Structural change in Chinese economy: Impacts on energy use and CO\textsubscript{2} emissions in the period 2013–2030

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Abstract

This study investigates the effect of the change of economic structure on the emissions and energy use in China. The study uses the ChinaLINDA model, a calculation framework especially well suited for analysing structural change and sectoral shifts in Chinese economy and industry. We illustrate the implications of the different economic development paths up to year 2030 regarding emissions, energy use and employment with a set of three scenarios.

In comparison with the reference scenario, the reduction in CO\textsubscript{2} emission level in policy scenario is less than $\frac{1}{3}$ by 2030 even with huge investment in renewable energy capacity and a clear turn away from carbon-intensive growth pattern. Cumulatively the difference of emissions between the reference scenario and policy scenario within 2013–2030 is less than 20%. The Chinese CO\textsubscript{2} intensity and energy intensity targets are rather stringent. Reaching the CO\textsubscript{2} intensity target is difficult even with the optimistic assumption of fast expansion of renewable energy capacity and fast structural change. However, while the renewable energy capacity grows fast, targets set for it are not equally ambitious. The set CO\textsubscript{2} intensity and energy intensity targets call for concretization.

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of energy policy.

*Keywords:* China, Structural change, Economic modeling, CO₂ emissions, Energy consumption

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1. **Introduction**

1.1. **Background**

The Chinese economy is in a transitional state: Chinese leadership hopes to steer the economic development away from exports and investment and towards serving the Chinese domestic market, increasing the living standard of the Chinese citizenry as well as reducing the environmental impact that the long-enduring high economic growth has caused. In addition to the general vision laid out in the 12th five year plan and related state planning documents, there are several factors that also drive the change towards a more service-oriented economy and higher-value-added industrial profile that will also be discussed in this paper.

Among the national economies, China is the largest emitter of CO₂ emissions and the development of its economic system in the next 15 years will have great weight in determining cumulative global emissions. An important question is what kind of impact these structural changes will have on emissions and energy use and how do these contrast with the emission-related targets set by the Chinese leadership for the next decades.
1.2. Research task

This study investigates the effect of the change of economic structure on the emissions and energy use in China. We present three scenarios that illustrate the different development paths for China’s economy up to year 2030 and their implications regarding emissions, energy use and employment. The study uses the ChinaLINDA model, a calculation framework especially well suited for analysing structural change and sectoral shifts in Chinese economy and industry.

Scenarios can be useful in handling uncertainty. They also provide a possibility for exploration of the future. In contrast to forecasts, that aim to play out the consequences of most probable developments, a set of scenarios can illustrate the possible developments even when they are not the most likely. The scenario set in this study opens up the alternative developments for Chinese economy with recent trends and political will directed to a more service-oriented economy in mind.

We attempt to answer the following two questions:

1. How much can we expect the reorientation of the Chinese economy and the policy initiatives of the Chinese leadership to lower the energy use and emissions in the time period 2013–2030?

2. How important is the profile of the industry for the amount of the emissions?

The Chinese targets concerning economic growth, emissions and energy expressed in planning documents such as the 12th five-year plan [18] and the 2011 white paper on climate change [14, Ch.VII] can already be seen as quite ambitious, and reaching these targets is by no means certain. The ChinaLINDA approach can give us an idea of the potential of the proposed policy actions and the likely bottlenecks and conflicts in reaching the targets. We present an answer to the research questions in the form of three scenarios that illustrate what can be achieved with the successful implementation of the stated policies concerning structural change and how much the industrial structure influences the energy use and emissions.
This study does not include calculations of the cost implications of different scenarios, even though extremely relevant for policy making, they are, however, outside the scope of this paper. Furthermore, the exploration of possible futures concerning economic structure could be expanded in future research with more variation to key drivers of economic development, as this study focuses on exploration of a similar economic activity level with different sectoral emphasis configurations in the Chinese economy.

1.3. Originality

There are several papers presenting scenarios about emissions and energy use in China (see for example [36], [38], [30], [10], [12]). However, these studies differ from our study both in methodology and aims. Some studies ([10], [12]) use input-output approach for scenario creation. The strength of the ChinaLINDA approach in comparison to these studies is that it allows for taking technological change into account clearly better. Input-output approaches usually assume a constant technology factor, which is an unrealistic assumption when examining energy systems with a time span of twenty to thirty years. Van Vuuren et al. [36] present a set of long-range energy and emission scenarios, but the parameters vary on a general, highly aggregated level and do not focus on the effect of economic structure on emissions. In comparison, our study takes the different energy use and emission impacts of economic activity in different sectors clearly better into account. The scenarios presented by Wang and Watson [38] look into the impact of economic structure on the economy among other things, but it is not the primary focus of the scenarios and the impact of economic structure cannot be isolated and analysed as many other things beside economic structure and industrial profile vary in the scenarios. Our scenario study focuses specifically on answering the research questions about the impact of the economic structure and in the scenarios we present only a select number of variables vary outside economic structure.
2. Drivers of structural change in China

Steenhof and Fulton have presented a high-level framework[31] of the drivers of the future development of the Chinese electricity sector. Figure 1 presents this framework. The identification of drivers of structural change in our study is based mostly on this framework.

Decomposition analysis has also been used for evaluating the contribution of different driving forces on China’s carbon emissions and energy use. Two fairly recent examples of this include studies by Kaivo-oja et al.(2014) [17] and Minx (2011) [20]. These studies underline the contribution of energy efficiency improvements in lowering the emissions and the opposite contribution of growing affluence in growth of the emissions.

Figure 1: Conceptual framework of the drivers and processes effecting the future development of China’s electricity sector [31]

2.1. Goals and policies

Hopes are expressed in the 12th five-year plan that China’s economy should be transformed from an investment- and export-driven economy to an economy
driven mostly by domestic consumption. This is hoped to help in reducing the inequality of income, decrease imprudent fixed asset investment and lessen China’s reliance on exports, making it less vulnerable to global trends. Smaller reliance on exporting should decrease the trade surplus and reduce the need to artificially devalue Yuan. As the construction sector and China’s current export industries are very energy- and emission-intensive, the policies aimed at shifting the focus from investment and exports to consumption are expected to lower the emissions and energy use.

China has not committed to absolute reductions to its emissions. Its position, until 2007, has been that developing economies should not be expected to commit to emission reductions. This position has since been changed. Before the climate conference of 2009 in Copenhagen China’s premier Wen Jiabao stated that China would reduce its carbon dioxide emissions per unit of GDP by 40% – 45% by 2020 compared to the 2005 level. While some commenters [27] see this target as unambitious to the point of being almost meaningless, even this target should mean a clear shift away from high-polluting industries such as steel, cement and aluminum industries.

China has set a target for renewable energy in terms of share of consumption: by 2020, 15% of all energy should come from renewable sources [30] [32]. Currently, about 8% of China’s total primary energy come from non-fossil sources. By 2020, installed capacity should reach 420 GW for hydropower [5], 200 GW for wind power (with 170 GW onshore and 30 offshore) [6], 100 GW for solar power [11] and 30 GW for biomass [6]. Vehicle fuels should also have at least 15% renewable energy content by 2020 . [32] The target for nuclear capacity is 86 GW by 2020 [30]. With the currently planned additional reactors, capacity in 2020 will increase to at least 58 GW.

2.2. Economic growth and economic reform

The last five-year plans have set GDP growth targets which, perhaps surprisingly, are not lower bounds in their nature but rather exact targets that, at least in theory, should not be exceeded. The 11th five year plan set the growth
target at 7.5%, while the actual growth turned out to be about 11% [18]. The 12th five-year plan sets the growth target to 7%, which may be exceeded again. It looks, however, that the GDP growth might be slowing down slightly. The component of fixed investment in Chinese GDP remains quite high and the ongoing urbanization process partially explains the abnormally high GDP growth rates.

The general trend of reforms in the Chinese economy has been an increasing market-economy orientation from 1980 onwards, but some observers argue that the reforms have stopped and even reversed since 2005 [26]. The policy of the state forcing mergers and consolidation in many fields and on the other hand actively grooming certain big corporations for becoming future “national champions” as expressed in the 12th five-year plan [18] can be seen as an indication of a partial reversal of market-oriented reforms. This is likely to slow the economic growth and along that, the energy use.

2.3. Demographic change

China is in the final stages of demographic transition, with the most significant mortality declines having taken place in the period 1950–1975 and the fertility level declined from 2.74 in 1979 to well below the replacement level of 2.1 to about 1.6 in 2010 [39]. The government-enforced one-child policy has been central to making the Chinese demographic transition exceptionally fast [13], but also causing problems such as sex imbalance and a looming dependency ratio crisis in the future [37], causing experts to recommend hasty modifications to the policy [23].

The size of Chinese work force is peaking in the next few years and generally the population aging is fast in comparison to the US and even to Europe [33]. The rapid increase of the number of elderly is a major challenge for the underdeveloped pension system [37]. The workforce will still remain big in comparison to EU-27 and USA, but China’s advantage of being easily able to supply masses of low-paid laborers for simple manufacturing jobs is coming to a close. China remains a demographic giant well into the future, but its relative share of
the global population will shrink considerably over the next decades. In 2030, China is estimated to be home to less than 17% of world’s population [33]. In summary, the demographic factors, that have been favourable to growth in the period 1980–2010, can be argued to be unfavourable to growth for the next 30-year period: the growth of the Chinese economy will slow down, reducing energy use.

2.4. Urbanization

The urbanization level of China is comparatively low, about 50%. It is rising rapidly and expected to continue rising over the next decades. The urban population is estimated to number over 1 billion in 2030. [19]. The urbanization and the huge migration involved are seen among the most motive forces of China’s economic growth and development [23]. The fixed investment required by the urbanization drives the strong growth of the Chinese economy. McKinsey Global Institute estimates that during the period 1999-2009 as much as 50% of the GDP has come from urban fixed investment [19], and its share of GDP is likely to remain high in the future. The construction sector is also very energy-intensive and will contribute greatly to energy use during the period 2013–2030. Urbanization of the next 20 years is also estimated to move about 300 million people from rural to urban areas, with many of these people being employed in jobs with much higher productivity than before. This process will also have major implications for the lifestyle of the new Chinese urbanites, changing consumption patterns of much of the Chinese population significantly: urbanization will also contribute to the environmental impact through this transformation.

2.5. Energy technology

Chinese energy policy has emphasised the use of non-fossil energy sources in the future energy production. The possibilities for a major increase of non-fossil energy depend largely technology development. The fast diffusion of Chinese wind power has relied on competitive domestic production, but in the future the
scale-dependent effect in the wind power market can reduce the growth figures [8].

The main drivers in the increasing installations of photovoltaic power in China are the reducing costs of the solar panels (< 0.6 USD/Wp), the support by the Renewable Energy Law of China through the feed-in tariff and the Special Renewable Energy Fund. The feed-in-tariff was 1 Yuan per kWh in 2012. In August, 2012, National Energy Administration (NEA) published "The Twelfth Five-year Plan of Renewable Energy Development" with the increased target of PV from 15 GW to 21 GW focusing on distributed PV market and in December 2012 it increased the target from 21 GW to 35 GW and published the target of 100 GW for 2020. [11]

In September 2012 the Chinese government unveiled plans to stimulate local PV demand with a programme to promote distributed solar generation. The measures were brought in to address overcapacity in China’s PV manufacturing industry and trade tensions with Europe and the US. China’s National Energy Administration (NEA) is formulating plans to set up distributed PV generation demonstration plants across the country. The plans were announced at a meeting convened by the NEA in June 2012. The pilot projects will operate in National Economic Development Zones and industrial parks across China with large numbers of industrial companies, high energy usage and prices, and strong solar resources. The NEA requires that the chosen parks should be financed by a single development team, using a 'self-generate/consume' model, and that the demand of the subsidies should be no more than 0.45 CNY / kWh. The expected fast increase of the natural gas use in China in the future relies on gas imports and the utilization of shale gas. China has largest shale gas deposits in the world [35] but the start-up phase has been slowed down due to the under-developed natural gas infrastructure in terms of pipelines and other facilities (see e.g. [21]).

Carbon Capture and Storage (CCS) is seen as one possibility of reducing CO2 emissions in future energy systems. The development of the technology
has been slow worldwide due to the high costs. Under the IEA BLUE Map Scenario, which calls for global CO2 emissions from the energy sector to be reduced by 50% from 2005 levels by 2050, it is anticipated that CCS could contribute about 19% of total emissions reduction. Under this scenario, China would need to build 10 to 12 large-scale projects by 2020 and ramp up to 600 projects by 2050 [3]. China is planning several coal and gas power plants that can bury their carbon deep underground and is looking into offsetting the extra cost of these power plants by using the captured carbon to recover oil from nearby wells ([24], see e.g.).

2.6. Energy markets

During the first decade of the 2000’s, China has turned into a net energy importer [2]. Figure 2 shows the percentage of energy use in China during the period 1971–2011. The current net energy imports are more than 10% of the total energy use [39]. China is the world’s largest coal producer, but in the last years, even coal consumption has exceeded production and China has become a net coal importer. As United States seems to become more self-sufficient and demand in EU is not likely to grow significantly, China will probably emerge as the most important importer of oil. China’s largest oil fields are mature and their production has already peaked [34].

The possibility of severe problems in supplying oil and gas to China before 2015 has been explored in recent energy scenarios by Shell [28]. The share of imported energy will increase in the future, because demand is expected to increase at a much faster rate than domestic energy production. Thus, the global energy market is an increasingly important driver of China’s energy future. The rapid change of China’s position from a major energy supplier to one of the World’s largest energy importers has brought a really big player in the global oil, gas and coal markets, and made policymakers and businessmen in other parts of the world anxious [25].

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[International Energy Agency]
China’s increasing oil demand has been driven more by investments in heavy industry than consumption, which has been a surprise especially in the oil market [25]. Imports of natural gas have been at a modest level, but LNG terminals in the coastal areas of China and a pipeline from gas-rich Siberia in Russia have been planned. China has a significant share of the World’s coal reserves, but it is also one of the world’s largest coal importers. Firing coal is still the most economical way of large-scale electricity production, and increasing coal demand is due to increasing need of electricity.

3. ChinaLINDA model

4. Model structure

ChinaLINDA is a case or application of a more general LINDA model used in the analysis of economy from an energy and emissions perspective. The LINDA (Long-range Integrated Development Analysis) model is based on intensity approach, building on the Extended Kaya Identity, which is used for calculation of
CO₂ emissions. Equation 1 presents the Kaya identity used in LINDA model.

\[
\text{CO}_2 = \frac{\text{CO}_2}{\text{TPES}} \times \frac{\text{TPES}}{\text{FEC}} \times \frac{\text{FEC}}{\text{GDP}} \times \frac{\text{GDP}}{\text{POP}} \times \text{POP}
\]  

(1)

where

- \text{CO}_2 \text{ is carbon dioxide emissions from fuel combustion;}
- \text{TPES} \text{ 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);}
- \text{FEC} \text{ is final energy consumption, meaning consumption of energy carriers such as district heat and electricity, and fuels used in residential heating and transport;}
- \text{GDP} \text{ is gross domestic product in real prices; and}
- \text{POP} \text{ 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.

Figure 3 shows a simplified diagram for the calculation procedure of residential electricity demand. The change rates and other parameters the model needs are provided by experts of relevant fields: The dashed lines in the figure indicate the flow of expert knowledge inputs. Similar calculation procedure is applied for the calculation of different fuels used at households.

The LINDA model, based on the given inputs, calculates future scenarios for the economy and the energy use in different sectors. Figure 4 gives a simplified
Table 1: Calculation procedures of the LINDA model

<table>
<thead>
<tr>
<th>Historical economic development</th>
<th>Future economic growth rates (by user)</th>
<th>Future economic development</th>
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<tr>
<td>- Sector 1</td>
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Figure 3: Linda model procedure for calculation of electricity demand and population illustration of the main calculation blocks of the model for energy demand construction in the different production sectors. This calculation is carried out for the different fuels and electricity in each modelled economic sector (agriculture, industry, transport, commercial, construction, others).

Figure 4: Calculation procedures of the LINDA model

Figure 5 indicates the linkages of different calculation modules in the LINDA model. The historical data is given as input in the model. This includes time...
series data of: a) the use of different fuels and electricity in different economic sectors; b) the electricity production; c) the power plant capacity using different energy sources; d) technical information of power plant operation (plant capacity factor and efficiency); e) the value added in different economic sectors; and f) the population data.

The energy demand for different fuels and electricity in different sectors of economy is calculated based on the historical data and user given inputs about the future changes in energy intensities and economic growth in each sector. The future economic growth rates that are used in the model can be based on government plans, econometric models or expert information. The change rates in future energy intensities in different sectors can be based on information of different technological development trends, plans for new investments in different sectors (e.g. investments in energy intensive metal production) or other expert information (see e.g. discussion by Steenhof[31]).

In the electricity production sector the investment plans for different types of power plants are given as input data for future scenarios. The fuel efficiency and plant load factor in addition to the installed capacity determine the needed fuel input to produce the electricity needed to cover the demand. The LINDA model does not utilize hourly load curves to calculate the electricity demand but uses a more straightforward calculation based on yearly averages.

The LINDA model output is future energy use by fuel in different sectors and related CO₂ emissions. The emissions are calculated using the IPCC guidelines. [16] The model can be used to create different scenarios by varying for instance the future economic growth figures in different sectors or the energy intensities. The shares of different fuels can also be varied easily to illustrate e.g. changes in government policies.

4.1. Input data

ChinaLINDA model draws input data on multiple sources. The population data in the model is supplied by Institute of population and labor economics, Chinese academy of Social Science [15]. The energy data is from Energy Statis-
tics Division, Chinese National Bureau of Statistics [9]. Economic data and data on other issues such as transportation and construction is from the China Statistical Yearbook [22]. Some input data concerning the sub-sectoral breakdown of the economy comes from a 2011 paper by Chen [4].

5. Scenarios

Our scenario study concentrates on the impacts of economic structure on energy demand and related CO$_2$ emissions. The starting point has been the construction of a reference scenario projecting the development in China up to year 2030. The reference scenario is based on the economic growth rates presented in a CASS research paper [29]. These figures are quite close to the growth rates of NBSC [3] and DRC [4]. The purpose of the reference scenario is to provide a robust general projection of future developments in China that

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2 Chinese Academy of Social Science  
3 National Bureau of Statistics of China  
4 Development Research Center of the State Council
can be used as a point of reference for the scenario comparisons.

The ChinaLinda model uses the sub-sectoral differentiation of the industrial sector shown in table 2. A clear strength of the ChinaLINDA model in comparison to many other systems of providing projections for energy demand and emissions in China is that the scenario construction is based on data and projections of the sub-sectoral developments. An obvious but not always accounted-for fact is that all sub-sectors of the industry do not grow at the same speed. The energy intensities of different sub-sectors of industry vary considerably (see figure 9) as well as the potential of decreasing energy intensity in these sub-sectors. Due to these facts, the differences in the growth patterns within the industrial sub-sectors will lead to considerable differences in energy demand and emissions even when the total value added in the industrial sector would be equal in the different set-ups. The same is also true for the general sectoral composition of the economy: Different growth rates for service sector and industrial sector will lead to very different levels of energy demand and emissions. The 12th five year plan has a strong emphasis on developing the service sector, and the future growth rate of the service sector is very important from this point of view.

We answer the research questions presented in section 1.2 by comparison of three scenarios constructed with the ChinaLINDA model. The scenarios are called a) Reference scenario, or REF for short, b) Policy scenario, or POL for short and c) Heavy industry scenario, or IND for short.

The economic growth rate of different sectors in the Reference scenario (REF) is presented in table 1. The industrial growth rate is high in this scenario: it represents a continuation of historical trends and policies emphasizing industrial growth in China. The total GDP growth rate is equal to the projections by Liu [29].

The future sectoral growth rates for the second scenario, titled ”Policy” (POL), are also presented in table 1. The Policy scenario plays out the implementation of energy and climate policy targets in China. In this scenario, the industrial growth is much slower than in the Reference scenario, but the growth in commercial sector is faster. The total growth rate in these two scenarios is
identical.

Table 1: Sectoral annual growth rates: historical rates, "Reference" scenario rates, "Policy" scenario rates and "Heavy industry" scenario growth rates.

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</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>4.2%</td>
<td>4.0%</td>
<td>2.7%</td>
<td>4.4%</td>
<td>4.4%</td>
<td>4.9%</td>
<td>4.8%</td>
<td>4.8%</td>
<td>4.6%</td>
<td>4.9%</td>
<td>4.8%</td>
<td>4.6%</td>
<td>4.9%</td>
<td>4.8%</td>
</tr>
<tr>
<td>Industry</td>
<td>17.7%</td>
<td>10.9%</td>
<td>9.0%</td>
<td>11.7%</td>
<td>11.4%</td>
<td>10.2%</td>
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<td>9.3%</td>
<td>7.1%</td>
<td>4.8%</td>
<td>3.9%</td>
<td>7.1%</td>
<td>4.8%</td>
<td>3.9%</td>
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<tr>
<td>Transportation</td>
<td>10.9%</td>
<td>9.5%</td>
<td>9.8%</td>
<td>11.5%</td>
<td>11.3%</td>
<td>9.6%</td>
<td>9.8%</td>
<td>9.8%</td>
<td>7.1%</td>
<td>4.8%</td>
<td>4.0%</td>
<td>7.1%</td>
<td>4.8%</td>
<td>4.0%</td>
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<tr>
<td>Commercial</td>
<td>16.9%</td>
<td>8.5%</td>
<td>9.8%</td>
<td>11.5%</td>
<td>11.3%</td>
<td>9.6%</td>
<td>10.0%</td>
<td>9.0%</td>
<td>10.4%</td>
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<td>Construction</td>
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<td>9.6%</td>
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<td>10.4%</td>
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<td>16.0%</td>
<td>9.8%</td>
<td>4.6%</td>
</tr>
<tr>
<td>Others</td>
<td>10.9%</td>
<td>3.6%</td>
<td>3.7%</td>
<td>13.3%</td>
<td>5.0%</td>
<td>6.0%</td>
<td>6.0%</td>
<td>8.0%</td>
<td>11.6%</td>
<td>10%</td>
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</tr>
<tr>
<td>Total</td>
<td>12.2%</td>
<td>8.1%</td>
<td>5.3%</td>
<td>12.5%</td>
<td>10.3%</td>
<td>9.4%</td>
<td>7.5%</td>
<td>1.2%</td>
<td>9.4%</td>
<td>7.4%</td>
<td>5.2%</td>
<td>9.6%</td>
<td>7.5%</td>
<td>5.1%</td>
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</table>

In order to compare the impacts of industrial structure on the emissions we have derived the scenario titled "Heavy industry" (IND) from the policy scenario. In this scenario, the sectoral growth rates are equal to the Policy scenario but the growth rates of industrial sub-sectors are different. The energy intensive sub-sectors are growing faster than in the Policy scenario, but the total industrial growth rates are equal. The growth rates of value added in the industrial sub-sectors in the three scenarios is presented in table 2. The differences in the value added of the industrial sub-sectors in 2030 in the three scenarios are shown in figure 6.

The fastest growth in all industrial sub-sectors occurs in the Reference scenario. The Heavy industry scenario derived from the Policy scenario differs from Policy scenario in that the growth is higher in paper, chemical, medicines, rubber and minerals and basic metals industries, but is correspondingly slower in electrical and electronics industry and the metal products industry, summing to an equal total growth for the industrial sector in both scenarios.

Figures 7 and 8 illustrate the differences in development of absolute sectoral value added between Reference and Policy scenarios as well as the relative share of the sectors in the economy. The Heavy industry scenario is equivalent in the development of value added of economic sectors to the policy scenario, from which it is derived, so it is not presented here.

In the Reference scenario, the share of commercial sector is declining while the share of industry continues to grow fast. The service sector will not reach the 2015 target of 47 % of GDP set in the 12th Five Year Plan as can be seen
Table 2: Annual industrial sub-sector growth rates: historical rates, "Reference" scenario rates, "Policy" scenario rates and "Heavy industry" scenario growth rates.

<table>
<thead>
<tr>
<th>Sub-sector</th>
<th>Historical</th>
<th>Reference</th>
<th>Policy</th>
<th>Heavy industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food, beverages and tobacco</td>
<td>18.0%</td>
<td>13.8%</td>
<td>4.5%</td>
<td>6.9%</td>
</tr>
<tr>
<td>Textile, leather</td>
<td>12.8%</td>
<td>15.7%</td>
<td>8.7%</td>
<td>6.3%</td>
</tr>
<tr>
<td>Wood, paper and printing, education, artwork</td>
<td>20.5%</td>
<td>13.7%</td>
<td>4.7%</td>
<td>8.1%</td>
</tr>
<tr>
<td>Chemical</td>
<td>13.6%</td>
<td>10.1%</td>
<td>7.5%</td>
<td>6.7%</td>
</tr>
<tr>
<td>Coal and gas, mining and processing</td>
<td>7.7%</td>
<td>10.8%</td>
<td>6.8%</td>
<td>2.2%</td>
</tr>
<tr>
<td>Mining and processing ores</td>
<td>16.9%</td>
<td>15.9%</td>
<td>4.3%</td>
<td>2.9%</td>
</tr>
<tr>
<td>Medicine, rubber, plastics, mineral products</td>
<td>14.6%</td>
<td>12.2%</td>
<td>8.2%</td>
<td>8.3%</td>
</tr>
<tr>
<td>Smelting and processing metals</td>
<td>11.4%</td>
<td>10.9%</td>
<td>14.8%</td>
<td>14.1%</td>
</tr>
<tr>
<td>Metal products and machinery, transport equipment</td>
<td>11.0%</td>
<td>7.7%</td>
<td>8.8%</td>
<td>1.0%</td>
</tr>
<tr>
<td>Electrical and electronics</td>
<td>11.0%</td>
<td>10.4%</td>
<td>26.4%</td>
<td>19.0%</td>
</tr>
<tr>
<td>Electricity, gas and water</td>
<td>16.1%</td>
<td>14.6%</td>
<td>7.7%</td>
<td>8.5%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>17.7%</strong></td>
<td><strong>10.3%</strong></td>
<td><strong>8.4%</strong></td>
<td><strong>6.8%</strong></td>
</tr>
</tbody>
</table>

Figure 6: The value added in industrial subsectors in 2030 in Reference, Policy and Heavy industry scenarios

in table 3. In the Policy scenario the share of service sector grows and in this scenario the government target is almost reached.

The comparison shows that the the targets of the 12th five year plan are actually considerably stringent. Reaching the energy intensity and CO₂ intensity targets is not easy even when extremely high speed of renewable energy production capacity construction is assumed. The pressure to increase energy production, especially electricity production, is high due to the rapidly increasing industrial production as well as the lifestyle change towards more energy-intensive, consumerist lifestyle associated with the urbanization process.

The development of the value added in industrial sub-sectors in the three
Figure 7: Comparison of sectoral value added in Reference and Policy scenarios

Figure 8: Comparison of sectoral value added shares in Reference and Policy scenarios

Table 3: 12th five-year plan targets for year 2015 and the outcome in the scenarios

<table>
<thead>
<tr>
<th></th>
<th>Target</th>
<th>Reference</th>
<th>Policy</th>
<th>Heavy Industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy intensity reduction</td>
<td>-16 %</td>
<td>-7.8 %</td>
<td>-14.6 %</td>
<td>-8.2 %</td>
</tr>
<tr>
<td>CO₂ emission intensity reduction</td>
<td>-17 %</td>
<td>-9.7 %</td>
<td>-16.7 %</td>
<td>-9.8 %</td>
</tr>
<tr>
<td>Non-fossil fuel share</td>
<td>11.4 %</td>
<td>11.4 %</td>
<td>12.4 %</td>
<td>11.5 %</td>
</tr>
<tr>
<td>Service sector share</td>
<td>47 %</td>
<td>36.0 %</td>
<td>43.4 %</td>
<td>43.4 %</td>
</tr>
</tbody>
</table>
scenarios is presented in table 4. The fast increase in the share of electrical and electronics sub-sector is assumed to continue in the Policy scenario. In addition, the share of metal products and machinery and transport equipment is assumed to increase. This type of industrial development would lead to a sizeable reduction of the energy intensity of the industrial sector since the fastest growing sectors are not very energy intensive. Compared to Policy scenario, the growth in the Heavy industry scenario is higher in the paper, chemical, medicines, rubber and mineral and basic metal industries, but slower in electrical and electronics as well as metal products industries. This increases the overall energy intensity considerably in the industrial sector, increasing the energy demand.

Table 4: Development of value added in different industrial sub-sectors in the scenarios. Values as billion CNY in 1990 price.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Food, beverages and tobacco</td>
<td>283</td>
<td>993</td>
<td>1393</td>
<td>2268</td>
<td>750</td>
<td>870</td>
<td>1060</td>
<td>750</td>
<td>870</td>
<td>1060</td>
</tr>
<tr>
<td>Textile, leather</td>
<td>226</td>
<td>868</td>
<td>1218</td>
<td>1994</td>
<td>656</td>
<td>760</td>
<td>927</td>
<td>688</td>
<td>798</td>
<td>972</td>
</tr>
<tr>
<td>Wood, paper and printing, education, artwork</td>
<td>195</td>
<td>718</td>
<td>961</td>
<td>1423</td>
<td>624</td>
<td>759</td>
<td>1020</td>
<td>787</td>
<td>1157</td>
<td>1884</td>
</tr>
<tr>
<td>Chemical</td>
<td>188</td>
<td>842</td>
<td>1295</td>
<td>2328</td>
<td>670</td>
<td>855</td>
<td>1266</td>
<td>842</td>
<td>1181</td>
<td>2323</td>
</tr>
<tr>
<td>Coal and gas, mining and processing</td>
<td>98</td>
<td>137</td>
<td>131</td>
<td>107</td>
<td>137</td>
<td>131</td>
<td>107</td>
<td>137</td>
<td>131</td>
<td>107</td>
</tr>
<tr>
<td>Mining and processing ores</td>
<td>66</td>
<td>162</td>
<td>217</td>
<td>354</td>
<td>148</td>
<td>180</td>
<td>242</td>
<td>176</td>
<td>207</td>
<td>278</td>
</tr>
<tr>
<td>Medicines, rubber, plastics, mineral products</td>
<td>321</td>
<td>1310</td>
<td>1925</td>
<td>3786</td>
<td>1142</td>
<td>1458</td>
<td>2158</td>
<td>1370</td>
<td>1748</td>
<td>2588</td>
</tr>
<tr>
<td>Smelting and processing metals</td>
<td>147</td>
<td>785</td>
<td>1153</td>
<td>2865</td>
<td>683</td>
<td>831</td>
<td>1117</td>
<td>859</td>
<td>1383</td>
<td>2850</td>
</tr>
<tr>
<td>Metal products and machinery, transport equipment</td>
<td>385</td>
<td>2461</td>
<td>3787</td>
<td>6781</td>
<td>2052</td>
<td>2619</td>
<td>3876</td>
<td>1782</td>
<td>2368</td>
<td>2914</td>
</tr>
<tr>
<td>Electrical and electronics</td>
<td>587</td>
<td>3317</td>
<td>5104</td>
<td>10609</td>
<td>3169</td>
<td>4241</td>
<td>6908</td>
<td>2829</td>
<td>3047</td>
<td>3715</td>
</tr>
<tr>
<td>Electricity, gas and water</td>
<td>100</td>
<td>304</td>
<td>355</td>
<td>430</td>
<td>304</td>
<td>355</td>
<td>430</td>
<td>319</td>
<td>370</td>
<td>451</td>
</tr>
<tr>
<td>Total</td>
<td>2515</td>
<td>11898</td>
<td>17515</td>
<td>31557</td>
<td>10336</td>
<td>13056</td>
<td>19111</td>
<td>10338</td>
<td>13059</td>
<td>19442</td>
</tr>
</tbody>
</table>

It is assumed in the scenario comparison that the changes in electricity intensity of production in the industrial sub-sectors are similar in the different scenarios. The development of electricity intensity of different industrial sectors is shown in figure 9.

The electricity consumption increases fast in the Reference scenario due to the fast growth of energy intensive industrial production. This naturally increases also the fuel use and the related CO₂ emissions from fuel combustion. The electricity demand in the Policy scenario is much lower because the industrial growth is smaller than in the Reference scenario. The higher growth of service sector in the Policy scenario does not increase electricity demand as
Figure 9: Electricity intensity in different industrial sectors in China and its development in the scenarios. Identical development concerning electricity intensity is assumed in all three scenarios.

much due to the lower electricity intensity of the service sector. In the Heavy Industry scenario the electricity consumption increases fast even though the total industrial value added is similar to the Policy scenario. As the energy intensive sectors grow faster in the Heavy Industry scenario, faster energy use growth follows. Figure 10 illustrates the differences in electricity consumption in the different scenarios.

The differences concerning the electricity production in the scenarios are
mainly in the construction of thermal power plants and nuclear power. In all the scenarios the construction of hydro, solar and wind power capacity is assumed to continue fast and at the same speed. In the Reference scenario the higher growth in electricity demand is mainly covered by construction of additional thermal and nuclear power plant capacity. The electricity production from different energy sources in the scenarios is shown in figure 11.

The sectoral final energy use in the different scenario is shown in figure 12. The industrial energy use is dominant in the reference scenario due to the fast economic growth in the industrial sector and the energy intensity of the sector. In the Policy scenario the industrial energy use saturates by 2020 and the growth comes mainly from residential sector (which includes the use of private cars). The fuel use in the scenarios is shown in 13. In the Reference and Heavy industry scenarios coal remains the main source of energy even though the use of oil products in the transport sector is increasing fast. The use of natural
gas is also increasing fast both in industry and in electricity production where the shift from coal to gas is remarkable. The fuel shares in the different sectors are assumed to be identical in the different scenarios and the differences in fuel consumption result from the different growth rates in different sectors.

The 12th Five Year Plan has set a target of non-fossil fuels to account for 11.4% of primary energy consumption. This target is reached in all the scenarios. In the Reference scenario the share of non-fossil fuels would be 11.4%, in the Policy scenario 12.4% and in the Heavy Industry scenario 11.4% (see table 3). The target can be reached with speedy construction of wind and solar energy capacity. In all the scenarios the capacity of wind power would be 414 GW, solar PV power capacity 341 GW and hydro power capacity which would be about 585 GW by the year 2030. In the Reference scenario the nuclear power capacity would be about 194 GW in 2030 and in the Policy and Heavy Industry scenarios 171 GW in 2030. In 2030 the thermal power capacity, using mainly coal (80%) and gas as energy sources, would be in 2030 about 1 672 GW in the Reference scenario, 1 104 GW in Policy scenario and 1 597 GW in Heavy Industry scenario. The energy sector investments would need to be huge in all the scenarios.

The development of the CO$_2$ emissions in the different scenarios is shown in figure 14. The CO$_2$ emission level in 2030 compared across scenarios is also presented in table 5. In the Policy scenario the emissions are 27% lower than in the Reference scenario and the CO$_2$ emissions from fuel combustion reach a
level of about 6000 million tons of CO₂ in 2020 and stabilize after that.

The 12th five-year plan has also set a target for energy intensity reduction and CO₂ intensity reduction for 2020. The target for energy intensity reduction is 16%, but in the Reference scenario a reduction of only 8% is reached. Policy scenario reaches 14.6% reduction while the Heavy industry scenario also ends up to about 8% reduction (see table 3). The target for CO₂ intensity reduction is 17%. The Reference and Heavy industry scenarios reach only 10% reduction while the Policy scenario comes very close to reaching the target with 16.7% reduction (see table 3). The policy scenario demonstrates that the targets of the 12th five-year plan are actually quite ambitious and require a fast shift to more efficient production systems and non-fossil fuel use in energy production.

ChinaLINDA model can also be used for projecting the change in the labour force demand and employment by estimating the changes in labour intensity in the different sectors. The employment in the Reference scenario is decreasing after 2020. This is due to the lower economic growth after 2020 and the decreasing labour intensity in all the sectors. In the policy scenario the labour demand also decreases after 2020, but the general employment rate is higher than in the Reference scenario. This is due to the higher labour intensity in the service sector and the faster growth in non-industrial sectors. In the Policy scenario the demand for workforce is about 8 million persons higher in 2030 than in the Reference scenario due to Policy scenario’s more labour-intensive economic structure. Figure [15] illustrates the development of employment in different sec-
Table 5: Summary of the scenario results. The second column for scenarios "Policy" (POL) and "Heavy industry" (IND) indicates the percentual difference of value in comparison to the "Reference" (REF) scenario.

<table>
<thead>
<tr>
<th>Year 2030</th>
<th>REF</th>
<th>POL</th>
<th>IND</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDP (100 billion CNY)</td>
<td>494</td>
<td>491</td>
<td>491</td>
</tr>
<tr>
<td></td>
<td></td>
<td>−1%</td>
<td>−1%</td>
</tr>
<tr>
<td>Agriculture</td>
<td>21</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+19%</td>
<td>+19%</td>
</tr>
<tr>
<td>Industry</td>
<td>316</td>
<td>191</td>
<td>191</td>
</tr>
<tr>
<td></td>
<td></td>
<td>−39%</td>
<td>−39%</td>
</tr>
<tr>
<td>Commercial</td>
<td>110</td>
<td>228</td>
<td>228</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+108%</td>
<td>+108%</td>
</tr>
<tr>
<td>Transport and communication</td>
<td>19</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+5%</td>
<td>+5%</td>
</tr>
<tr>
<td>Construction</td>
<td>29</td>
<td>28</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td></td>
<td>−5%</td>
<td>−5%</td>
</tr>
<tr>
<td>Electricity consumption (Mtoe)</td>
<td>885</td>
<td>683</td>
<td>853</td>
</tr>
<tr>
<td></td>
<td></td>
<td>−23%</td>
<td>−4%</td>
</tr>
<tr>
<td>Final Energy Consumption (Mtoe)</td>
<td>2 774</td>
<td>2 276</td>
<td>2 754</td>
</tr>
<tr>
<td></td>
<td></td>
<td>−18%</td>
<td>−1%</td>
</tr>
<tr>
<td>Fuel consumption (Mtoe)</td>
<td>3 584</td>
<td>2 655</td>
<td>3 464</td>
</tr>
<tr>
<td></td>
<td></td>
<td>−26%</td>
<td>−3%</td>
</tr>
<tr>
<td>CO₂ emissions in 2030 (Mtons)</td>
<td>12 446</td>
<td>9 054</td>
<td>11 973</td>
</tr>
<tr>
<td></td>
<td></td>
<td>−27%</td>
<td>−4%</td>
</tr>
<tr>
<td>Employment (millions)</td>
<td>586</td>
<td>667</td>
<td>667</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+14%</td>
<td>+14%</td>
</tr>
</tbody>
</table>

tors in China in the scenarios. The employment in Heavy industry scenario is similar to the Policy scenario because no data on industrial sub-sector labour force was available and changes in these could not be included in the model.

6. Comparison to previous scenario studies

As in most other scenario studies on Chinese economy and emissions, all scenarios presented feature a sharp increase in electricity use and fuel use. This is due to high estimated economic growth, comparatively slow decrease in electricity intensity in economic production sectors and urbanization process, which greatly increases household electricity consumption. The electricity production figures in the presented scenarios for 2030 do not differ greatly from the scenarios by the International Energy Agency. The reference scenario figures are only a little higher than IEA Current Policy scenarios, while the policy scenario figures are little bit lower that the IEA New Policies scenario.

Comparison of the REF, POL and IND scenarios to several scenario studies
on Chinese economy are presented in figure 16.

The compared scenarios are constructed by International energy agency (IEA "New Policies" scenario, "450" Scenario, "Current policies" scenario) [2], United States Energy Information Administration (Scenarios IEO "Ref", "High" and "Low") [11], Chinese Energy Research Institute (Scenarios ERI "Baseline", "Low carbon", "Accelerated low carbon") [40], Lawrence Berkley National Laboratory (Scenarios LBNL "CIS", "CIS with CCS") [40], Dai et al. (Scenario Dai et al.) [5].

IEA New Policies IEA 450 IEA Current Policies LBNL CIS LBNL CIS with CCS ERI Baseline ERI Low carbon ERI Accel low carbon Jiang Baseline Jiang
7. Conclusions and discussion

A comparison of the most relevant outcomes of the three scenarios is presented in table 5. The "Policy" scenario represents a rather optimistic future where the current policies, some actually very ambitious, are successfully implemented: from that scenario, we can learn how great an impact could those policies have on emissions and energy use. The "Heavy industry" scenario, derived from the "Policy" scenario, then tells us how the abatement of CO\textsubscript{2} reached in the "Policy" scenario can largely be annulled if the industrial profile leans towards energy-intensive activities.

The scenario analysis illustrates the stringency of the longer-term CO\textsubscript{2} intensity and energy intensity targets. Even with the optimistically fast expansion of renewable energy capacity simulated in the policy scenario reaching these targets is difficult. On the other hand, the goals set for renewable energy capacity seem unambitious in contrast to the capacity growth levels required to reach the CO\textsubscript{2} intensity and energy intensity targets. Many targets previously set for 2020 have already been reached.

The CO\textsubscript{2} emissions could be as much as 27% lower assuming a strong development of the service sector and a turn away from the energy-intensive industries and the carbon-intensive pattern of growth, but this will also require huge investments in renewable energy capacity. The Policy scenario assumes 156 GW of new hydropower capacity, 124 GW of new photovoltaic capacity and 140 GW of new wind power capacity (totalling 478 GW) to be constructed during the period 2014–2020 and another 150 GW of hydropower, 200 GW of photovoltaic and 200 GW of wind power capacity (totalling 550 GW) to be constructed in the later period 2021–2030. Even with the heavy investing in renewables, coal use would need to be roughly on the same level as in 2013 for the entire period 2014–2030 to supply the needed electricity. The cumulative CO\textsubscript{2} emissions over the period 2011–2030 would be 202 GT in the Reference scenario. In the policy
scenario, the cumulative emissions would add up to 167 GT, 35 GT less. The Heavy industry scenario would result in 195 GT of cumulative CO\textsubscript{2} emissions for the period.

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