Conference Paper

China and India: Energy Service and Related Material Demand Projections

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CHINA AND INDIA: ENERGY SERVICE AND RELATED MATERIAL DEMAND PROJECTIONS

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1. Background

India and China are the two most populous countries in the world, each home to a fifth of the world's population. However, both countries have experienced a very different pattern of economic development. Gross domestic product (GDP) per capita has increased an astonishing nine-fold in China since 1990 while India's GDP per capita increased only three times during the same period (World Bank, 2018). As a result, China currently contributes 28% of global carbon dioxide (CO_2) emissions, more than four times the amount of India's CO_2 emissions. China's CO_2 emissions growth has been fueled by the expansion of manufacturing industries and notably by a rapid increase of energy-intensive material production. In 20 years, China has become the largest producer of cement, steel, aluminum, and ammonia and is among the largest countries producing chemicals, petroleum products, and other basic materials that require significant amount of energy for their production. However, the Chinese economy is gradually shifting toward more services, reaching more than 50% of China's GDP in 2015 and resulting in a decoupling of CO_2 and GDP growth. Conversely, India's economic growth has primarily been driven by its fast-growing service sector which is leading to the emergence of a growing middle class with aspirations for a better quality of life (Javalgi and Grossman 2016; Bhattacharyya 2015). India's subsequent rapidly growing urbanization favored by recent policy reforms and planned public infrastructure investments is contributing to the growth of the industry sector in the country (World Bank 2018b) as the material needs of the population increase.

These macro-economic trends suggest that energy use and related CO_2 emissions from the manufacturing of goods and materials will peak in China in the next decade but will continue to grow and maybe accelerate in India. However, many unanswered questions remain on the scale and timing of these trends, driven by energy service demand and related material production.

2. Research Question

The main research question being addressed in this paper is what are the key drivers of energy service and related material demand in China and India given their different stages of economic development? The paper focuses on capturing the main physical drivers of material demand and related energy growth in order to identify what subsectors need to be addressed on a priority basis to develop sustainable pathways to support the forecasted economic growth in both countries. This paper presents detailed assumptions on manufacturing activity and energy intensity to project energy consumption for material production as well as information on fuels and fuel-switching to project energy-related CO_2 emissions.

The study describes in detail the methodology and underlying assumptions to develop a bottom-up, transparent baseline scenario to 2050 for both China and India that includes no major new technology breakthroughs and no newly adopted policies. This baseline scenario is developed to form the basis for future development of alternative material production and energy consumption scenarios for policy makers to inform targeted policy interventions.

3. Modeling Approach

In order to provide insights on these energy and energy-related CO_2 emissions trends, Lawrence Berkeley National Laboratory (LBNL) developed the Demand Resources Energy Analysis Model (DREAM) for China and India. LBNL's DREAM is a bottom-up simulation model that uses micro-level data to reflect the penetration and usage of individual technologies across sectors that enables detailed assessments of

technology investments and policy actions. Data are organized using an accounting and scenario-based modeling platform called LEAP (Long-range Energy Alternative Planning System). LEAP is a software tool for integrated energy-environment and greenhouse gas mitigation analysis developed by the Stockholm Environment Institute (Heaps, 2016).

In China and India, growth in the most energy-intensive industry sectors is primarily driven by material demand from urbanization and infrastructure development. For example, 78% of cement production in India is to meet building construction demand while in China the drivers for cement production are infrastructure (37%), building construction (36%), and urbanization (24%) (TERI 2017, DBS, 2018). In the case of steel production, building and infrastructure construction represents 62% of steel demand and automobile manufacturing represents 10% in India while in China, building and infrastructure construction represents 43% of steel consumption and automobile manufacturing represents 5%.

The LBNL DREAM model uses a physical accounting of material production that is interlinked to the demand for material based on increased technology penetration. The model was developed to take into account the linkages that exist between the consumer sectors' material demands and the productive sector's material production. For each sector, material production is derived from demand from other sectors and average material intensity values. For example, cement production is a factor of projected annual construction of urban, rural, and commercial floor space construction area, highway and paved road area, and railway length, combined with material intensity values to determine the resulting cement demand. Table 1 provides the details of these material demand drivers for each sector.

Table 1. Drivers of Material Intensity Production

Material	Drivers
Steel	Building floor space (rural, urban, commercial), railways, vehicle, steel finished products, infrastructure and steel net exports
Cement	Building floor space (rural, urban, commercial), roads, railways, urban paved area, industrial construction and cement net exports
Ethylene	Population and per capita demand for plastics
Ammonia	Sown area and fertilizer intensity
Aluminum	Vehicles, power generation equipment needed to meet increased power demand, new urban construction, and other aluminum products
Paper	Population and per capita demand for paper
Glass	Flat glass: vehicles production, building construction, vehicles Container glass: per capita demand for container glass
Copper	New urban construction, power generation equipment needed to meet increased power demand, and vehicles

The cement production equation is provided below to illustrate how material production drivers are embedded in the DREAM model. Cement production is modeled as a function of new urban and rural commercial and residential construction, urban paved roads, expressways and Class I and II highways (which are made of cement), railways, and net exports of cement. The formula for modeling cement production is:

$$P_c = [(CFSu + CFSr) \times CI1 + (RFSu \times CI2) + (RFSr \times CI3)] + (PA \times CI4) + (H \times CI5) + (R \times CI6) + Ex$$

Where:

P_c	= Annual cement production
CFSu	= Urban commercial floorspace (3 year rolling average)
CFSr	= Rural commercial floorspace (3 year rolling average)
RFSu	= Urban residential floorspace (3 year rolling average)
RSFr	= Rural residential floorspace (3 year rolling average)
CI1	= Commercial building cement material intensity
CI2	= Urban residential building cement material intensity
CI3	= Rural residential building cement material intensity
PA	= Urban paved area
CI4	= Paved area cement material intensity
H	= Highways, specifically expressways, and Class 1 and 2 highways (3 year rolling average)
CI5	= Highway cement material intensity
R	= Railroad track length, 3 year rolling average
CI6	= Railroad track cement material intensity

This approach explicitly accounts for the effect of growing commercial and residential building construction and targeted expansion of urban paved areas, highways and rail tracks on cement production. In particular, the expansion of urban paved areas and highways are modeled after Japanese experience of infrastructural development while the railway track forecast assumes meeting the 2020 targets set forth in the railway development plan (Fridley et al., 2012 and Hasanbeigi et al., 2017).

4. Results

4.1 Material Production

Material production projections are calculated in DREAM based on the demand for new consumer products, urbanization, population growth, and construction floor space. Table 4 provides results of the material production baseline modeling projection for India and China in 2050 compared with actual 2015 production levels. This baseline projection shows that India's production of materials is expected to remain below China's levels of today for all materials except paper.

Table 2. Material Production in China and India, 2015 (Actual) and 2050 (Projected)

Materials	**India 2015** (million tons)	**India 2050** (million tons)	**China 2015** (million tons)	**China 2050**
Steel	95.5	457.6	808.4	582.3
Cement	283.5	1,127.7	2,400.1	1,647.2
Aluminum	2.4	13.0	32.0	38.3
Ammonia	13.5	19.6	46.0	47.6
Paper	14.9	132.7	111.2	218.6
Glass	4.7	38.5	64.0	58.3
Copper	0.8	14.6	6.8	22.2

Figure 1 shows that the baseline scenario projected production of a number of key industrial commodities in China such as steel and cement are projected to peak around 2020 due to a gradual decrease of demand for building and infrastructure materials. Other materials, such as ethylene and glass, peak later and then gradually decrease to 2050. Ammonia production is projected slowly decrease between 2017 and 2050, while paper production is project to continue to grow during this time period.

Figure 2 provides the baseline scenario projection of commodity production in India from 2017 to 2050, showing that production of all materials continues to increase, although some the growth in production of ammonia is much slower than the growth in production of all of the other commodities, especially glass and paper.

Figure 1. Trends in Material Production in China in the Baseline Scenario, 2017-2050 (2017=100%)

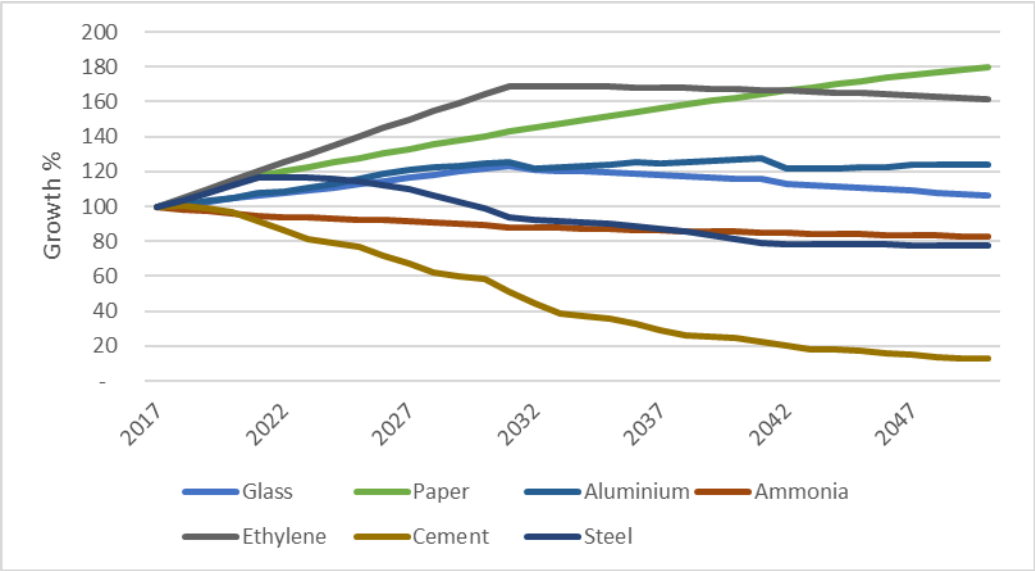
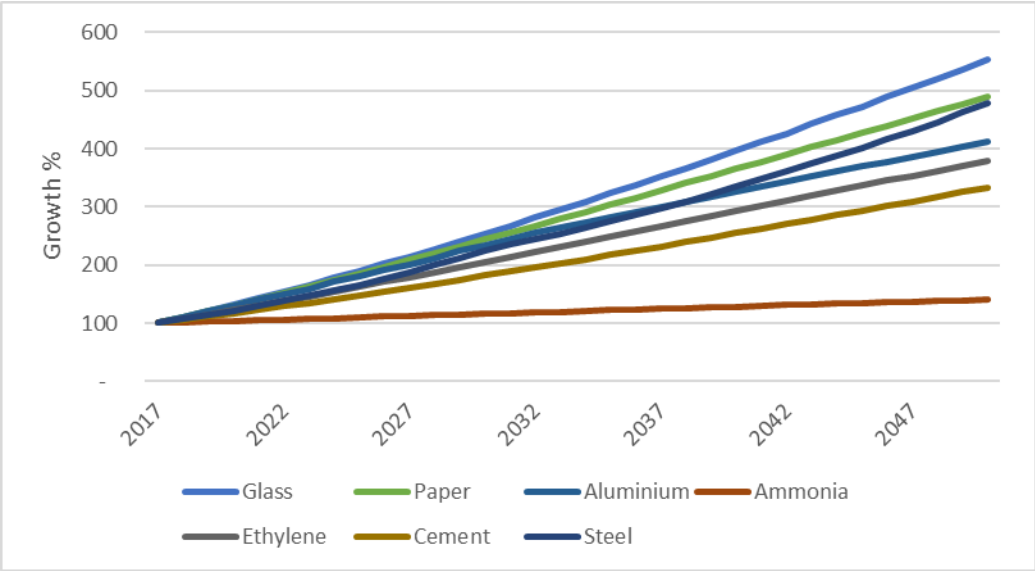


Figure 2. Trends in Material Production in India in the Baseline Scenario, 2017-2050 (2017 = 100%)



4.2 Energy Demand

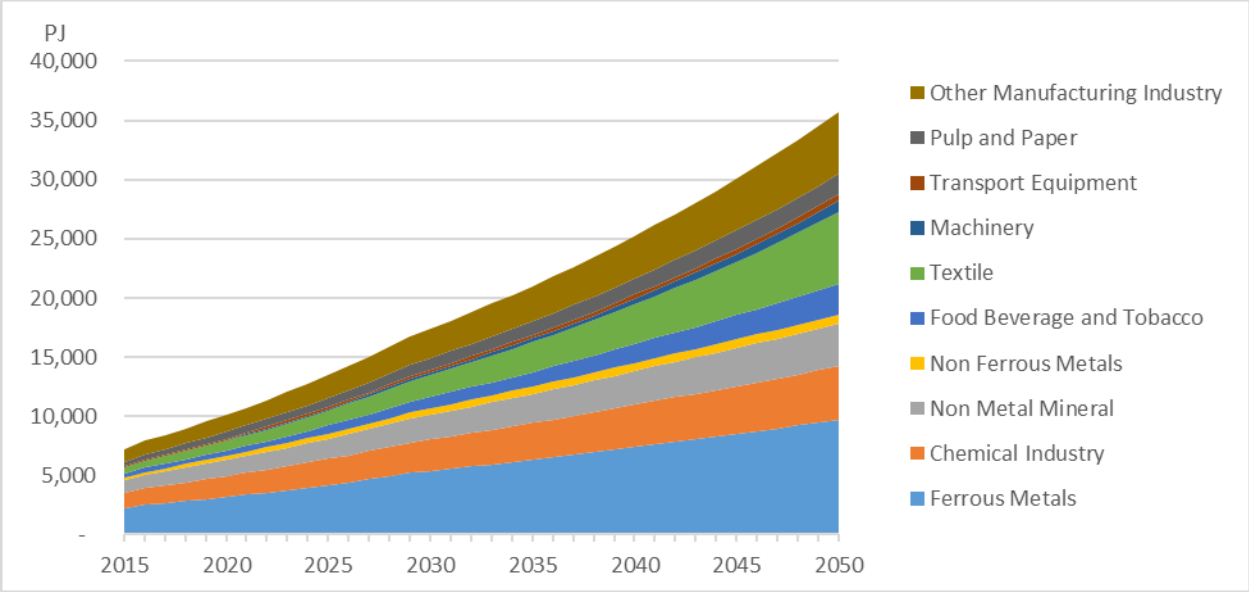
Combining the material production projections with energy intensity values for each material commodity – which show slight autonomous improvement over time in the baseline scenario – the DREAM model calculates final energy demand for each industrial subsector.

Total energy demand in both China and India is dominated by a few energy-intensive sectors, particularly by the main construction commodities – cement and steel – which are driven by urbanization and its demand for built infrastructure.

In 2015, industry energy consumption in China and India are ery disparate. The industry sector consumed 55.3 exajoules (EJ) in China and 7.3 EJ in India, representing 62% and 38%, respectively, of each country's total final energy consumption. However, this significant difference resumes as industry energy use increase rapidly in India and levels off in Chine. By 2050, China industry secto consumes 52.3 EJ and India's consumes 35.7 EJ. (Figure 3 and Figure 4)

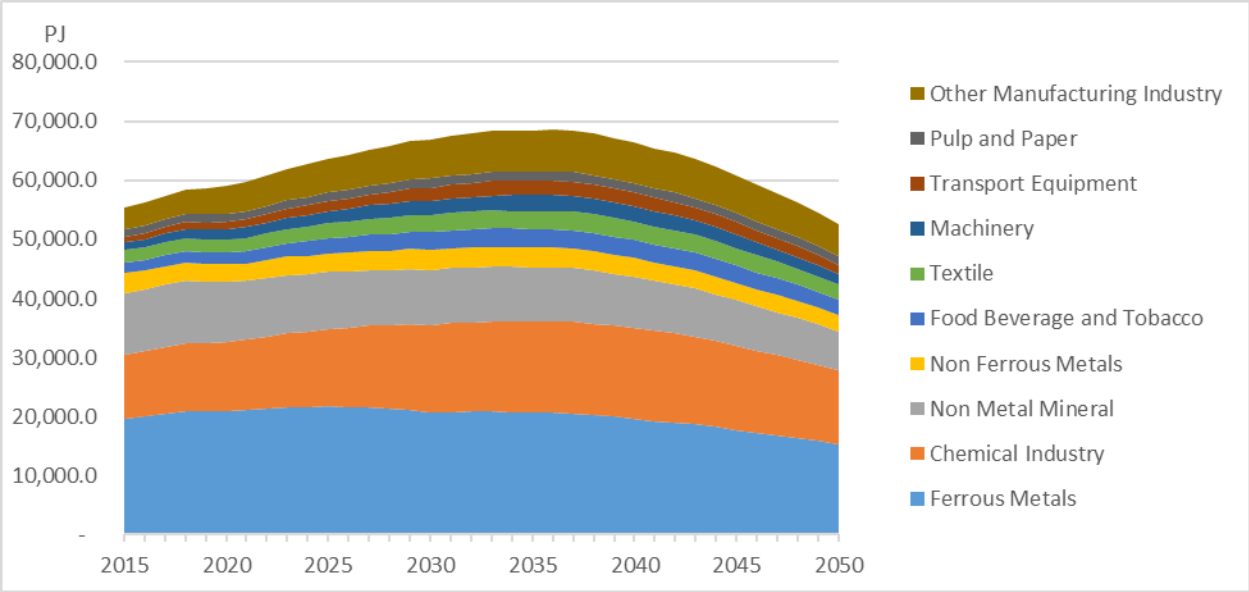
The energy-intensive[1] industries represent 72% of all the sector's energy consumption in 2015, while only representing 30% of the total industry value added in India. In China, energy-intensive industry represents an even larger share of the energy consumption of the industry sector with a share of 83%. The explosion of construction in China in recent years has played a driving role in the demand for construction materials and therefore Chinese energy demand as a whole. The slowing of this construction boom will have a major impact as seen by the peaking of industrial energy use before 2030 in the baseline scenario of the China DREAM model. In India, an opposite trend can be expected as the rate of construction has been comparatively much lower in the past. As household incomes in India rise, consumers are expected to purchase more energy-using assets like appliances and cars, require larger home and offices, and demand access to improved infrastructure. As a result, India's industry sector is projected to grow in the baseline scenario to meet the increased demand for manufactured goods and raw materials essential for infrastructure development.

Figure 3. India Final Energy Projection in the Baseline Scenario, 2015-2050



[1] Ferrous metals, chemical industry, non-metallic minerals, non-ferrous metals, and pulp and paper.

Figure 4. China Final Energy Projection in the Baseline Scenario, 2015-2050



4.3 Energy-related CO_2 Emissions

Due to the heavy reliance on fossil fuels for manufacture of industrial commodities in India and China, the DREAM model baseline scenario shows that industry sector energy-related CO_2 emissions are expected to remain large, especially in a few energy-intensive industries. Iron and steel production is by far the largest source of direct CO_2 emissions in the industry sector in both countries. Growth in this sector is expected to be significant in India as steel is a major input to infrastructure development. Moreover, the steel sector is very coal intensive in both countries and there is little incentive for the sector to transition to lower carbon fuels.

In China, the energy consumption of the energy-intensive industries will gradually decline relative to other sectors, though they are still projected to account for 52% of total final energy consumption in 2030 in the baseline scenario. In the case of steel and cement, China's expected transition from rapid industrialization and infrastructure development to faster growth and expansion in the services sector after 2010 underlies the slowdown and eventual decline in total iron and steel output and in the decline of the cement industry.

Figure 5 and

Figure 6 shows projected direct and indirect CO_2 emissions from fuel combustion in China's and India's industry subsectors in the baseline scenario. Total CO_2 emissions in India are projected to more than quadruple from 2015 to 2050, from 932 $MtCO_2$ in 2015 to 3,883 $MtCO_2$ in 2050. To the contrary, total Co2 emissions in China are projected to reduce by 24% during the same period, reaching 5,139 $MtCO_2$. While India emissions are projected to increase significantly over the next 35 years, they will still be significant lower than total emissions in China.

In both countries, the share of direct versus indirect remains constant. The direct CO_2 emissions are projected to represent 50% of total CO_2 emissions in the industry sector, close to the level of 51% in 2015 in India. In China, the share of direct emissions 41% in 2050 versus 42% in 2015, representing a higher share of overall electrification of the industry sector than India.

Among energy intensive subsectors, the iron and steel, cement, and chemicals sectors are by far the largest source of emissions in both countries. Direct CO_2 emissions from the ferrous metal, non-metal mineral products, chemical materials, and pulp and paper subsectors are projected to represent 80% in China and 74% in India of total direct emissions in 2050 in the baseline scenario. These sectors are hard to decarbonize, as low carbon technology solutions are nascent and consist of a combination of solutions that include expanding renewable energy for heat use, increasing energy efficiency, and encouraging material efficiency.

Figure 5. Direct and Indirect Energy-Related CO_2 Emissions from Industry in China in the Baseline Scenario, 2015-2050

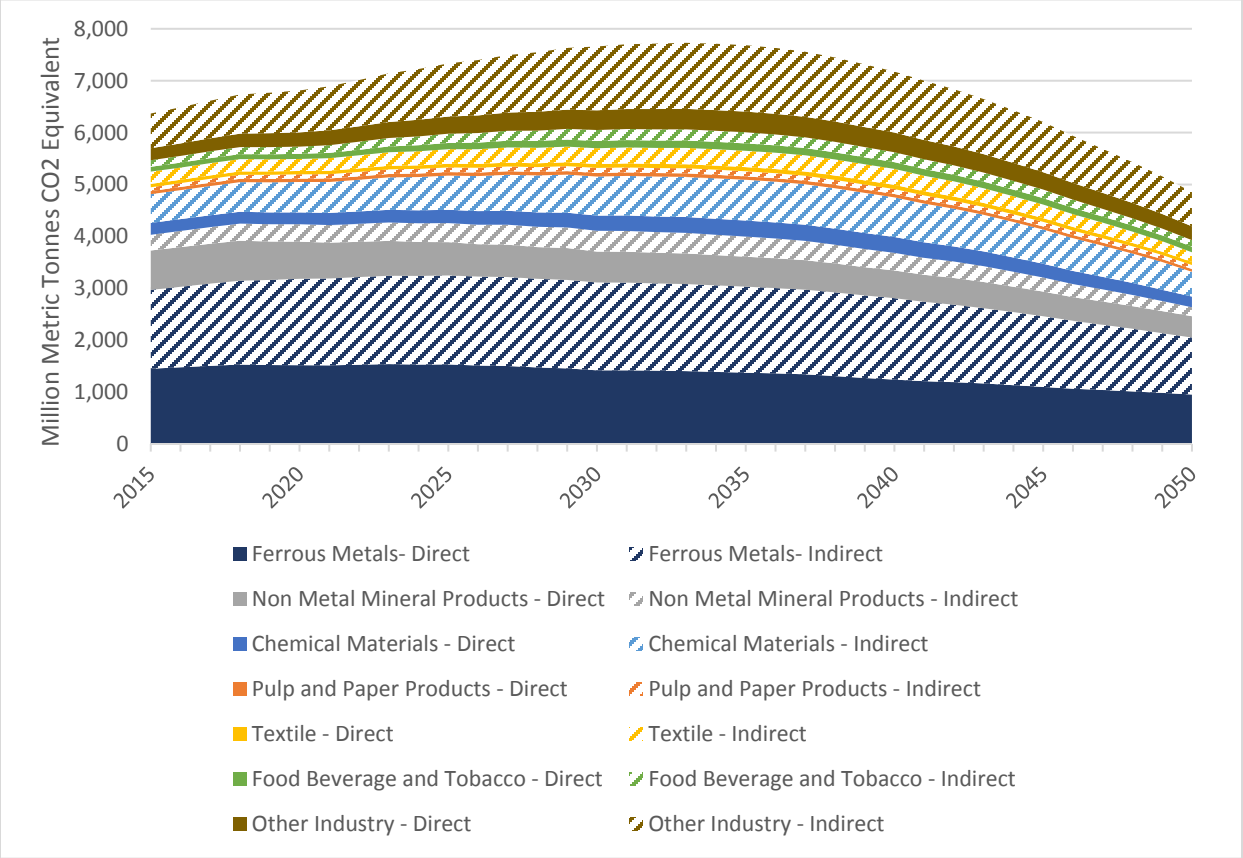
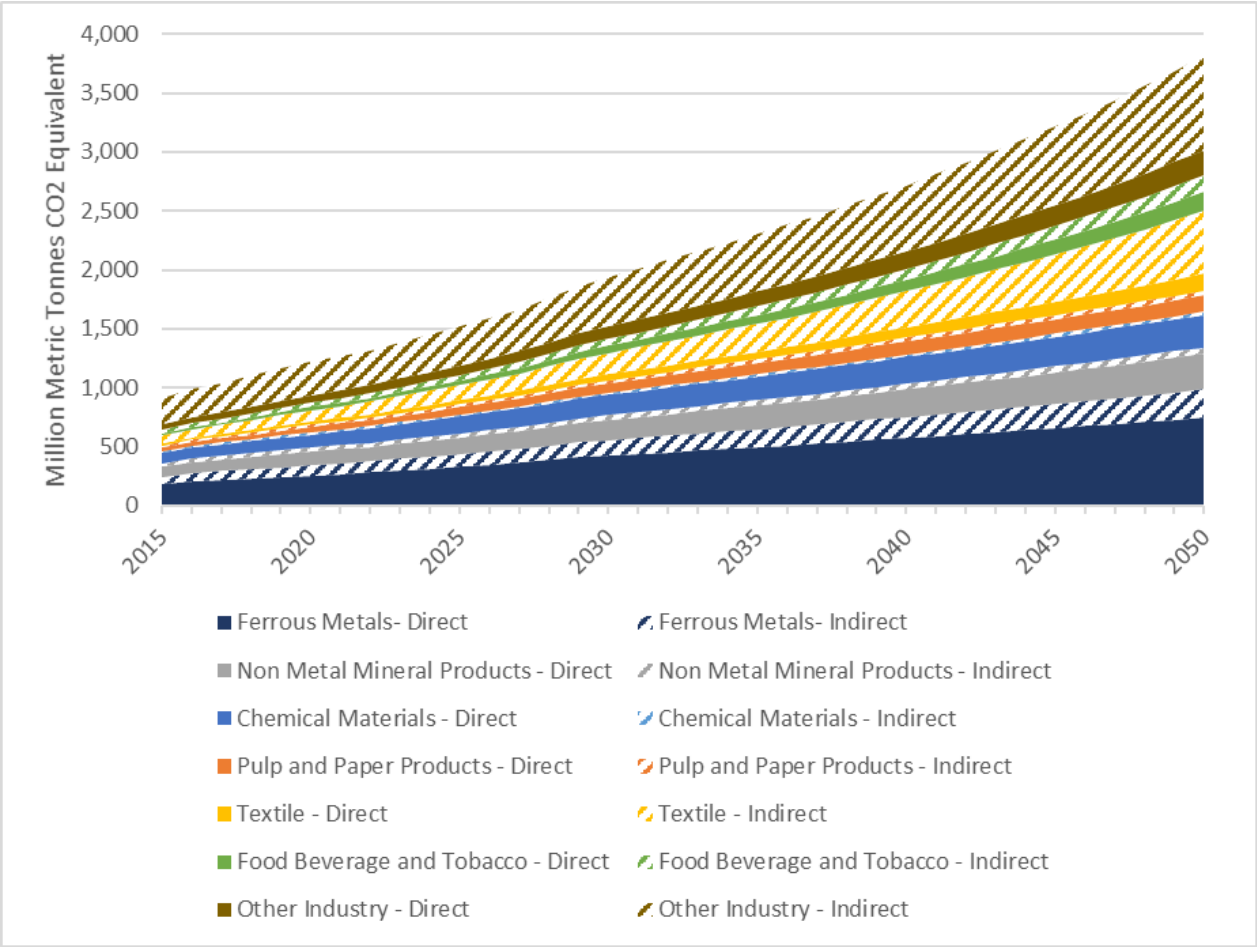


Figure 6. Direct and Indirect Energy-Related CO_2 Emissions from Industry in India in the Baseline Scenario, 2015-2050



5. Findings

The pace at which China's and India's energy demands change over the course of the next thirty-five years will be a function of three factors: the efficiency by which industrial products are produced, infrastructure and building expansion, and the materials intensity of that physical expansion. The intent of this modeling exercise is to provide a reasonable baseline scenario of growth in material production, energy use and related CO_2 emissions considering China's and India's current policy commitments and global technology trends.

By providing a comprehensive economy-wide bottom-up accounting of sectoral energy demand the analysis is able to answer important questions regarding how China and India will grow their industry production. The model takes a physical accounting approach of material production that interlinks growth in activity across sectors and provide a solid and transparent baseline on which low carbon pathways can be built to estimate policy action impacts. The originality of the paper is to provide a method to forecast material production and provide estimates that can be then used by policy makers in setting energy efficiency and material efficiency initiatives.

Acknowledgments

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