energy intensity for these sectors has been better than the average improvement of the energy intensity in Chinese economy.

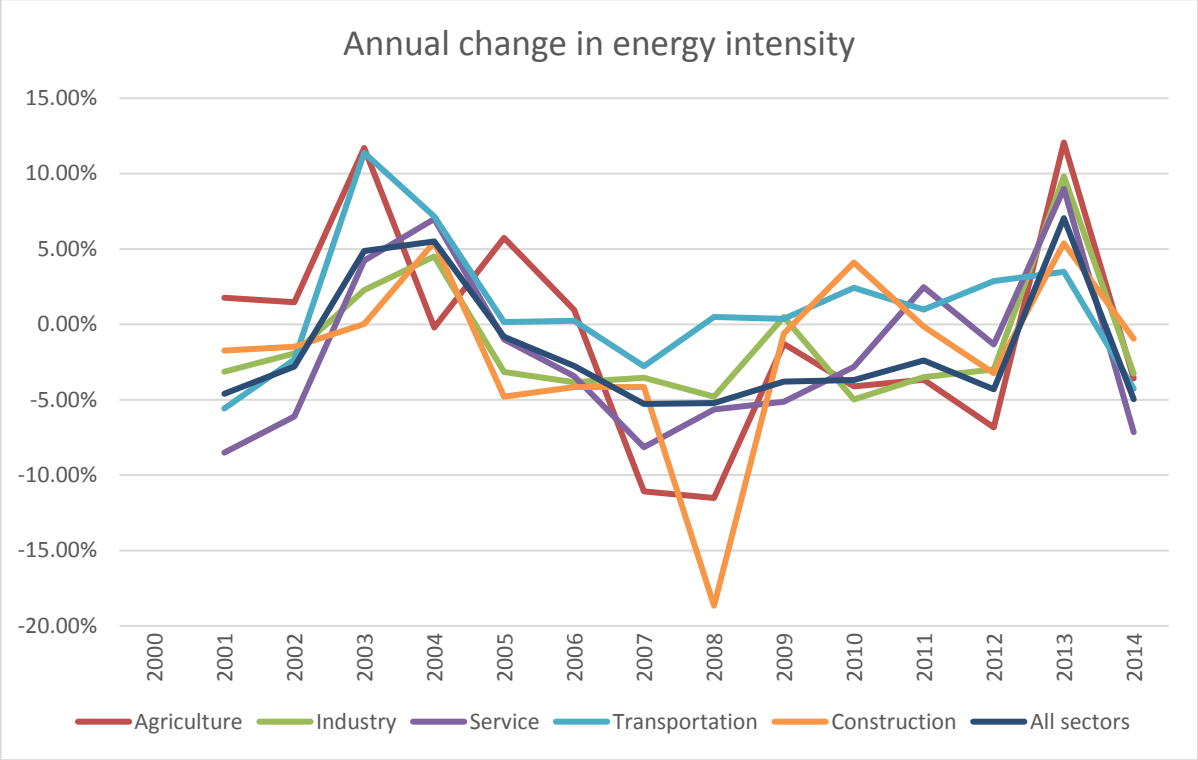

Figure 5. Annual change in the sectoral energy intensity in China.

Figure 5 shows the annual change of energy intensity in the different economic sectors in China. The total energy intensity improvements for the entire economy are more than 20% in the period 2000—2014, meaning that the energy intensity is about 78% in 2014 of what is was in year 2000. The industrial sector shows fairly consistent improvement of energy intensity over the period, summing up to a 17% decrease in energy intensity. The service sector has improved the energy intensity the most, being about 25% less energy intensive in 2014 in terms of unit of energy used to produce a unit of value. The energy intensity change trend for transport sector is quite stable but positive, meaning that the energy intensity of the transport sector is increasing. The energy intensity trend for agricultural sector is less stable in the period 2000-2014, but the overall development is that the energy intensity has

decreased more than 10%. The overall picture is that the Chinese economy has made fairly consistent energy intensity improvements over the examination period, amounting to a reduction of more than 20% in energy intensity.

Structural decomposition of the energy trends in agriculture, transport, industry, service and construction sectors

Figure 6 shows the decomposition analysis results using a 5-sector breakdown of the Chinese economy. The series display the absolute quantity, structural, intensity and total effects on energy use in relation to the base year 2000 level. The quantity effect (**Q**) embodies the effect of economic expansion or the general increase in the level of economic activity. The structural effect (**S**) reflects the impact of the structural shift of activities between the sectors. The intensity effect (**I**) is the most interesting as it captures the energy efficiency improvements as the effects of economic growth and structural change have been factored out. The total effect is the sum of the quantity, structural and intensity effects and the total change in the energy consumption from the year 2000.

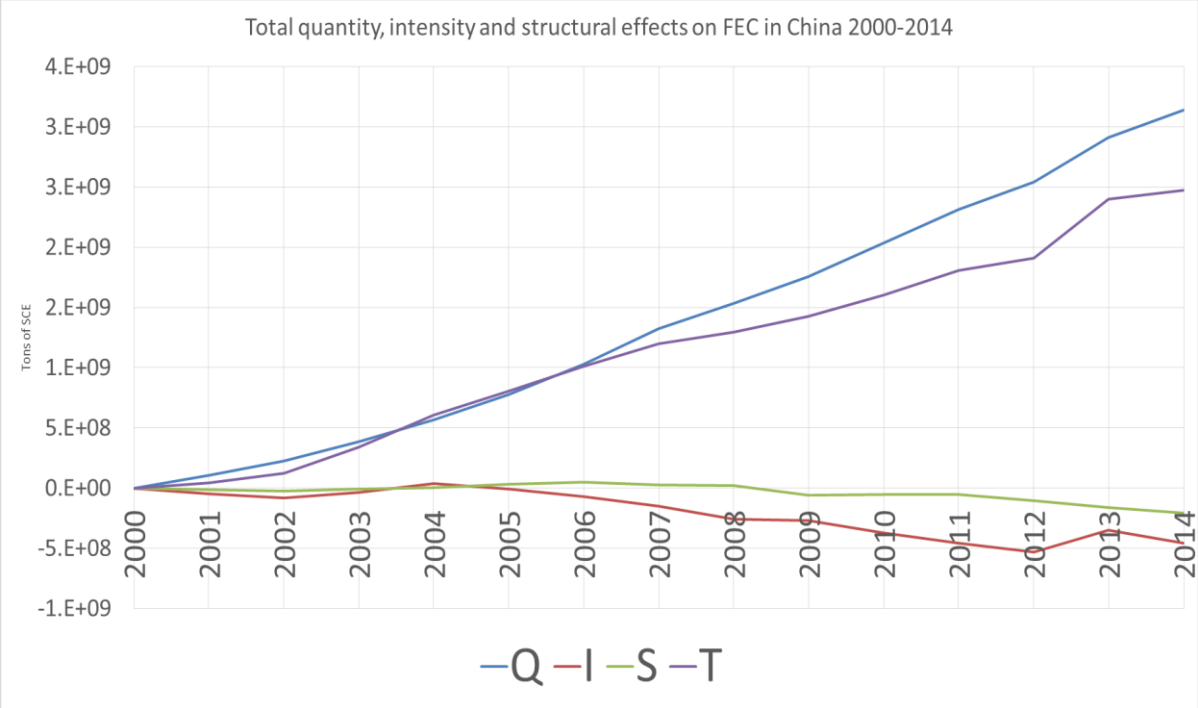

Figure 6. Total quantity, intensity and structural effects on FEC in China 1990-2014.

The total growth in energy consumption over the examination period has been about 2.5 Gigatons of coal equivalent. The quantity effect has contributed about 3.15 Gigatons of coal equivalent in terms of energy consumption growth in period 2000—2014. In China, the structural effect is unusual or different from the structural effects in EU or USA in the sense

that the structural effect on energy consumption is quite small and the energy efficiency improvements measured by the intensity effect are clearly higher than the effects of structural change. The structural shift has amounted to about 0.2 Gigatons of coal equivalent of energy use reduction. The energy consumption increasing quantity effect is partially cancelled by the structural shift and the energy efficiency improvements in the whole economy, summarized by the intensity effect. The energy efficiency improvements in China amount for total of 0.46 Gigatons of coal equivalent less energy consumed. Without the structural change and the improvements in energy efficiency, the change in the energy use would have been equal to the development in the quantity effect, increasing by 3.15 Gigatons of coal equivalent. All and all, the savings through improved energy efficiency appear to be dwarfed by the speedy economic expansion.

Structural decomposition of the Chinese economy using 24 economic sectors

To form a more detailed picture of the energy intensity and energy efficiency trends in China, a more detailed 24-sector decomposition analysis has also been performed. The 24-sector examination is less aggregated especially in terms of industrial subsectors. As the energy intensity in the aggregated industrial sector is comparatively high, it makes sense to investigate the efficiency trends in the subsectors in more detail.

	Change in FEC:		75294	Change in FEC:		63482	Change in FEC:		81629			
	2001-2005			2005-2009			2009-2013			2001-2013		
	Q	I	S	Q	I	S	Q	I	S	Q	I	S
Agriculture	1966	837	-890	2705	-1502	-989	2334	-512	-425	7046	-955	-2567
Mining and quarrying	4953	-3528	992	6817	-3156	236	6763	-1336	-397	20305	-10320	1359
Manufacture of food products, beverages and tobacco products	1721	-810	-164	2276	-1536	161	2141	-1381	638	6856	-4388	578
Manufacture of textiles, wearing apparel and leather products	1943	1239	-661	2996	-1174	-756	2674	-904	-738	7037	-219	-2199
Manufacture of wood and of products of wood and cork, except furniture; manufac	211	148	-4	379	-137	41	403	-69	39	897	54	61
Manufacture of paper and paper products	1158	389	-372	1665	-501	-732	1368	-537	-839	3963	-472	-1891
Printing and reproduction of recorded media	104	86	-97	148	20	-113	135	-31	-32	403	110	-293
Manufacture of coke and refined petroleum products	3827	-1577	2370	6053	-6640	3362	5760	2005	-3610	15258	-7515	3808
Manufacture of chemicals and chemical products	8131	-631	676	12254	-5698	-564	12618	5058	-4237	33813	-3032	-3174
Manufacture of basic pharmaceutical products and pharmaceutical preparations	428	-69	-153	563	-237	-140	560	-148	198	1749	-542	-206
Manufacture of rubber and plastic products	763	590	-280	1267	-32	-441	1213	-458	-224	2945	448	-995
Manufacture of other non-metallic mineral products	6654	2044	-560	10608	-10598	5115	10181	-2601	-1	26565	-10039	4316
Manufacture of basic metals	13304	-3533	12246	24218	616	-3920	25286	10961	-21089	54556	2878	656
Manufacture of fabricated metal products, except machinery and equipment	708	258	-52	1192	-459	183	1280	-54	1	3055	-108	110
Manufacture of computer, electronic and optical products	426	-10	332	819	388	-405	863	-461	97	1796	28	226
Manufacture of electrical equipment	369	54	107	672	-96	105	741	-99	-56	1637	-77	238
Manufacture of machinery and equipment n.e.c.	1085	46	90	1757	-613	138	1719	2	-992	4277	-532	-513
Manufacture of motor vehicles, trailers and semi-trailers	746	-362	122	1165	-1099	942	1068	-1494	261	3088	-3103	1365
Manufacture of furniture; other manufacturing	721	-202	-500	875	211	-754	801	144	-510	2876	139	-2231
Electric Power, Gas and Water Production and Supply; Recycling and Disposal of Wa	5961	-3377	2492	8710	2699	-7400	8248	-345	-2472	23162	-2118	-6529
Construction	1097	-35	83	1734	-1141	542	1894	125	322	4901	-1289	1008
Wholesale and Retail Trade; Hotels, Restaurants	1552	363	-230	2432	-1400	411	2687	348	647	6928	-746	627
Transport, Storage and Post	5784	2182	-1250	9214	-219	-3209	9718	1838	-1555	24745	4603	-6843
Services	2920	-46	405	4737	-2221	940	5218	-111	987	13058	-2699	2472
Total quantity, intensity and structural effect	**66534**	**-5941**	**14701**	**105254**	**-34524**	**-7248**	**105676**	**9939**	**-33986**	**270913**	**-39893**	**-10615**
Total effect (Q+I+S) on FEC	75294			63482			81629			220405		
Change in FEC	55.6 %			30.1 %			29.8 %			162.7 %		

Table 2. Absolute quantity, intensity and structural effects on FEC, in 10000 tons of standard coal equivalent.

Table 2 displays the absolute sectoral effects of economic expansion (Quantity effect), energy efficiency improvements (Intensity effect) and structural change (Structural effect) on final energy consumption. Table 3 displays the same information in relative terms: the values in Table 3 represent the contribution of quantity, intensity and structural effects on the total change of final energy consumption in the time period in question. For instance, in the period 2001-2005, the quantity effect in the agricultural sector has contributed an increase of 1.5% to the final energy consumption. The energy efficiency development in the agricultural sector has been negative, meaning that the energy efficiency appears to have worsened and the intensity effect reflecting the impact of energy efficiency improvements contributes positively (+0.6%) to the total change in final energy consumption. The structural effect for agricultural sector is negative, as expected, and contributes a decrease of 0.7% to the total change in final energy consumption.

The most interesting part of the structural decomposition analysis are the trends pertaining to energy efficiency improvements, the effects of which are isolated to the intensity effects.

The overall picture for China for the entire analysis period 2001—2013 (tabulated in the last column triplet) is that the energy efficiency has improved considerably, contributing a nearly 30% decrease to the final energy consumption. The structural effect also has decreased the final energy consumption, but the main component of reductions in the energy consumption stem from energy efficiency improvements instead of structural change. The level of economic expansion (the quantity effect) by far defeats the decreases of energy efficiency improvements and structural change.

In the entire analysis period 2001—2013 the biggest contributor sectors to increasing energy use have been manufacturing of basic metals (+42.9%), manufacturing of chemicals and chemical products (+20.4%), transport, storage and postal sector (+16.6%) and manufacture of other non-metallic mineral products (+15.4%). The same four sectors also have the greatest increase in the level of economic activity summarized by the quantity effect.

The greatest negative contributions to energy use through improving energy efficiency represented by the intensity effect stem from mining and quarrying (-7.6% contribution to the change in energy use), manufacture of other non-metallic mineral products (-7.4%), manufacture of coke and refined petroleum products (-5.5%) and manufacture of food products, beverages and tobacco products (-3.2%). On the other hand, there are several sectors where the energy efficiency development over the period 2001—2013 appears to be negative (the sector is getting less energy efficient) as measured by the intensity effect. These are transport, storage and post (+3.40 %), manufacture of basic metals (+2.12 %), manufacture of rubber and plastic products (+0.33 %), manufacture of furniture; other manufacturing (+0.10 %), printing and reproduction of recorded media (+0.08 %), manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials (+0.04 %) and manufacture of computer, electronic and optical products (+0.02 %).

	2001-2005			2005-2009			2009-2013			2001-2013		
	Q	I	S	Q	I	S	Q	I	S	Q	I	S
Agriculture	1.5 %	0.6 %	-0.7 %	1.3 %	-0.7 %	-0.5 %	0.9 %	-0.2 %	-0.2 %	5.2 %	-0.7 %	-1.9 %
Mining and quarrying	3.7 %	-2.6 %	0.7 %	3.2 %	-1.5 %	0.1 %	2.5 %	-0.5 %	-0.1 %	15.0 %	-7.6 %	1.0 %
Manufacture of food products, beverages and tobacco products	1.3 %	-0.6 %	-0.1 %	1.1 %	-0.7 %	0.1 %	0.8 %	-0.5 %	0.2 %	5.1 %	-3.2 %	0.4 %
Manufacture of textiles, wearing apparel and leather products	1.4 %	0.9 %	-0.5 %	1.4 %	-0.6 %	-0.4 %	1.0 %	-0.3 %	-0.3 %	5.2 %	-0.2 %	-1.6 %
Manufacture of wood and of products of wood and cork, except furniture; manufac	0.2 %	0.1 %	0.0 %	0.2 %	-0.1 %	0.0 %	0.1 %	0.0 %	0.0 %	0.7 %	0.0 %	0.0 %
Manufacture of paper and paper products	0.9 %	0.3 %	-0.3 %	0.8 %	-0.2 %	-0.3 %	0.5 %	-0.2 %	-0.3 %	2.9 %	-0.3 %	-1.4 %
Printing and reproduction of recorded media	0.1 %	0.1 %	-0.1 %	0.1 %	0.0 %	-0.1 %	0.0 %	0.0 %	0.0 %	0.3 %	0.1 %	-0.2 %
Manufacture of coke and refined petroleum products	2.8 %	-1.2 %	1.7 %	2.9 %	-3.2 %	1.6 %	2.1 %	0.7 %	-1.3 %	11.3 %	-5.5 %	2.8 %
Manufacture of chemicals and chemical products	6.0 %	-0.5 %	0.5 %	5.8 %	-2.7 %	-0.3 %	4.6 %	1.8 %	-1.5 %	25.0 %	-2.2 %	-2.3 %
Manufacture of basic pharmaceutical products and pharmaceutical preparations	0.3 %	-0.1 %	-0.1 %	0.3 %	-0.1 %	-0.1 %	0.2 %	-0.1 %	0.1 %	1.3 %	-0.4 %	-0.2 %
Manufacture of rubber and plastic products	0.6 %	0.4 %	-0.2 %	0.6 %	0.0 %	-0.2 %	0.4 %	-0.2 %	-0.1 %	2.2 %	0.3 %	-0.7 %
Manufacture of other non-metallic mineral products	4.9 %	1.5 %	-0.4 %	5.0 %	-5.0 %	2.4 %	3.7 %	-0.9 %	0.0 %	19.6 %	-7.4 %	3.2 %
Manufacture of basic metals	9.8 %	-2.6 %	9.0 %	11.5 %	0.3 %	-1.9 %	9.2 %	4.0 %	-7.7 %	40.3 %	2.1 %	0.5 %
Manufacture of fabricated metal products, except machinery and equipment	0.5 %	0.2 %	0.0 %	0.6 %	-0.2 %	0.1 %	0.5 %	0.0 %	0.0 %	2.3 %	-0.1 %	0.1 %
Manufacture of computer, electronic and optical products	0.3 %	0.0 %	0.2 %	0.4 %	0.2 %	-0.2 %	0.3 %	-0.2 %	0.0 %	1.3 %	0.0 %	0.2 %
Manufacture of electrical equipment	0.3 %	0.0 %	0.1 %	0.3 %	0.0 %	0.0 %	0.3 %	0.0 %	0.0 %	1.2 %	-0.1 %	0.2 %
Manufacture of machinery and equipment n.e.c.	0.8 %	0.0 %	0.1 %	0.8 %	-0.3 %	0.1 %	0.6 %	0.0 %	-0.4 %	3.2 %	-0.4 %	-0.4 %
Manufacture of motor vehicles, trailers and semi-trailers	0.6 %	-0.3 %	0.1 %	0.6 %	-0.5 %	0.4 %	0.4 %	-0.5 %	0.1 %	2.3 %	-2.3 %	1.0 %
Manufacture of furniture; other manufacturing	0.5 %	-0.1 %	-0.4 %	0.4 %	0.1 %	-0.4 %	0.3 %	0.1 %	-0.2 %	2.1 %	0.1 %	-1.6 %
Electric Power, Gas and Water Production and Supply; Recycling and Disposal of Wa	4.4 %	-2.5 %	1.8 %	4.1 %	1.3 %	-3.5 %	3.0 %	-0.1 %	-0.9 %	17.1 %	-1.6 %	-4.8 %
Construction	0.8 %	0.0 %	0.1 %	0.8 %	-0.5 %	0.3 %	0.7 %	0.0 %	0.1 %	3.6 %	-1.0 %	0.7 %
Wholesale and Retail Trade; Hotels, Restaurants	1.1 %	0.3 %	-0.2 %	1.2 %	-0.7 %	0.2 %	1.0 %	0.1 %	0.2 %	5.1 %	-0.6 %	0.5 %
Transport, Storage and Post	4.3 %	1.6 %	-0.9 %	4.4 %	-0.1 %	-1.5 %	3.5 %	0.7 %	-0.6 %	18.3 %	3.4 %	-5.1 %
Services	2.2 %	0.0 %	0.3 %	2.2 %	-1.1 %	0.4 %	1.9 %	0.0 %	0.4 %	9.6 %	-2.0 %	1.8 %
Total quantity, intensity and structural effect	**49.1 %**	**-4.4 %**	**10.9 %**	**49.9 %**	**-16.4 %**	**-3.4 %**	**38.5 %**	**3.6 %**	**-12.4 %**	**200.0 %**	**-29.4 %**	**-7.8 %**
Total effect (Q+I+S) on FEC		55.6 %			30.1 %			29.8 %			162.7 %	

Table 3. Relative quantity, intensity and structural effects on FEC. Percentages are contributions to the change of final energy consumption between base year and comparison year, and their sum is equal to the total change in FEC.

The time periods used in the analysis help to see the trends for the different effects in each sector and for the total economy. The period 2005—2009 has seen fast energy efficiency improvements, but on the level of the whole economy, this overall energy efficiency trend has been reversed in the period 2009—2013. For that period, the overall energy efficiency improvements appear to be negative, and the worsening energy efficiency has contributed a 3.6% increase to the energy consumption.

As the size of the sector influences the size of the efficiency improvements reflected by the sectoral intensity effects, the energy efficiency performance comparison between the different sectors requires relating the intensity effect of the sector to the change of the energy consumption in the sector in question. If the ratio of intensity effect over quantity effect is computed for each sector and these values computed for the periodic decomposition of 2005—2009 are compared to values computed for the period 2009—2013 decomposition, some sectoral energy efficiency trends can be observed more clearly. The energy efficiency trend has worsened most (meaning that the difference between intensity effect value of period 2009—2013 and intensity effect value of period 2005—2009 is the greatest) for manufacture of coke and refined petroleum products sector, followed by manufacture of chemicals and chemical products, manufacture of other non-metallic mineral products, construction sector and wholesale and retail trade sector. The most positive trend of development for energy efficiency appears to be manufacture of computer, electronic and optical products sector, followed by manufacture of motor vehicles, trailers and semi-trailers, printing and reproduction of recorded media, manufacture of rubber and plastic products and electric power, gas and water production and supply and recycling and disposal of waste sectors.

FEC/VA: tons of SCE per constant 2010 USD	2001	2013	Change	Annual
Agriculture	1.17E-12	1.00E-12	-14 %	-1.23 %
Mining and quarrying	9.40E-12	5.50E-12	-41 %	-4.36 %
Manufacture of food products, beverages and tobacco products	4.33E-12	2.18E-12	-50 %	-5.57 %
Manufacture of textiles, wearing apparel and leather products	4.35E-12	4.19E-12	-4 %	-0.31 %
Manufacture of wood and of products of wood and cork, except furniture	1.85E-12	1.95E-12	5 %	0.43 %
Manufacture of paper and paper products	1.24E-11	1.08E-11	-13 %	-1.13 %
Printing and reproduction of recorded media	1.23E-12	1.65E-12	34 %	2.47 %
Manufacture of coke and refined petroleum products	3.71E-11	2.23E-11	-40 %	-4.16 %
Manufacture of chemicals and chemical products	2.84E-11	2.58E-11	-9 %	-0.80 %
Manufacture of basic pharmaceutical products and pharmaceutical preparations	4.45E-12	3.18E-12	-29 %	-2.76 %
Manufacture of rubber and plastic products	4.26E-12	4.98E-12	17 %	1.31 %
Manufacture of other non-metallic mineral products	2.91E-11	1.96E-11	-33 %	-3.26 %
Manufacture of basic metals	3.52E-11	3.67E-11	4 %	0.35 %
Manufacture of fabricated metal products, except machinery and equipment	4.77E-12	4.61E-12	-3 %	-0.29 %
Manufacture of computer, electronic and optical products	1.35E-12	1.37E-12	2 %	0.14 %
Manufacture of electrical equipment	2.01E-12	1.91E-12	-5 %	-0.39 %
Manufacture of machinery and equipment n.e.c.	3.04E-12	2.66E-12	-12 %	-1.10 %
Manufacture of motor vehicles, trailers and semi-trailers	5.03E-12	1.73E-12	-66 %	-8.51 %
Manufacture of furniture; other manufacturing	4.42E-12	4.66E-12	5 %	0.44 %
Electric Power, Gas and Water Production and Supply; Recycling and Disposal of Waste	1.99E-11	1.80E-11	-10 %	-0.86 %
Construction	1.71E-12	1.30E-12	-24 %	-2.24 %
Wholesale and Retail Trade; Hotels, Restaurants	1.25E-12	1.11E-12	-11 %	-0.96 %
Transport, Storage and Post	7.94E-12	9.66E-12	22 %	1.65 %
Services	1.03E-12	8.28E-13	-20 %	-1.81 %
TOTAL:	5.57E-12	4.53E-12	-19 %	-1.72 %

Table 4. Sectoral energy intensities and intensity changes

The general energy intensity trends serve as a basis for the ChinaLinda analysis of the impacts of different energy efficiency trends in China. The 24-sector energy intensities and their average changes annually and total changes over the period 2001—2013 are shown in Table 4. The ChinaLinda model operates on a more aggregate sectoral division, so the 24-sector data has been aggregated to conform to the ChinaLinda model sectoral structure.

Energy intensity (tons of SCE / USD)	2001	2013	change	annual
Agriculture	0.00011651	0.000100459	-13.8 %	-1.2 %
Industry	0.001144503	0.000961963	-15.9 %	-1.4 %
Service	0.000109656	9.07643E-05	-17.2 %	-1.6 %
Transportation	0.000793556	0.000966008	21.7 %	1.7 %
Construction	0.000171055	0.000130408	-23.8 %	-2.2 %
All sectors	0.000560248	0.000461593	-17.6 %	-1.6 %

Table 5. Five-sector aggregate energy intensity changes.

Table 5 presents the total change in the energy intensities in the period 2001—2013 and annual sectoral energy intensity changes. Three-year averages have been used to get the values for 2001 and 2013. The ChinaLINDA analysis of the development of the Chinese economy, energy system and emissions as a function of differing energy intensity trends is partially based in these observed energy intensity trends.

ChinaLINDA analysis of outcomes of existing trends and comparison to policy targets

ChinaLINDA is a case or application of a more general LINDA model used in the analysis of economy from an energy and emission perspective. The LINDA (Long-range Integrated Development Analysis) model is based on intensity approach, building on the Extended Kaya Identity, which is used for the calculation of CO2 emissions [2]. The following equation presents the main Kaya identity components used in LINDA model.

$$CO_2 = \frac{CO_2}{TPES} \times \frac{TPES}{FEC} \times \frac{FEC}{GDP} \times \frac{GDP}{POP} \times POP$$, where

- CO2 is carbon dioxide emissions from fuel combustion,
- TPES is total primary energy supply (including all fuels and other forms of primary energy, before the combustion process and transfer and distribution of electricity or heat),
- FEC is final energy consumption, meaning consumption of energy carriers such as district heat and electricity, and fuels used in residential heating and transport,
- GDP is gross domestic product in real prices, and
- POP is the amount of population.

This Kaya identity forms the basic conceptual framework behind the LINDA model and the choice of modeled factors is somewhat based on the Extended Kaya Identity. ChinaLINDA is a so-called accounting framework-type of model, and compared against the Extended Kaya Identity the model is much more detailed including different fuels and electricity, electricity production as well as different sectors of economy in the calculation procedures. In addition, the population, accounted as households, is divided into rural and urban groups.

As there are a great multitude of factors that can be varied by the user in the ChinaLINDA model, including but not limited to population growth, economic development in different sectors, energy production system details including construction of new power plants and plant efficiencies, and fuel use mix in different economic sectors, the analysis focuses on varying only general energy development. For most technical parameters of the model, such as fuel mix, power plant efficiencies, and construction of new power plants, a reasonable continuation of existing trends is assumed. For the economic development, which is central to the energy efficiency related observations made, the trend forecast relies upon the targets of the 13th five-year plan and a slowing-down trend of economic growth after the 2016—2020 period. The overall GDP growth target for the 13th FYP is 6.5% annually. The GDP growth is assumed to slow down further in the period after 2020. Table 6 presents the assumed

annual sectoral GDP growth rates. With the assumed sectoral growth rates, the total growth of the economy falls into the growth track projected in the 13th FYP.

	2014-20	2020-25	2025-30
Agriculture	4.0 %	3.0 %	3.0 %
Industry	6.5 %	6.0 %	5.5 %
Transportation, communication	6.0 %	5.0 %	5.0 %
Commercial	8.0 %	7.0 %	6.0 %
Construction	9.0 %	8.5 %	8.0 %
Others	6.0 %	5.0 %	5.0 %
Total	6.5 %	5.9 %	5.5 %

Table 6. Annual sectoral GDP growth rates assumed in the ChinaLINDA projection

As for the energy efficiency development, the ChinaLINDA approach makes it possible to compare the existing energy intensity development trend with the targets of 13th five-year plan. Table 7 presents the annual energy intensity changes for the different economic sectors under the assumption that the targets of the 13th five-year plan are reached. Table 8 presents the annual energy intensity changes for the sectors based on the assumption that observed trends continue over the 13th five-year plan period and the energy intensity change keeps improving after that at a reasonable pace.

	2014-20	2020-25	2025-30
Agriculture	-3.0 %	-4.0 %	-5.0 %
Industry	-7.0 %	-9.0 %	-11.0 %
Commercial	-6.0 %	-7.0 %	-8.0 %
Transportation	-4.0 %	-5.0 %	-6.0 %
Construction	-12.0 %	-14.0 %	-16.0 %

Table 7.Energy intensity development compliant with the targets of the 13th FYP

	2014-20	2020-25	2025-30
Agriculture	-1.2 %	-1.6 %	-2.2 %
Industry	-1.4 %	-1.9 %	-2.6 %
Commercial	-1.6 %	-2.2 %	-2.9 %
Transportation	1.7 %	0.0 %	-1.8 %
Construction	-2.2 %	-3.0 %	-4.0 %

Table 8. Energy intensity development projection in line with observed trends.

Varying the energy intensity growth rates and keeping the rest of the possible parameters equal in the ChinaLINDA model results in a range of scenarios, different in terms of final

energy consumption and CO_2 emissions, among other things. Two projections are presented for final energy consumption and CO_2 emission level, based on assuming either the development along the continuation of trends (table 8) or successful implementation of 13th FYP policies resulting in energy intensity targets [4]. The projection with the successful policy assumptions is presented in table 9. Table 10 presents the projection of emissions and energy consumption under assumption of continuation of observed trends.

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
CO2 (Mtons)	8401	8630	8873	9131	9353	9557	9780	10023	10287	10506	10752	11026	11329	11662
FEC (Mtoe)	2594	2629	2667	2709	2741	2736	2736	2743	2756	2735	2724	2723	2731	2750

Table 9. Projection of CO_2 emissions and final energy consumption under the policy scenario

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
CO2 (Mtons)	9037	9499	9987	10502	11026	11521	12042	12588	13161	13683	14230	14803	15404	16032
FEC (Mtoe)	2970	3143	3327	3523	3693	3862	4039	4226	4423	4585	4754	4932	5119	5316

Table 10. Projection of CO_2 emissions and final energy consumption under the observed trend continuation scenario

As data beyond year 2014 is not available, the scenarios start to differentiate before the first year (2017) shown in the tables, resulting in different values for the starting years. The difference in final energy consumption between the two scenarios for year 2030 is more than 2500 Mtoe, meaning that the energy consumption would be larger by a factor of nearly 2 in the trend scenario. The difference in terms of CO_2 emissions is 4370 Megatons, or 37%. The magnitude of differences in the projections speak on the other hand to the stringency of the Chinese energy efficiency targets and on the other hand the significant potential of energy savings in the Chinese energy systems and economy.

Summary

The analysis of energy intensity development shows manufacture of motor vehicles, trailers and semi-trailers, manufacture of food products, beverages and tobacco products, mining and quarrying, manufacture of coke and refined petroleum products and manufacture of other non-metallic mineral products as interesting economic sectors in terms of best development towards less energy intensive production. The printing and reproduction of recorded media, transport sector, manufacture of rubber and plastic products, and manufacturing of furniture and wood products show negative development or comparatively slow positive development in energy intensities, hinting at possible energy savings potential within the activities of these sectors.

The mining sector has overall contributed most significantly to energy savings through energy efficiency improvements, and nearly as important is the manufacture of non-metallic mineral products sector. A third very significant sector in absolute energy savings through efficiency gains is the manufacture of coke and refined petroleum products sector. Problematic sectors with large quantity effects but negative energy efficiency development are especially manufacture of basic metals sector and the transport sector. The poor efficiency development and high volume of economic activity in these sectors hint at significant efficiency gains that might possibly be made by policy interventions.

The Chinese policy targets for energy efficiency appear stringent in light of the observed development of energy efficiency. If the policies are, however, successfully implemented and the aspired energy intensity goals are met, the energy saved and the emissions avoided are decisively lower than in the case of continued development along the observed trend of energy intensity in China.

References

[1] Energy Efficiency Market Report. 1st ed. Paris: International Energy Agency, 2017. Web. 25 Apr. 2017.

[2] J. Luukkanen, J. Panula-Ontto, J. Vehmas, Liu Liyong, J. Kaivo-oja, L. Häyhä, B. Auffermann, Structural change in Chinese economy: Impacts on energy use and CO2 emissions in the period 2013–2030, Technological Forecasting and Social Change, Volume 94, May 2015, Pages 303-317, ISSN 0040-1625, http://doi.org/10.1016/j.techfore.2014.10.016. (http://www.sciencedirect.com/science/article/pii/S0040162514003023)

[3] World Development Indicators, The World Bank. Available at http://data.worldbank.org/. Accessed 1.-5.4.2017.

[4] ChinaLINDA scenario ”Policy”. Ying Chen, Jinxing Jiang. The parameters of this ChinaLINDA scenario are extracted from various policy documents detailing the 13th five-year plan and its targets.

[5] International Energy Agency, World Energy Balances 2016.

[6] Timmer, M. P., Dietzenbacher, E., Los, B., Stehrer, R. and de Vries, G. J. (2015), "An Illustrated User Guide to the World Input–Output Database: the Case of Global Automotive Production", Review of International Economics., 23: 575–605

[7] Chinese National Statistics, National Bureau of Statistics of China. Available at http://www.stats.gov.cn/english/Statisticaldata/AnnualData/. Accessed 1.-5.4.2017.

[8] J.W. Sun, Changes in energy consumption and energy intensity: A complete decomposition model, Energy Economics, Volume 20, Issue 1, 1 February 1998, Pages 85-100, ISSN 0140-9883, https://doi.org/10.1016/S0140-9883(97)00012-1.