The carbon footprint of Chinese healthcare system

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Abstract

Carbon footprint of healthcare system is a key indicator for measuring and reducing the carbon emission stemming from healthcare service. In developed countries, carbon footprints of healthcare system are estimated to be 3%–10% of the total national CO_2 equivalent emissions. However, it remains unknown for developing countries. This study quantified the carbon footprint of Chinese healthcare system and identified the major emission sources. We did an environmentally extended input-output analysis of Chinese healthcare system for the year 2012. The expenditure data were obtained from China Health and Family Planning Statistics Yearbook. The energy data of medical institution sector were transformed from input-output table and the energy data of other 45 sectors were obtained from China Energy Statistics Yearbook. The results show that in 2012 China spent CNY 2449.8 billion on health care leading to 217.1 megatonnes CO_2 emissions. Healthcare accounted for 2.2% of China's total CO_2 emissions lower than developed countries. Within medical institutions, 79% of carbon footprint stemmed from indirect CO_2 emissions due to procurement, such as pharmaceuticals and 21% stemmed from building and transport energy. This study indicates that the share of carbon footprint of healthcare system in the national total is lower than developed countries and have a large room for growth. Therefore, China's medical institutions should consider the energy efficiency indicators when equipped with more medical instruments. Furthermore, this study suggests that pharmaceutical sector be included in the national carbon emission trading system to reduce the carbon intensity of drugs as well as the carbon footprint of healthcare system.

Introduction

Climate change will increase human health risk, such as heat-related disease, vector-borne and water-borne disease,[1,2] so health sector plays an important role in adapting to climate change. However, health sector itself is also emitting greenhouse gases. Although health sector is not a carbon-intensive sector, such as manufacturing, hospitals use more energy than general public buildings for more facilities and higher reliability.[3] In addition, more greenhouse gases emissions stem from upstream supply chains of healthcare service, for instance, purchased pharmaceuticals and medical instruments in hospitals.

Carbon footprint is an indicator measuring the lifecycle CO_2 emissions of a product, sectoral or national consumption covering the entire supply chains. There are many methods to estimate carbon footprint. The Life Cycle Assessment (LCA) is the most appropriate for product-level carbon footprint estimation and input-output technique is the most appropriate for sectoral and national carbon footprint estimation. The carbon footprint of national healthcare sector varies: 546 megatonnes (8% of the national total) in 2007[4] and 655 megatonnes (10%) in 2013[5] in US, 36 megatonnes in Australia (7%),[6] 33 megatonnes in Canada (5%),[7] and 23 megatonnes in England.[8] The carbon footprint of specific healthcare service is also assessed, for instance, renal service,[9] dental service,[10] maintenance hemodialysis,[11] peritoneal dialysis,[12] critical care unit,[13] and operating theatres.[14]

As the country with the most carbon emissions and the largest population in the world, the carbon footprint of China's health sector has not been estimated to date. Quantitative assessment of the carbon footprint of Chinese healthcare system can help identify emission hotspots and promote emission reduction. In China, several local governments have established hospital building energy standards to reduce energy consumption and CO_2 emissions in hospitals. Some studies conducted surveys of building energy consumption for hospitals in Beijing[15] and Shandong[16], but ignored the indirect energy use or carbon emissions of purchased medicines, medical instruments, etc. Besides, pharmaceutical industry, an essential part of Chinese healthcare system, its direct CO_2 emissions increased rapidly in last two decades[17] but its indirect CO_2 emissions were unknown.

This is the first study to quantify the direct and indirect carbon emissions of the entire healthcare system in a developing country. This study aims to quantify carbon footprint of Chinese healthcare system and identify carbon emission hotspots in the system. This study examined 6 categories in Chinese healthcare system, including public and private hospitals, community health care, public health, other health care institutions, and pharmaceuticals. The results contribute knowledge of the carbon footprint of national healthcare system so that policy makers, especially in developing countries, can develop relevant carbon mitigation policies.

Methods

Analytical framework

A detailed description of the data, analytical framework, and uncertainty analysis, partly described in previous study.[18]

This study adopted input-output technique to calculate the carbon footprint or lifecycle carbon emission of healthcare system. The input-output technique, developed by Wassily Leontief, is a quantitative economic model representing the interdependencies between different sectors of a national economy.[19] Compared with LCA, input-output analysis can capture the lifecycle emissions without truncation error since it does not need to set system boundaries.

In the framework of input-output analysis, total CO_2 emissions or carbon footprint of a sector are CO_2 emissions caused by final use (consumption, capital formation and export) of the sector. Total CO_2 emissions are larger than direct (on-site) emissions for sectors with more final use than intermediate use, e.g., manufacturing of equipment. By contrast, total CO_2 emissions are smaller than direct emissions for sectors with more intermediate use than final use, e.g., manufacturing of metal products. I estimated the direct CO_2 emissions for each sector (see the next section) and then divided the emissions by total output of corresponding sector to obtain the direct emission factors. Thereafter, I calculated the total emission factors by multiplying the direct emission factor vector with Leontief's inverse matrix. Finally, multiplying the total emission factor with expenditure of a sector yields total CO_2 emissions for that sector.

I used the latest input-output table of China in 2012 published by the National Bureau of Statistics of China[20] to calculate the Leontief's inverse matrix. The input-output table is import-inflow competitive and needs to subtract the import portion from the intermediate and final use since the imported products do not emit in China. I used additional OECD data[21] to exclude imported products to construct a non-competitive input-output table. The input-output table was aggregated from 139 sectors to 46 sectors corresponding to the sector classification in energy statistics.

Chinese healthcare system includes medical institution sector and pharmaceutical sector. These two sectors are closely interactive since a large proportion of products in pharmaceutical sector are purchased by medical institutions. Chinese medical institutions can be divided into 5 categories: public hospitals, private hospitals, community health care, public health and other health care institutions. The expenditure of medical institutions and pharmaceutical sector can be obtained from the input-output table and more detailed expenditure of different medical institution categories were given in China Health and Family Planning Statistical Yearbook.[22]

To identify which expenditure in medical institutions causes the largest CO_2 emissions, I used structural path analysis to reveal the indirect emissions of medical institutions. The indirect emissions of medical institutions can be divided into first order indirect emissions (e.g., emissions from the production of pharmaceuticals purchased by hospitals), second order indirect emissions (e.g., emissions from the production of chemicals which are the raw material of pharmaceuticals purchased by hospitals) and so on. I added up all the first order and subsequent indirect emissions by procurement category. With regard to pharmaceuticals, the largest procurement category, I further decomposed its indirect emissions, i.e., the second order and subsequent indirect emissions of medical institutions.

Direct emission estimation

I compiled the CO_2 emission inventory containing emissions from energy use and industrial processes to calculate direct emissions for all sectors. It is noteworthy that China's energy statistics give the energy consumption of the other services sector which includes information technology, finance, real estate, business services, scientific research, education, healthcare, culture, sports, entertainment, etc. This study used a top-down approach to estimate the energy consumption of medical institutions, which assumed that the ratio of energy consumption to monetary inflow from energy sectors in medical institution sector is the same as the other services sector. The monetary flow between medical institution sector and all the sectors can be found in China's input-output table since it has a more detailed sector classification. Furthermore, two additional data are used to analyze the uncertainty of the estimated CO_2 emissions of medical institution sector: total floorage of all medical institutions in China and average energy consumption per unit of floorage for public buildings. The result shows that the two estimates are quite close (within 5%), confirming the reliability of the emission estimation.

Statistical analysis

This study quantified the uncertainty of CO_2 emission multipliers, but did not quantify the uncertainty of China's input-output data since the related data is not available. I estimated the uncertainty of CO_2 emissions by source category and then combined the uncertainties to derive the overall uncertainty. For emission factors and activity data, 95% confidence interval is often regarded as appropriate for range definition which is suggested by IPCC.[23] I used the uncertainty of China's emission factors and activity data investigated by previous study.[24] Finally, I derived the overall uncertainty of carbon footprint by using the error propagation functions recommended by IPCC.

Results

In 2012 China spent CNY 2449.8 billion on healthcare system including CNY 1998.6 billion on medical institutions and CNY 451.2 billion on pharmaceuticals. The largest healthcare expenditure category was public hospitals (CNY 1421.3 billion) accounting for 58% of Chinese healthcare expenditure (Table 1). A considerable percentage of hospitals expenditure was pharmaceuticals expenditure. The second and third largest expenditure category is non-hospital purchased pharmaceuticals (CNY 451.2 billion, 18%) and community health care (CNY 313.8 billion, 13%), respectively.

The overall CO_2 emissions caused by Chinese healthcare system were 217.1 megatonnes (95% CI 206.8-227.5). This sector accounted for 2.2% (95% CI 2.1%-2.3%) of China's total CO_2 emissions of 9978.2 megatonnes in 2012. Table 1 gives the direct and total CO_2 emissions for 6 healthcare expenditure categories. The direct CO_2 emissions for Chinese healthcare system were 42.0 megatonnes in 2012, only 0.4% of China's total CO_2 emissions. The direct emissions were mainly from pharmaceuticals (23.8 megatonnes) and public hospitals (13.0 megatonnes). The total CO_2 emissions of healthcare system were much larger than direct CO_2 emissions since most pharmaceuticals and healthcare services were produced for final use rather than intermediate use. The three largest total CO_2 emissions categories were: public hospitals (115.8 megatonnes), pharmaceuticals (54.3 megatonnes) and community health care (25.6 megatonnes). Figure 1 shows the breakdown of total CO_2 emissions for 5 medical institution categories in Chinese healthcare system. Public hospitals (71%) were significantly leading in overall healthcare carbon footprint and community health care (16%) were the second largest medical institution. The total CO_2 emission factors of public and private hospitals (81.5 tonnes per million CNY) were 9 times the direct emission factors (9.0 tonnes per million CNY) since large CO_2 emissions were from electricity, pharmaceuticals and medical instruments production outside hospitals. Pharmaceuticals had even higher total CO_2 emission factors of 120.4 tonnes per million CNY.

***Table 1*: CO_2 emissions for Chinese healthcare system in 2012**

	Total expenditure (billion CNY)	Direct CO_2 emission factor (tonne per million CNY)	Total CO_2 emission factor (tonne per million CNY)	Direct CO_2 emissions (megatonne)	Total CO_2 emissions (megatonne)
Public hospitals	1421.3	9.0 (8.1-9.8)	81.5 (76.6-86.3)	13.0 (11.7-14.2)	115.8 (108.9-122.7)
Private hospitals	107.5	9.0 (8.1-9.8)	81.5 (76.6-86.3)	1.0 (0.9-1.1)	8.8 (8.2-9.3)
Pharmaceuticals	451.2	15.0 (12.3-17.6)	120.4 (112.4-128.3)	23.8 (19.5-28.0)	54.3 (50.7-57.9)
Community health care	313.8	9.0 (8.1-9.8)	81.5 (76.6-86.3)	2.9 (2.6-3.1)	25.6 (24.0-27.1)
Public health	135.6	9.0 (8.1-9.8)	81.5 (76.6-86.3)	1.2 (1.1-1.4)	11.0 (10.4-11.7)
Other health care institutions	20.4	9.0 (8.1-9.8)	81.5 (76.6-86.3)	0.2 (0.2-0.2)	1.7 (1.6-1.8)
Total	2449.8			42.0 (37.4-46.6)	217.1 (206.8-227.5)

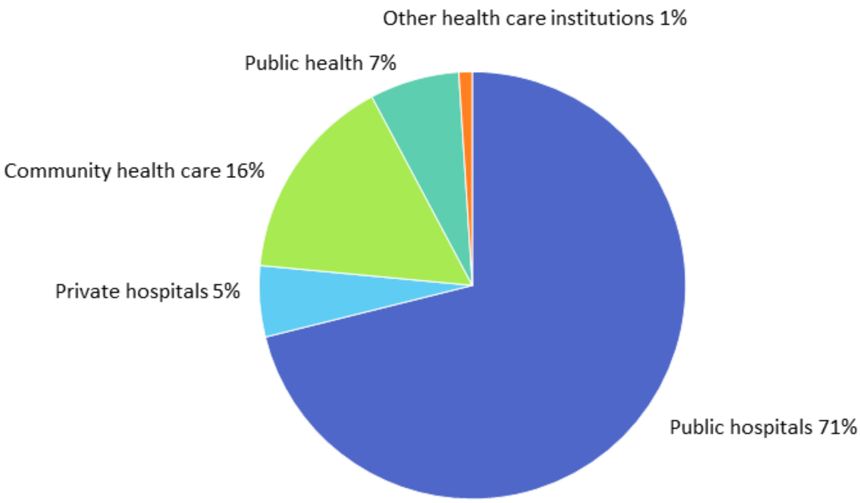

***Figure 1*: Breakdown of carbon footprint for 5 medical institution categories in 2012**

Figure 2 provides insight into the total healthcare CO_2 emissions stemming from different sectors. Among the 217.1 megatonnes carbon footprint of Chinese healthcare system, 75% were attributed to various medical institutions: hospitals, community health care, public health, etc. and 25% were attributed to pharmaceutical sector. From an on-site emission perspective, electricity & steam sector contributed to 46% of the carbon footprint with 73.6 megatonnes attributed to various medical institutions and 25.9 megatonnes attributed to pharmaceutical sector. The on-site CO_2 emissions from medical institutions and pharmaceuticals themselves contributed to 8% and 10% of the carbon footprint, respectively. In addition, other sectors with large CO_2 emissions attributed to healthcare system were: transport (7%), iron & steel (6%), nonmetal (6%) and chemicals (6%).

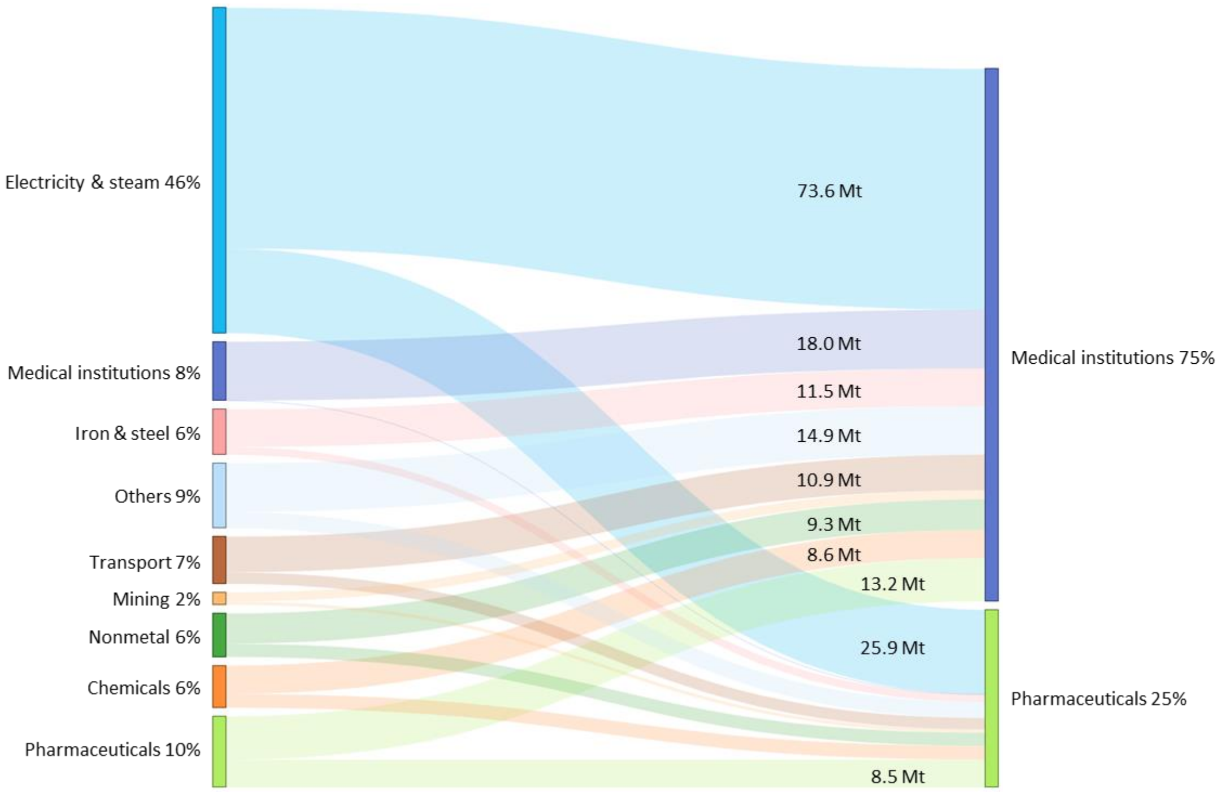

***Figure 2*: Total healthcare CO_2 emissions stemming from different sectors**

With structural path analysis, we gave insight into the carbon footprint of medical institutions. We found that 129.2 megatonnes CO_2 emissions (contributing 79% of total) were embodied in procurement and 33.6 megatonnes (21%) were from building and transport energy use. Figure 3 illustrated that pharmaceuticals contributed 84.3 megatonnes (52%) to the carbon footprint of medical institutions leading in all the procurement. Medical instruments contributed 12.7 megatonnes (8%) to the carbon footprint. In addition, apparel, outsourced transport, wholesale, retail, hotels & catering and food also contributed a lot to the carbon footprint. Among the CO_2 emissions embodied in the procurement of pharmaceuticals, more than a half were attributed to the upstream raw material procurement from itself (47.3 megatonnes). In addition, chemicals (7.4 megatonnes), agriculture (6.3 megatonnes), electricity & steam (5.8 megatonnes), nonmetal (2.4 megatonnes) and transport (2.1 megatonnes) also contributed to the CO_2 emissions embodied in the procurement of pharmaceuticals. The direct (on-site) emissions from medical institutions, for instance, lighting, heating, ventilation, air conditioning, operation, transport, were relatively small. For the direct emissions, 17.9 megatonnes (11%) of were from fossil fuels uses and 15.7 megatonnes (10%) were from electricity & steam uses.

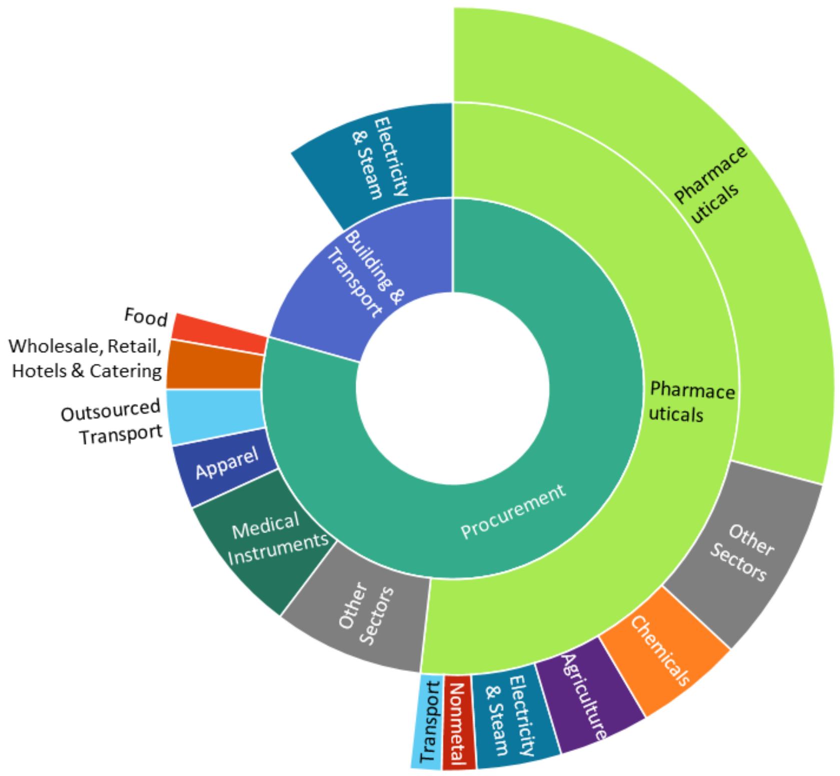

***Figure 3*: Breakdown of carbon footprint of medical institutions in 2012**

Discussion

This study provides important information to compare the healthcare sector with other sectors in China and global healthcare sector in terms of carbon footprint. China's healthcare expenditure accounted for 4.5% of GDP[25] in 2012 and this study found that the carbon footprint of this sector was 2.2% of China's total. It means that the carbon intensity of healthcare sector is lower than the national average. Healthcare is more carbon intensive than most service sectors, such as finance, real estate, business services, scientific research, education, culture, sports, entertainment. On the one hand, hospitals are among the most energy intensive commercial buildings. On the other hand, hosptials procure large amount of goods containing considerable energy consumption. Therefore, both the direct and total CO_2 emission factor of medical institution sector (9.0 and 81.5 tonne/million CNY) is higher than the other services sector (6.1 and 59.8 tonne/million CNY). The results indicate that the total CO_2 emission factor of pharmaceutical sector (120.4 tonne/million CNY) is one of the lowest among all the manufacturing sectors, and other sectors include food, apparel, electronic equipment, and gas. That is because the raw materials for pharmaceuticals are mainly from agriculture, a sector with relative low carbon intensity.

Compared with existing estimations, the carbon footprint of Chinese healthcare system is equivalent to one third of that of the US,[5] and 6-9 times that of Australia,[6] Canada,[7] and England.[8] Considering China's large population, its healthcare carbon footprint per capita (0.2 tCO_2e/cap) is well below that of the US (2.1 tCO_2e/cap), Australia (1.5 tCO_2e/cap), Canada (0.9 tCO_2e/cap), and England (0.5 tCO_2e/cap).

China's power structure is dominated by coal, meaning higher carbon intensity. For instance, CO_2 emissions per unit of energy use were similar for China and Australia (73.1 vs 72.2 tonnes CO_2 /terajoule),[26] higher than the US, Canada and England. Healthcare carbon footprint per capita in China, however, was much smaller than those countries. These results reflect that China's medical institutions do not have as many devices as developed countries, on the other hand, China's healthcare services are more energy efficient.

The share of healthcare carbon footprint in China's total (2.2%) was lower than developed countries, such as the US (10%),[5] Australia (7%),[6] and Canada (5%).[7] Similarly, China's healthcare expenditure was relatively small (4.5% of GDP) compared with the US (16.4%), Australia (8.7%), Canada (10.2%) and the UK (8.3%).[25] The proportion of China's healthcare expenditure in GDP has much room for growth since a rapid improvement in healthcare services is required. The growth of healthcare expenditure, such as procurement of medical instruments, will inevitably lead to an increase in carbon footprint. Energy efficiency indicators should be considered by hospitals when purchasing medical instruments.

There are also some differences in the carbon footprint of healthcare subsets between China and developed countries. In China, purchased pharmaceuticals contributed to 52% of total carbon footprint of medical institutions, however, that figure was only 11% in England.[27] Potential reasons for such difference include that China's pharmaceutical sector has higher carbon intensity and China's hospitals are equiped with less medical instruments. With the continuous enrichment of medical instruments, building energy consumption for hospitals will increase in China and there are barriers in economic incentive, technology and regulations to improve the energy efficiency.[15] Some local governments, e.g., Shanghai, Hunan, Zhejiang and Shandong, have set standards for the quota of energy consumption for medical institutions. This standard can effectively slow the growth of direct CO_2 emissions in hospitals. However, there are currently no restrictions on indirect emissions due to the lack of lifecycle emissions for procuement. Despite this, circular medical products can help reduce the carbon footprint of healthcare system.[28] Furthermore, this study suggests that pharmaceutical sector be included in the national carbon emission trading system to reduce the carbon intensity of drugs as well as the carbon footprint of healthcare system.

The limitation of this study was that the energy statistics for Chinese healthcare system were not available, hence, the direct CO_2 emissions estimation had higher uncertainty. Nevertheless, the direct emissions only account for a small portion in the carbon footprint of healthcare system, so the overall uncertainty was lower. Another limitation was the lack of links to research on health impacts from climate change. In other words, it is unknown that how much CO_2 emissions stemmed from healthcare system were attributed to curing diseases caused by climate change. Climate change and healthcare system are two-way interactions and the feedback from healthcare system will further contribute to global climate change.

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