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Discussion Paper

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Managing China's energy productivity potential: what are the lessons for policy makers?

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Summary

Maximizing the economic welfare extracted from the energy system is a key priority for all governments. This can be measured by a country's energy productivity. Perhaps nowhere else in the world is this issue more salient than in China. China is the world's largest energy consumer and has led global economic growth in the first part of the twenty-first century. Furthermore, in the interconnected world we live in, decisions in China have global impacts. In periods of some of its fastest growth (from 2002-2005) China experienced declining energy productivity. In 2006, China put in place ambitious energy intensity targets. Combined with policies at the sector and product level, these contributed to China reversing its falling energy productivity. Building on this success, China's 12th Five Year Plan, extended and deepened these reforms. But within China's system of provincial and industrial energy intensity targets there is a blind spot which could reduce the potential welfare gain from these plans. Assessing the embodied energy in interprovincial trade reveals these potential gains and provides the information required to encourage regional practices to align better with national objectives. The response from Chinese policymakers to the challenges of building new infrastructure while managing resource and environmental constraints provides a valuable lesson for governments in rapidly developing countries, such as Saudi Arabia. A summary of key lessons from the Chinese experience of managing energy productivity is presented in the conclusion.

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Introduction

With low and declining energy productivity, Saudi Arabia is currently facing a set of energy policy challenges very similar to those that China has been navigating over the last couple of decades.

China's energy policy trilemma, how to balance the competing needs of economic development, security of energy supply, and the curtailment of carbon emissions, is as acute as it is for any country (WEC, 2012). Already the world's second largest economy, much of China's population remains poor and it still sees itself as a developing country. The burgeoning economy has driven up energy demand and raised oil import levels to over 50% of total oil consumption (Xu, 2013), fueling concerns over energy security. Domestic energy consumption is primarily coal, and this contributes to China being the world's largest emitter of greenhouse gases, responsible for 24% of global CO2 emissions. Moreover, as air quality deteriorates and health concerns magnify, China is increasingly seeking to control pollution.

One response to the trilemma lies in improving energy efficiency. Much has been written on the topic and China has not always been compared favorably to other countries. It has been labelled nine times less efficient than Japan and five times less than Europe (Wang, 2013). Yet its track record of improving efficiency over the last thirty years, albeit starting from a low base, is impressive. In contrast to the global average of 1.2% per year between 1980 and 2000, and 0.5% between 2000 and 2010 (IEA, 2012), China reduced its energy intensity by an average of 4% each year (See Figure 1).

China's geographic and developmental diversity make further improvements in energy efficiency challenging. National statistics tell only half the story; analyses and policies based solely on such statistics will miss the provincial and inter-provincial complexities which offer the country both great challenges and enormous opportunities in furthering its efficiency agenda. This paper provides a detailed look behind the national picture, to explore not just the provincial story, but the connections between the provinces. As part of the effort to further enhance China's energy productivity potential, this gives policy makers new insight into how to foster greater cooperation among provinces to achieve national priorities. This may also provide insight for policymakers in other regions.

Chinese energy productivity in context

In 2006, China attracted international attention with its 11th Five Year Plan (FYP) by committing to an aggressive target to lower its national energy intensity by 20% by 2010, relative to 2005 levels. This policy was particularly noteworthy as it was made in response to rising energy intensity (2002-2005), the first time this had happened since China's opening up in the 1980s (see Figure 1).

This period of rising declining productivity, or as generally referred to by policymakers, rising energy intensity, has been well studied (NDRC, 2004a; Kahrl and Roland-Holst, 2008; Guan et al., 2009; Yuxiang and Chen, 2010) and won't be discussed in detail here.

The response from China's central government to this rising energy intensity was a significant policy-driven transformation. Starting from November 2004, the National Reform and Development Commission (NDRC) passed the Medium and Long Term Energy Conservation Plan (NDRC, 2004b) setting out detailed energy conservation targets and identifying Ten Key Energy Savings Projects, which were subsequently incorporated into China's 11th FYI as important industrial energy intensity reduction measures (NDRC, 2006).

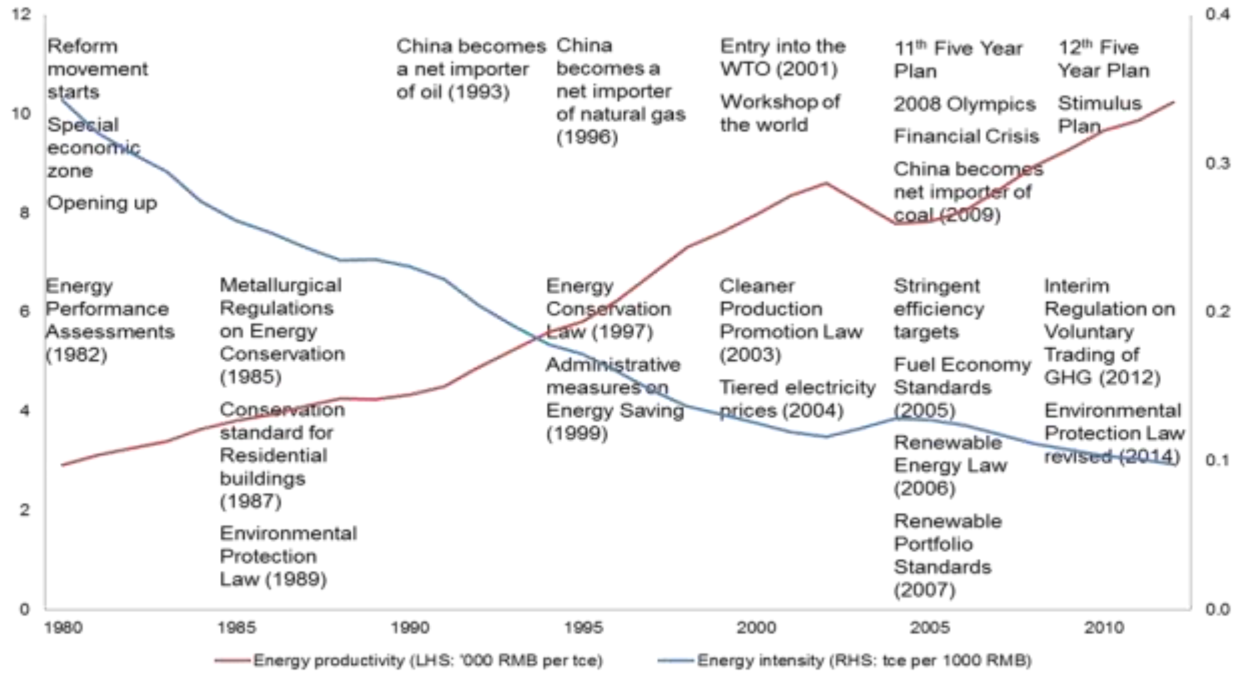

Figure 1: Evolution of Chinese energy productivity and intensity, key policies and events

The State Council set out a comprehensive set of energy intensity targets for key industrial processes (Table 1) and energy performance standards for industrial products and equipment, through the Identified Energy Efficient Product List (IEEPL). Table 1 shows performance and targets for material efficiencies in key industrial process. As the industrial sector comprises 70% of energy consumption in China, these policies were closely tied to driving down energy intensity from 2005 onwards.

The Top 1000 program targeted the largest energy consuming enterprises across nine sectors. The threshold for inclusion was an annual consumption of a minimum of 180,000 tons of coal equivalent (tce) of energy. Combined, these enterprises accounted for one third of China's total energy use and almost half of industrial energy use in 2004 (NDRC, 2006). The program required enterprises to conduct mandatory energy audits and develop energy savings plans to be reviewed against a set of criteria specified by the NDRC. Ji Xie (2010) estimated the energy saved by the program between 2006 and 2009 was equal to 136 million tce. Official estimates suggested it was closer to 150 million tce, with total carbon dioxide savings of almost 400 million tons (NDRC, 2011). To encourage implementation, success at achieving the energy savings targets was tied directly to government officials' annual job evaluations (State-Council, 2007).

In June 2004, the NDRC established a market-based policy of differential electricity pricing for high energy consuming industries where prices were set based on the energy intensity level of each enterprise (Price et al., 2008). Enterprises were grouped into one of four categories "encouraged", "permitted", "restricted" and "eliminated". The first two categories paid the normal price for electricity in their area, while the latter two paid a premium of

	units	2000 Actual	2005 Actual	2010 Target	2020 Target
Coal-fired power	Kgce/kwh	392	377	360	320
Steel	Kgce/t	906	760	730	700
10 kinds of non-ferrous metals	tce/t	4.8	4.7	4.6	4.5
Aluminum	tce/t	9.9	9.6	9.5	9.2
Copper	tce/t	4.7	4.4	4.3	4.0
Refining	Kgoe/t.factor	14	13	12	10
Ethene	Kgce/t	848	700	650	600
Ammonia production	Kgce/t	1372	1210	1140	1000
Caustic soda	Kgce/t	1553	1503	1400	1300
Cement	Kgce/t	181	159	148	129
Plate glass	Kgce/box	30	26	24	20
Building Ceramics	Kgce/m2	10.0	9.9	9.2	7.2
Railway transportation	tce/1MtKmeq.	10.4	9.7	9.4	9.0

Table 1: Industrial sector energy intensity targets under the 11th FYP Source: State Council (2006)

RMB0.05 and RMB0.20 per kWh respectively. These charges have been increased in an effort to force inefficient plants to close and, in 2007, the policy was adjusted to allow provincial authorities to retain revenue from the extra charges to provide stronger incentives for the measure's implementation (NDRC, 2007b; Taylor et al., 2010).

In 2007, the State Council again took action to phase out inefficient enterprises with the Small Plant Closures and Phasing Out Outdated Production Capacity program which was accompanied by a complete list of closure thresholds (MIIT, 2010). As part of the program, the Ministry of Finance provided some compensation to eligible enterprises (MOF, 2011). It was further extended in the 12th FYP.

In February 2011, China announced that it had met the 11th FYP's 20% target with a final reported reduction of 19.1% (MIIT, 2011). Despite this, overall energy consumption had grown much faster than planned. The 11th FYP assumed a 2010 primary energy consumption target of 2.7 billion tce: a 4% average annual growth in energy consumption (NDRC, 2007a). Actual 2010 energy consumption reached 3.2 billion tce, an average annual growth of 6.6% (CCIN, 2013). The intensity target was able to be met due to greater than expected economic growth.

Informed by the experience of the successful 11th FYP, the 12th FYP contained even more stringent and focused targets (see Figure 2). The 2015 energy consumption target of 4 billion tce assumes average GDP growth of around 8%. This is a planned reduction of 16% in energy intensity from 2010 levels by 2015. This will bring the total estimated reduction under the 11th and 12th FYPs (2006-2015) to 32% below 2005 levels (PRCSC, 2012). It also supports the closely related target of reducing carbon intensity (carbon emissions per unit of GDP) by 17% below 2010 levels by the end of 2015 and 40-45% below 2005 levels by 2020 (State-Council, 2009).

As part of this, industrial energy intensity is to be reduced by 21% relative to 2010 by the end of 2015. It is expected that this will deliver an estimated total energy saving of around 67 million tce. Specific targets for the main industrial sectors and products have also been released, though these will be difficult to assess because of the lack of official baseline data for 2010. In Table 2 we show the latest available data, which is for 2007, to put these targets in context (MIIT, 2012).

The 12th FYP put forward a set of differentiated provincial targets in recognition of China's unbalanced economic development. The developed coastal regions with relatively modern infrastructure have more stringent energy intensity reduction targets (lightly shaded provinces in Figure 2) while the less developed interior (darkly shaded provinces) have less challenging targets. All provinces experienced declining energy intensity between 2005 -2010 (with the gradated bars moving from left to right). The solid markers in Figure 2 represent each province's energy intensity target under the 12th FYP.

The 11th FYP's 20% energy intensity reduction target was not met uniformly across all the provinces. Figure 2 shows provincial reductions varied between 33% and 6%. Guangdong and Shanghai, both developed areas, only managed to

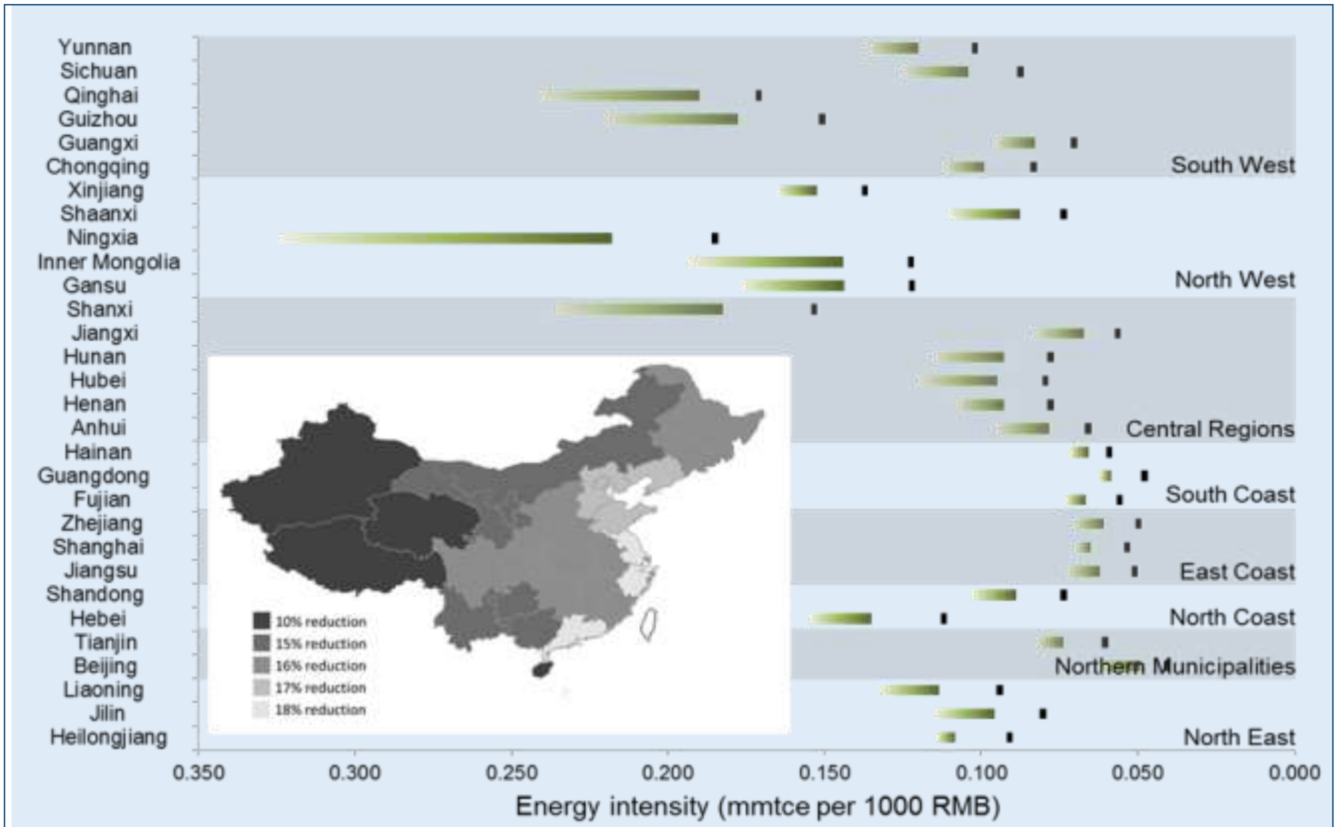

Figure 2: Change in Energy Intensity improves for all provinces over 11th FYP (2005-2010) shown by the gradated bar moving from left (2005) to right (2010). 12th FYP targets for 2015 with 2010 as base year are shown by the solid black mark. The shaded map shows the energy intensity targets in the 12th FYP. Source: State Council (2012); MIIT (2011) KAPSARC analysis

General industrial EI target 12th FYP:	Industrial Energy Intensity to reduced by 21% relative to 2010 by 2015			
Sub-sectors	2007 Energy consumption million tce*	2007 IVA Bn RMB*	2007 Energy intensity*	2015 targeted reduction
Smelting and pressing of ferrous metal	47,774	9,007	5.30	18%
Smelting and pressing of non-ferrous metal	10,686	4,478	2.39	18%
Processing of petroleum, coking, processing of nuclear fuel	13,177	3,097	4.25	18%
Manufacture of raw chemical materials and chemical products	27,245	7,340	3.71	20%
Manufacture of non-metallic mineral products	20,355	4,849	4.20	20%
Manufacture of machinery	8,207	22,366	0.37	22%
Light industry	20,560	30,001	0.69	20%
Manufacture of textiles	6,208	4,9142	1.26	20%
Manufacture of electronic equipment	2,007	7,925	0.25	18%

Table 2: Industrial sector energy intensity targets under the 12 FYP

Source: MIIT (2012) * Industrial Value Added (IVA) measures the net economic contribution of each industrial sub-sector. Official sub-sector level data have not been released for 2004 or for 2008 onwards. The absence of a 2010 baseline makes sub-sector energy intensity targets difficult to evaluate.

reduce their energy intensity during the 11th FYP period by around 6%; their target for the 12th FYP is 18% relative to 2010. In contrast, Beijing improved its performance by over 20% by 2010 and must find a further 17% before 2015. The interplay between the provinces discussed in section three can help explain how these future targets will be achieved in significant part via embodied energy imports from other provinces.

For example, as Beijing has reduced its energy intensity, it has become more and more reliant on other provinces for the goods and energy it needs to supply its local economy. Hebei province, straddled with a reputation for bad pollution, provides Beijing with 30% of its imports of embodied energy and is one of the biggest net exporters of embodied energy. It is a major center for the steel industry and, at least partly as a result, has one of the highest provincial energy intensity scores. The question for policy makers is whether or not Beijing has become cleaner at Hebei's expense. Moreover, given Hebei's low energy efficiency, has this actually worsened the national average? Similar questions can be asked of Guangdong, Shanghai, and all the developed, energy importing regions. This problem has been discussed in an international context before (Hayashi and Krey, 2006; Zhou et al, 2013; Neiderberger and Spalding-Fecher, 2006); its investigation within China is long overdue.

An alternative way of framing these policy goals is to shift the focus from controlling or reducing energy intensity (unit of energy over unit of GDP) to boosting energy productivity (the inverse). Energy productivity places a premium on increasing the economic and social benefit of fuel use and in this way can better align energy efficiency targets to the overall agenda of sustainable GDP growth. This shift has been adopted elsewhere including in the United States and Germany, and is under consideration or being actively discussed in other countries (ASE, 2013; FRG, 2013; AASE, 2014; KAPSARC, 2014).

Yet an important consideration is missing from this standard picture of energy targets and trends. A significant amount of energy originates and flows between regions in the goods that are traded between provinces, the embodied energy in trade. If steel or cement used in Guangdong was produced in Yunnan then the energy that went into producing that steel is typically attributed to Yunnan. Perhaps a better way of accounting for this energy is to attribute it to the province in which the steel or cement itself is consumed, in this case Guangdong, at the source of demand, rather than that of supply.

If the overall national target of a 16% reduction in energy intensity over the life of the 12th FYP is to be met in the most effective way, considering the embodied energy flowing through supply chains between provinces can be of value to policymakers. This can also help inform target setting in a way that prevents "energy outsourcing" and compliance leakage. Most crucially, it also offers policy makers the insight required to improve the energy efficiency of interprovincial supply chains.

Embodied Energy in Interregional trade

Method and background to the analysis

For China, consistent with international convention, the concept of 'embodied energy' was defined by the International Federation of Institutes for Advanced Study as the total energy consumption, both direct and indirect, in the life cycle of a product or service (Chen, 2009). Most attention, however, has been given to examining the embodied carbon in China's net exports in the context of the "carbon-outsourcing" hypothesis. This posits that advanced economies have achieved significant emission reductions by importing high-carbon energy intensive industrial goods from the developing world (mainly China), while shifting to produce higher value-added and lower GHG emitting services in their own economies (Davis and Caldeira, 2010; Su and Ang, 2011; IPCC, 2014).

Less attention has been given explicitly to embodied energy, though this is a key part of such carbon-based analysis, and less still has been given to looking at embodied energy flows between regions and regional sectors within a country, as distinct from simply between countries. In focusing on this in our analysis we aim to fill an important knowledge gap and to provide one of the most detailed expositions of such flows in China. This information is of immediate relevance for economic planners in China looking to better understand the energy system, and coupled with information on provincial energy intensity performance and targets, highlights opportunities for potential cost-effective mitigation options. Though we exclude international exports and imports from our analysis, it also has a high degree of international significance for those seeking to better understand the regional heterogeneity of the country and challenges faced by China in increasing energy productivity.

In our analysis we have developed a multi-regional input-output model for the embodied energy in trade between 30 provinces. This is based on provincial input - output tables for China for 2007, which is the most recent year for which complete data exists (China Energy Statistical Year Books, 2008 and 2013). We also calculate energy consumption data for 30 sectors based on the energy balance tables for each province and use this to derive the interprovincial embodied energy flows between the sectors across provinces.

The fundamental information used in such analysis are the flows of products from each industrial sector, considered as a producer, to each of the other sectors considered as consuming sectors. This produces an intra-provincial matrix for a given province where the distribution of output through different sectors of the province is given along the rows, and the composition of inputs required by different sectors is given by the columns. Multi-regional input-output models extend the single region model by reflecting inter-regional trade in goods and services. The corresponding resource and environmental impacts resulting from consumption activities in one region can thus be traced to specific production sectors in other regions through the interregional supply chain (Leontief, 1986).

We focus on the interprovincial trade between each regional grouping, excluding the trade flows which move from each province to the international export sector. In this closed system, defined by each region's input-output data, the sum of total embodied exports between regions equals the sum of total embodied imports. An important topic for future research, yet to be attempted, would be to extend this analysis to account for the embodied energy flows from each province to the international export market, to provide an even more comprehensive picture of provincial embodied energy flows.

In our analysis embodied energy is attributed to the first point of consumption, rather than the final point. This means that where energy is used to produce steel in region 1, which is then exported to region 2 to produce a car before the car is exported to region 3, the embodied energy from the steel production is attributed to region 2, and the embodied energy from the car's manufacture to region 3. This attribution of embodied energy to the first point of consumption, may be seen to understate the embodied energy consumption of region 3, and overstate that of region 2. However, this is the typical convention for this type of analysis and the method which we have followed in our paper. A more detailed and formal description of our methodology and data is available on request.

Results

For ease of illustration, we have aggregated our results into eight regional groups: the North East, which comprises Heilongjaing, Jilin and Liaoning; the Northern Municipalities (Beijing and Tianjin); the North Coast (Hebei and Shandong); the East Coast, comprising Shanghai, Jiangsu and Zhejiang; the South Coast (Guangdong, Fujian and Hainan); the Central Regions (Shanxi, Henan, Hubei, Hunan, Anhui and Jiangxi); the North West (Inner Mongolia, Shaanxi, Ningxia, Gansu and Xinjiang); and the South West, which comprises Sichuan, Chongqing, Yunnan, Guizhou, Guangxi and Qinghai (Figure 3). Each region has a different shade on the grayscale. A more detailed provincial picture is provided in the Appendix to this paper. (Figure A1).

There are three key trading blocks. The Central Region is the main embodied energy exporter, with significant flows to the East and North Coasts, while the Southwest Region is the main supplier of embodied energy to the South Coast provinces. A smaller trading block exists in the north between the interior Northwest Region and the Northern Municipalities and Northeast. These distinct groupings reflect the regional characterization of internal trade within China, due to the limited transport infrastructure linking the country, combined with the distances involved.

The most significant sectors which have a high volume of embodied energy in traded goods are the electricity, steel smelting and the coal mining sectors (see Figure 4). These sectors have a strong degree of interrelationship, but are separated out according to the Chinese statistical yearbooks.

Several clear regional and sectoral patterns emerge. The more industrialized East Coast and South Coast provinces and the Northern Municipalities are the main embodied energy importers, while the less industrialized Central and two western regions are the main embodied energy exporters.

Embodied energy in the steel smelting sector includes the energy embodied in physical steel imports and exports between provinces as well as

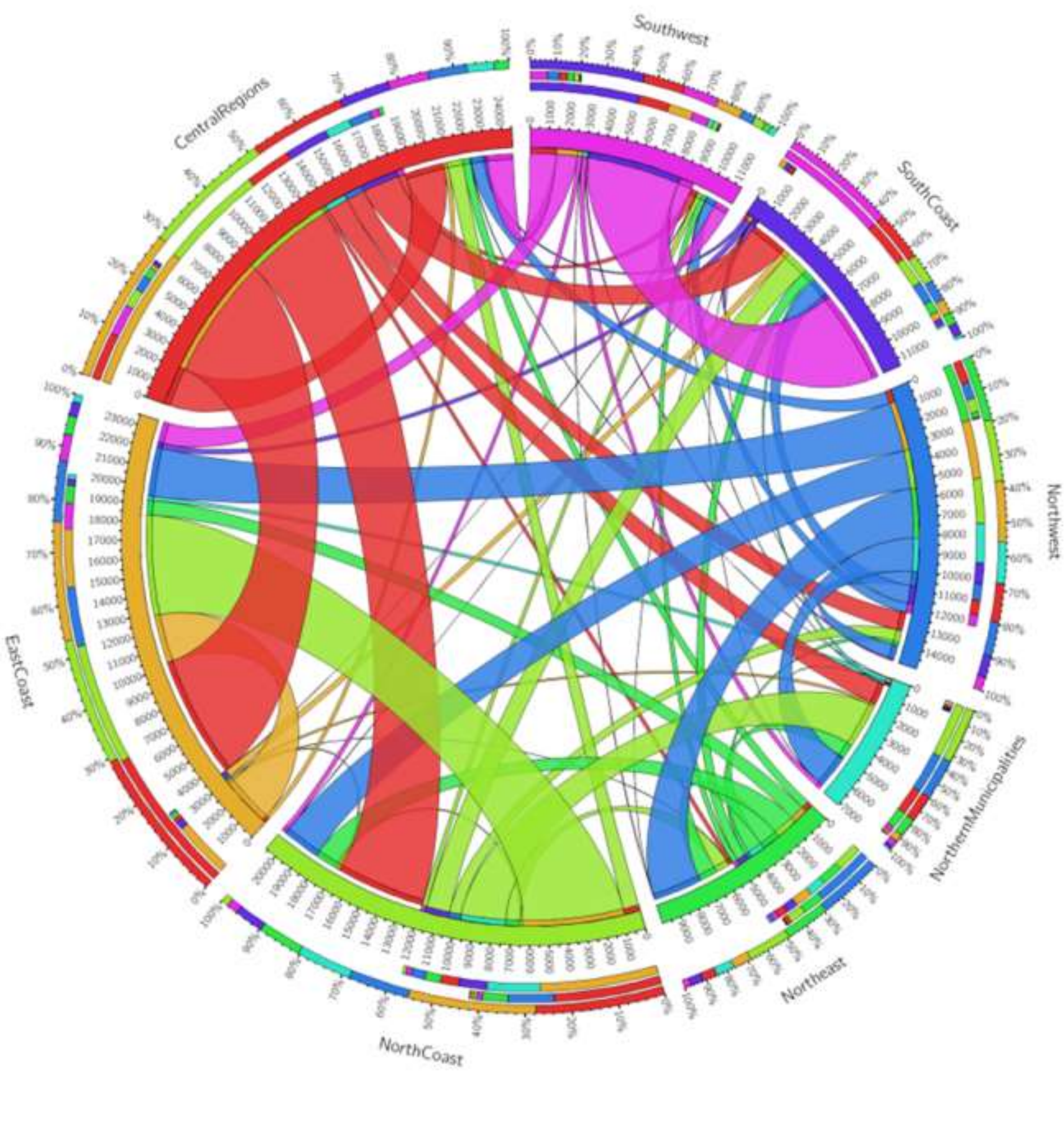

Figure 3: Flows of embodied energy between regions in China (2007, million tce)

Sources: Chinese Statistical Year Book and Chinese Energy Statistical Year Book (years 2008 and 2013) Chinese Academy of Sciences-KAPSARC Analysis. Bands touching the edge of the circular diagram, denote the origin of the embodied energy flow (exports); conversely, where a band finishes at a non-connected section of the internal circular boundary, it denotes embodied energy flows into that region (imports). The outer circle denotes the percentage share of embodied imports and exports for each region. Width of the bands indicates volume of flows which is indicated in million tce on the inner circle adjacent to the bands.

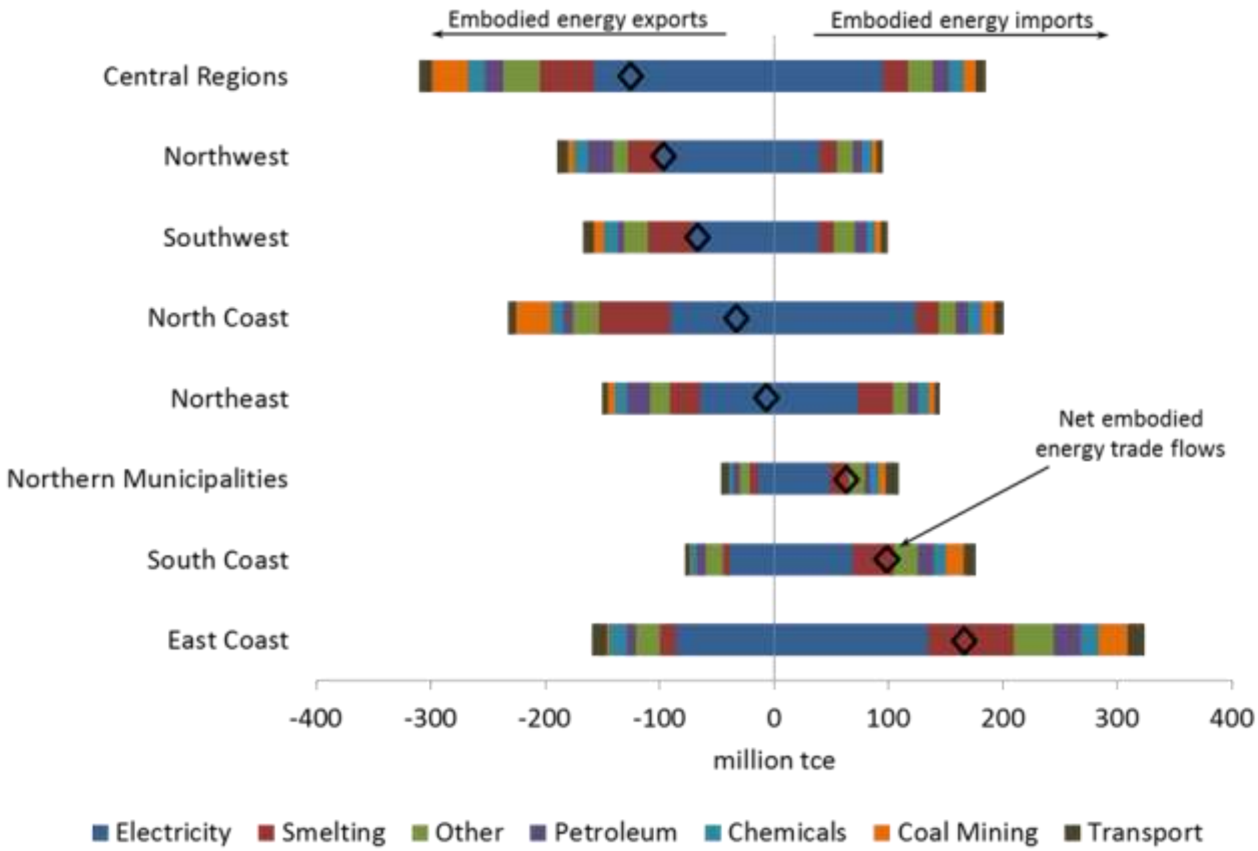

Figure 4: Sector breakdown of embodied energy imports and exports by province (2007, million tce)

Sources: Chinese Statistical Year Book and Chinese Energy Statistical Year Book (years 2008 and 2013) Chinese Academy of Sciences-KAPSARC Analysis. This Figure shows the main energy consuming sectors, the top six of which together comprise around 80% of the total embodied energy flows between provinces. These sectors are: electricity and gas provision, iron smelting, petroleum processing, chemical processing, coal mining and transport. The remaining sectors (other mining, other heavy industry, light industry, agriculture and services) we group into the category 'other'.

any goods which include steel such as automobiles, ships, construction, electrical appliances and other machinery made of steel which was manufactured in one region and consumed in another region.

For example, Zhejiang is one of the top importers of embodied energy from steel smelting activities. The three main provinces it imports from are Jiangsu, Hebei, and Henan. Zhejiang is a major manufacturer of automobiles and machinery in China. The embodied energy represented in these sectoral flows describes the energy that went into the production of the steel imported from these other provinces that is then used in Zhejiang to produce goods. This data describes only bilateral trade. If the car which was built in Zhejiang is bought by a consumer in Shanghai or Guangdong, the embodied energy from steel smelting is only attributed to Zhejiang.

The energy that is expended within Zhejiang to produce the cars, be it indigenous steel smelting in Zhejiang, electricity in the manufacturing process or chemicals used to produce plastic components, is associated with the car when it is exported to another province. In our example above, this would mean that the embodied energy associated with the car would flow from Zhejiang to Guangdong, but this would not include the embodied energy from steel smelting that Zhejiang imported from Jiangsu.

To give another example, take embodied energy from the coal mining sector. This includes the energy that was used to extract, wash, grade and process coal (as well as a small amount of peat) which is associated with exports and imports of that coal to and from another province. For example, Hebei is the largest exporter of embodied energy from coal mining. This coal is mainly exported to Zhejiang, Jiangsu, Shanghai, Tianjin, and Beijing. In these provinces, the coal can then be used to manufacture steel or produce electricity.

The embodied energy in the trade of electricity is a little different, as it includes both the energy of the electricity being traded and the energy that went into the production of the electricity. This is different to the trade in coal where only the direct and indirect energy that went into the mining and processing of that commodity is included, and the energy value of the coal itself is not attributed as embodied energy.

The effect of accounting for embodied energy on provincial energy intensity targets

In our final piece of analysis we take the net embodied energy flows from each province and use it to adjust the official energy consumption data for 2010 to calculate a measure of energy intensity which includes embodied energy in trade (Figure 5). Because the latest comprehensive data on interprovincial embodied energy in trade can only be calculated for 2007, we have applied these flows to the 2010 energy consumption data. While clearly this is a limitation, it still provides a good sense of the direction and magnitude of the adjustment to each province's energy intensity performance if embodied energy were taken into account. The next release of comprehensive provincial input-output tables will be for the year 2012; at the time of writing, these had yet to be published. Once the 2012 data are released they will provide an important update to this analysis.

On the South Coast, the energy intensity of Guangdong and Zhejiang moves up from around 0.06 tons per 1000 RMB in both to around 0.08 and 0.09 tons per 1000 RMB, or an increase of around 34% and 50% respectively. Conversely, in Shanxi energy intensity falls from 0.18 to 0.11 tce per 1000RMB or around 38%. This outcome of falling adjusted energy intensity is replicated across the Central Region and reflected in rising adjusted energy intensity in the East Coast and North Coast regions.

Large falls in adjusted energy intensity are also exhibited in the North West regions of Ningxia (23%) and Inner Mongolia (41%); with corresponding rises in energy intensity in the Northern Municipalities of Beijing (41%) and Tianjin (50%).

In the South West and South Coast regions, large falls in adjusted energy intensity are exhibited by Guizhou (28%) and Yunnan (24%), whereas significant increases in adjusted energy intensity are reflected in Guangdong (34%).

It is clear that accounting for the embodied energy in interprovincial trade is of significant consequence for the interpretation of China's energy intensity targets. In many cases, provinces which are 'performing well' are revealed to be sourcing significant energy intensive inputs from the provinces which are 'performing badly' in terms of energy intensity levels. Greater awareness among policy makers at both the provincial and national levels of these linkages could lead to improved coordination between provinces, especially those that are closely linked. This could help encourage improved cooperation between provinces in the pursuit of national energy policy priorities. For example, by highlighting the supply chain linkages in this way, investment from the more developed industrial and efficient coastal areas could be encouraged towards the less developed energy

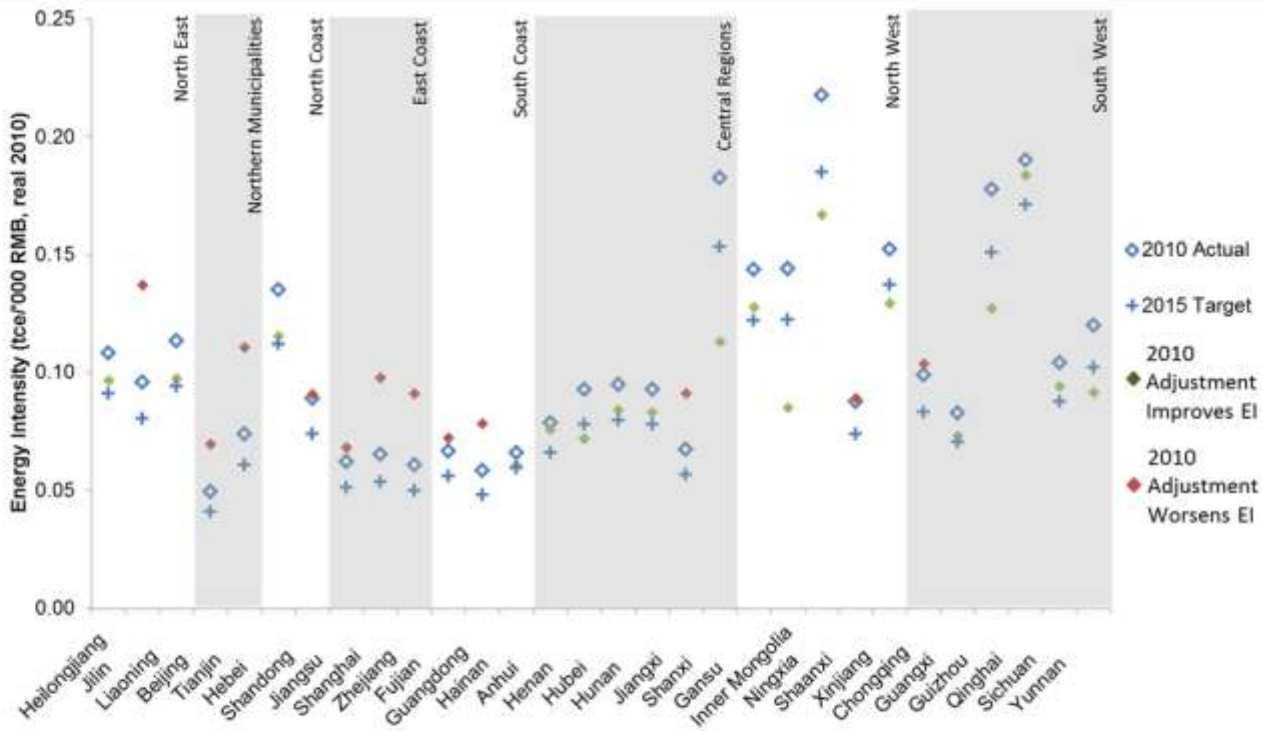

Figure 5: Accounting for embodied energy on provincial energy intensity trends

Sources: Chinese Statistical Year Book and Chinese Energy Statistical Year Book (years 2008 and 2013) Chinese Academy of Sciences-KAPSARC Analysis. Incorporating embodied energy in interprovincial trade shows that for provinces which are either large net embodied energy exporters or importers, the adjustment has a significant effect on their energy intensity. For embodied energy exporters, energy

intense interior. This may also assist with broader policy objectives to improve infrastructure and transport linkages in the less developed regions of China.

A difficulty comes as industry leaves the developed provinces in search of lower wages and, not infrequently, less onerous regulation. The arrival of energy intensive industries is often seen as a boon by less-developed provinces. Such industry will generate jobs, boost incomes and raise living standards. Forgoing such opportunities for the sake of environmental or other national concerns is a hard task, and the semantics makes it even harder. The quest to reduce energy intensity too often sounds like attempts to limit growth. Industry consolidation schemes have often led to job losses, and provincial authorities have sometimes tried to protect companies they see as locally important from Beijing's edicts.

Such analysis can also provide economic planners with insight to assist with the integration of China's regional pilot emissions trading schemes. These comprise a set of regional policy experiments targeted at constraining GHG emissions in significant part by managing energy demand and promoting greater energy efficiency. Developing these schemes with the supply-chain linkages between embodied energy producing and consuming provinces in mind is likely to help align development and pollution control incentives more strongly than if permits are traded between provinces with less strong economic ties.

Conclusions

China's experience managing the energy productivity of its economy over the last few decades provides a useful example to other rapidly developing countries, including Saudi Arabia. The process of building new infrastructure (the houses for people to live in, commercial buildings and industrial facilities, the ports, utility and transport networks) consumes a massive amount of energy and locks in years of future energy use commitments. Yet these are integral to the process of nation building, and central to the goal of lifting standards of living. This paper has described how some of these issues have been managed through the policy frame of energy productivity, or in the language of Chinese policymakers, energy intensity.

The Saudi Arabian Minister for Petroleum, Dr Ali Al -Naimi, has spoken of the need to reduce wasted energy resources and increase value in the economy, noting that it takes more than double the world average amount of energy to generate $1000 of GDP in the Kingdom. Indeed the Middle East as a region is one of the few places in the world where energy productivity is declining each year. Without a concerted effort, it will be difficult for the region to increase the value it derives from its energy resources. Learning from the experience of other countries can therefore improve policy outcomes in the region.

Western countries may lead in the field of energy productivity, but for developing countries they may not hold all the answers. This paper looks East, to one of Saudi Arabia's most rapidly growing trading partners, and to China, to investigate what lessons can be learned for improving the management of the Kingdom's energy productivity.

In conclusion we draw out the main policy lessons in the following points:

- As shown by its period of falling energy productivity (2002-2005), rising energy productivity in China was not an inevitable process of its economic development. It required ambitious and often difficult economic reforms.
- Reforms to enhance the energy productivity of the Chinese economy were taken in a step by step fashion. The energy intensity targets and actions described in detail in this paper are largely from the 12th FYP which was informed significantly by the 11th FYP, which was informed by past experiences. Thus, decision makers should be skeptical of silver bullet solutions taken from other jurisdictions. An evolutionary approach to policy making may be required. An oft quoted phrase of Deng Xiaoping is 'crossing the river by feeling the stones'.
- International as well as interprovincial trade has played an important role in the evolution of Chinese energy productivity. The energy embodied in trade is an important consideration in accurately understanding and managing energy productivity in any region or country. In practice, it tends to be overlooked, hiding potential gains that could be made from cooperation with major trading partners.
- Using energy productivity, rather than energy intensity, as the organizing concept to manage energy efficiency in the economy, offers several advantages. It is increasingly being used by advanced economies, such as the United Statesand Germany, and is actively under discussion in other nations.
- Energy productivity offers a new way forward to better align the often competing agendas which are found in national and international energy and climate debates.

Appendix

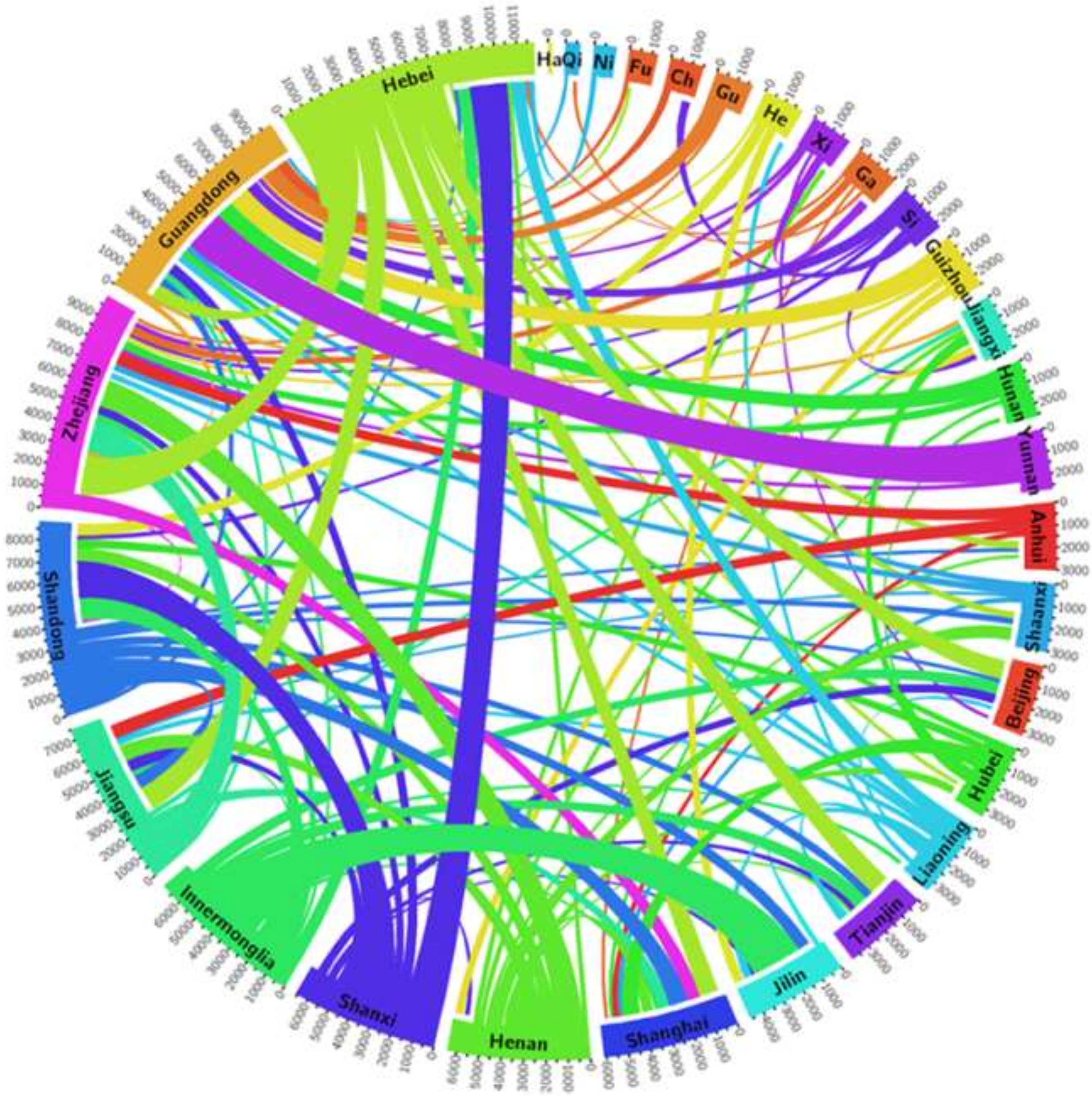

Figure A1: Flows of embodied energy between provinces in China (2007, million tce)

Sources: Chinese Statistical Year Book and Chinese Energy Statistical Year Book (years 2008 and 2013) Chinese Academy of Sciences-KAPSARC Analysis. Bands touching the edge of the circular diagram, denote the origin of the embodied energy flow (exports); conversely, where a band finishes at a non-connected section of the internal circular boundary, it denotes embodied energy flows into that region (imports). Width of the bands indicates volume of flows which is indicated in million tce on the inner circle adjacent to the bands.

References

AASE (Australian Alliance to Save Energy) (2014). "Joint statement of lifting Australia's Energy Productivity." Available at: http://www.a2se.org.au/files/Docs/140414_Joint_Statement_.pdf .

ASE (Alliance to Save Energy) (2013). "Energy 2030 On the Road." [Online]. Available at: http://www.ase.org/resources/energy-2030-road-report.

CCIN: China Climate Change Info Net (2013). "The outlook on controlling overall energy consumption in China." [Online]. Available at: http://www.ccchina.gov.cn/Detail.aspx?newsId=17481&TId=57 (Chinese).

Chen, H.M. (2009). "The energy and environment impacts of China's international trade," Fudan University.

Davis, S.J., Caldeira, K. (2010). "Consumption-based accounting of CO2 emissions." Proceedings of the National Academy of Sciences 107(12): 5687-5692.

FRG (Federal Republic of Germany) (2013). "Communication from the Federal Republic of Germany to the European Commission of 19 June 2013." [Online]. Available at: http://ec.europa.eu/energy/efficiency/eed/doc/reporting/2013/de_2013report_en.pdf.

Guan, D., Peters, G.P., Weber, C.L., Hubacek, K. (2009). "Journey to world top emitter: An analysis of the driving forces of China's recent CO2 emissions surge." Geophysical Research Letters 36(4): L04709.

IEA (2012). "World Energy Outlook 2012." [Online]. Available at: http://www.iea.org/publications/freepublications/publication/name-49561-en.html.

IPCC (2014). "The Mitigation of Climate Change, Fifth Assessment Report," UNFCCC, Geneva, Paris.

Kahrl, F., Roland-Holst, D. (2008). "Energy and exports in China." China Economic Review 19(4): 649-658.

KAPSARC (2014). "The case for energy productivity: more than just semantics," KAPSARC Discussion Paper. KS-1402-DP01B, March, 2014.

Leontief, W. (1986). Input-output economics. Oxford University Press.

Ministry of Industry and Information Technology (2010). "Phasing Out Backward Capacities for 11th FYP." [Online]. Available at: http://www.miit.gov.cn/n11293472/n11293832/n13095885/13232432.html (Chinese).

Ministry of Industry and Information Technology (2011). "DDRC announced the accomplishment of the 11th Five-Year energy saving targets for each province." [Online]. Available at: http://www.miit.gov.cn/n11293472/n11293832/n12768545/13880926.html (Chinese).

Ministry of Industry and Information Technology (2012). "The 12th FYP for Industrial Energy-saving." [Online]. Available at: http://www.miit.gov.cn/n11293472/n11293832/n11293907/n11368223/14475991.html (Chinese).

Ministry of Finance (2011). "Management Regulation on Fiscal Rewards for Phasing-Out Outdated Production Capacity." [Online]. Available at: http://www.miit.gov.cn/n11293472/n11293877/n13138101/n13138133/13745753.html (Chinese).

National Development and Reform Commission (NDRC) (2004a). "Guidance of Adjustment and Management of the Projects in Iron and Steel, Electrolytic Aluminum, and Cement Industry." [Online]. Available at: http://www.ynetc.gov.cn/Item/1276.aspx (Chinese).

National Development and Reform Commission (NDRC) (2004b). "Medium and Long Term Energy Conservation Plan." [Online]. Available at: http://baike.baidu.com/view/10910606.htm?fr=aladdin (Chinese).

National Development and Reform Commission (NDRC) (2006). "Implementation Suggestions of Ten Key Energy-Conservation Projects during the Eleventh Five-Year Plan." [Online]. Available at: (Chinese).

National Development and Reform Commission (NDRC) (2007a). "Energy Development Plan of the 11th Five Year Plan." [Online]. Available at: http://www.ccchina.gov.cn/WebSite/CCChina/UpFile/File186.pdf (Chinese).

National Development and Reform Commission (NDRC) (2007b). "Notice of NDRC on Local Provincial Government to retain revenue collected through the differential electricity pricing system." [Online]. Available at: http://www.china.com.cn/economic/txt/2007-10/12/content_9040150.htm> (Chinese).

National Development and Reform Commission (NDRC) (2011). "Review of the Eleventh Five-Year Plan: Top 1000 Program Exceeded Targets." [Online]. Available at: http://www.gov.cn/gzdt/2011-09/30/content_1960586.htm (Chinese).

PRCSC (2012). "China's Energy Policy 2012." Information Office of the State Council.

Price, L.K., Wang, X., Yun, J. (2008). "China's Top-1000 Energy-Consuming Enterprises Program: Reducing Energy Consumption of the 1000 Largest Industrial Enterprises in China." Lawrence Berkeley National Laboratory; Peking University, China Energy Conservation Association.

Song, F., Zheng, X. (2014). "What drives the change in China's energy intensity: combining decomposition analysis and econometric analysis at the provincial level," School of Economics, Renmin University.

State Council (2006). "Implementation of the 11th Five Year Plan: Targets and Division of Work." [Online]. Available at: http://www.molss.gov.cn/gb/zt/2006-11/21/content_149505.htm (Chinese).

State Council (2007). "Notice about the issuance of comprehensive energy saving and pollution reduction work plan." [Online]. Available at: http://www.gov.cn/jrzg/2007-06/03/content_634545.htm (Chinese).

State Council (2009). "China's Commitment: to reduce carbon intensity by 40-45% below 2005 level." [Online]. Available at: http://www.nbd.com.cn/articles/2009-11-27/255297.html (Chinese).

Su, B., Ang, B.W. (2011). "Multi-region input-output analysis of CO2 emissions embodied in trade: the feedback effects." Ecological Economics 7142 - 53.

Taylor, R.P., Draugelis, G.J., Zhang, Y., Co, A.U.A. (2010). "Accelerating Energy Conservation in China's Provinces," World Bank.

Wang, Y.-h. (2013). "Fundamental Principles of China's Energy Security Strategy." International Relations and Diplomacy 1(1): 34-41.

WEC (2012). "World Energy Trilemma: time to get real, the agenda for change". World Energy Council, London.

Xie, J. (2010). "Presentation on the energy savings results in China," Energy Efficiency Forum.

Xu, X. (2013). "World Energy China Outlook 2013-2014 - Executive Summary." Institute of World Economics and Politics; Chinese Academy of Social Sciences.

Yuxiang, K., Chen, Z. (2010). "Government expenditure and energy intensity in China." Energy Policy 38(2): 691-694.

Zhang, Z. (2000). "Decoupling China's Carbon Emissions Increase from Economic Growth: An Economic Analysis and Policy Implications." World Development 28(4): 739-752.

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