Emerging Issues Report

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Material Requirements for Infrastructure Development

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About this report

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1 Overview

This literature review aims to identify published studies providing projections of the global demand for, and remaining stock of, materials important for construction that could be constraints to the development of infrastructure worldwide.

Our review found very little evidence and few projections addressing this issue. Although a wide variety of materials could potentially constrain infrastructure development, in our research we were only able to identify good quality projections for four materials: aluminium, cement, steel, and wood. Estimates of the energy needs, water requirements and likely carbon emissions of mining and processing these resources are also provided.

Demand for all of the materials we were able to study is projected to increase exponentially, along with related trends such as population and economic growth. Although this suggests the possibility of exhausting the available reserves of raw materials, it is highly likely that substitution of alternative materials, changes in construction techniques, and scarcity enabling the exploitation of formerly uneconomic reserves may help prolong reserves of commodities. We did not identify any commodities that appear to be in near-term short supply on a global aggregate basis, although local shortages of individual materials are quite possible.

We also found several studies projecting the financial investment needed to meet the demand for infrastructure, so we have presented a summary of this information as well. We also attempted to estimate the skilled labour requirements in terms of the number of additional qualified consulting engineers which would be required to design and construct the additional road infrastructure required; we were unable to make similar estimates for other types of infrastructure due to limited information being available.

Our key findings are:

- The global infrastructure investment requirement for the period 2015-2030 is approximately $63 trillion (i.e. $3.9 trillion per year). This is an increase of about 56% of the current global infrastructure spend.
- Global production of aluminium is growing exponentially at a rate of 4.1% per year (Menzie et al. 2010). Assuming no changes in techniques, this suggests that known bauxite reserves could be exhausted by 2055.
- Global production of cement has been projected by the IEA (2009) to grow exponentially at a rate of 0.8% to 1.2% per year, but actual production has already far exceeded this projection due to high growth in emerging markets and developing countries.

- Global production of steel is projected to grow exponentially at a rate of 1.4% per year (Accenture 2017). Assuming no changes in techniques, known iron ore reserves could be exhausted by 2070.
- Global production of wood is projected to grow exponentially at a rate of 1.9% per year (Turner et al. 2006). Although wood is in principle a renewable resources, water stress appears likely to be an important constraint, as one source suggests that future wood production could require as much water as 29% of total current global water consumption (World Water Exchange 2016).

Table 1 Estimated energy, water requirements and carbon emissions between 2015 and 2030

Materials	Cumulative material demand	Energy	Water	CO_2	Energy	Water	CO_2
		per tonne of material			In total		
	(billion tonnes)	(kWh/t)	(Litres)	($kgCO_2$)	(TWh)	(Million m^3)	(Mt CO_2)
Cement	50.1 (1)	110	307	914	5,518	15,400	45,850
Steel	26.7 (2)	5,700	28,500	2,000	152,147	760,733	53,385
Aluminium	1.7 (3)	72,000	88,000	20,900	120,967	147,849	35,114
Total					**278,632**	**923,982**	**134,349**

Source: (1) adapted from IEA, 2010; (2) adapted from Accenture, 2017; (3) adapted from Menzie et al., 2010.

It should be emphasised that all of these projections have a high degree of uncertainty associated with them.

2 Methodology

The review question lends itself to an unbiased aggregation approach where the aim of the study is to identify a sufficient number of studies that provide relevant forecasts. With sufficient resources, such an approach would ideally seek to identify all relevant literature, but in keeping with the resource constraints of this particular study, careful consideration was given to locating a sample of studies most pertinent to addressing the research question. This was achieved by carrying out a key word search of titles and abstracts of studies via internet based search engines and via accessing databases and the websites of specific organisations. Following the initial screening process the full text of pertinent studies were retrieved for further scrutiny.

To be included in the scope, identified studies had to satisfy the following criteria:

i. Resources: raw and processed physical materials and human resources used in the investment, design, construction and maintenance of physical infrastructure (airports, bridges, commercial and residential buildings, dams, energy extraction/generation facilities, freshwater, storm water and sewage infrastructure, ports, power stations, railways, roads and telecommunications)

ii. Study design: Projections which determine the current and future resource requirements associated with planning, financing, building and maintaining infrastructure

iii. Language: English language only.

The review focused on identifying good quality studies which projected global demands, rather than those which focused on individual countries or groups of countries.

The primary raw materials used for the construction of physical infrastructure include clays, gravels, rock, sands and wood. Processed materials primarily used for physical infrastructure include asphalt / bitumen (processed from petroleum but also found naturally), bricks (made from clays), cement (i.e. clay, limestone or calcium silicate), ceramics (primarily from clays), concrete (i.e. cement plus sands and gravels of various sizes and water), foam (synthetic polystyrene or polyurethane), glass (melted sand and silicates), metals (primarily aluminium from bauxite; iron and steel from iron ore), paper (from wood) and plastics.

In our research, however, we were only able to identify good quality projections of the availability of four materials: aluminium, cement, steel and wood. Secondary sources of information were used to project the associated raw material requirements: bauxite for aluminium, limestone and clay for cement, and iron ore for steel. Estimates associated with the energy and water requirements and likely carbon emissions associated with mining and using these resources are also provided.

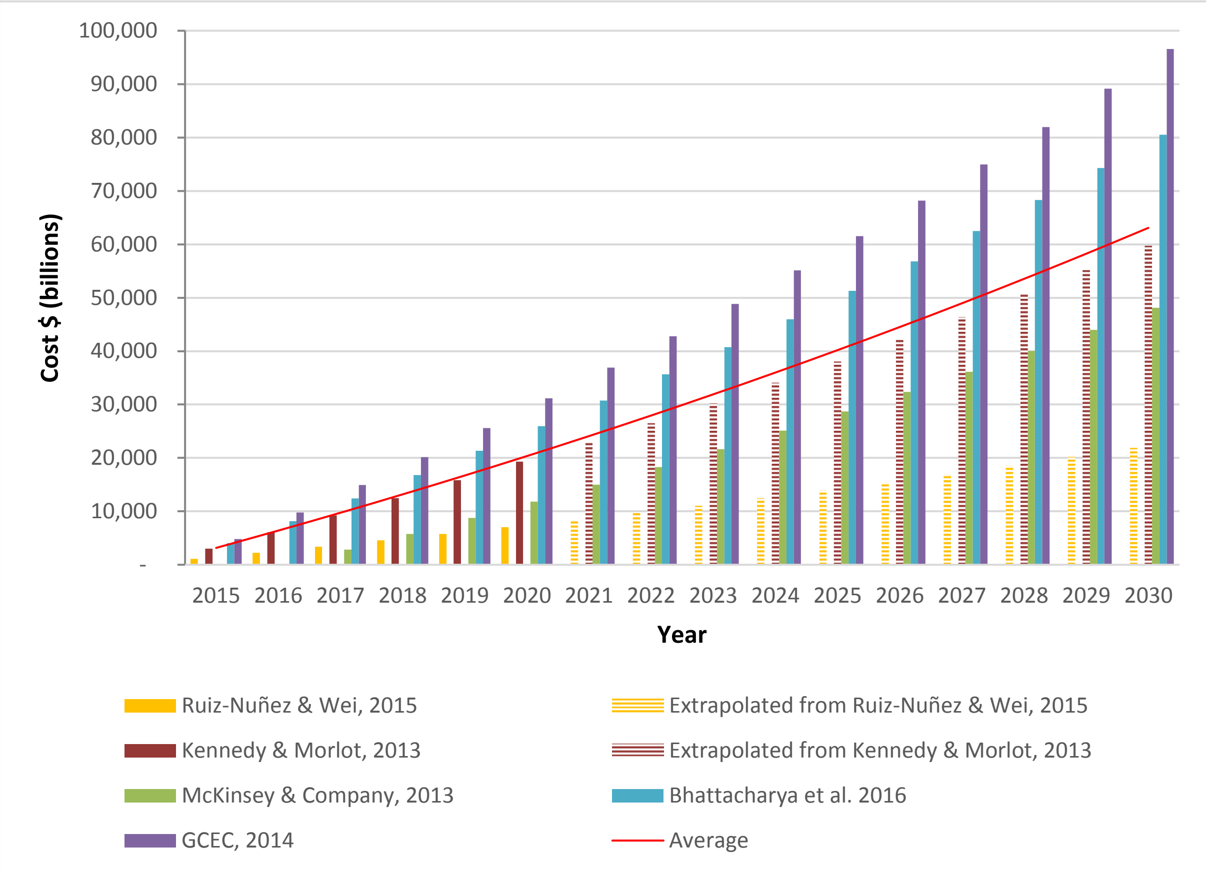
The study utilised the following databases, websites and search engines:

- Scopus
- Web of Science
- Google Scholar
- Google
- World Bank
- Asian Development Bank
- African Development Bank
- OECD
- New Climate Economy
- FindIT.bham.ac.uk.

3 Financial requirements

The review of the literature found estimates of the total global infrastructure investment requirement for the period 2015-2030 at 2015 prices ranging between $21.8 trillion and $96.6 trillion. The average across all of the studies was $63 trillion, equivalent to an annual investment of about $3.9 trillion per year which is 50% more than current annual infrastructure spending of $2.5 trillion per year (McKinsey & Company, 2016). Figure 1 shows the global cumulative projected investment in infrastructure by different authors. All estimates have been converted to 2015 prices and adapted for the period 2015-2030; the red line shows the average investment value of the projections.

Figure 1 Global cumulative investment for the period 2015-2030 by different authors (in 2015 US$)



Our review found six studies which estimated the investment needed for global infrastructure development (see Table 2). The studies apply a wide range of methodologies, estimate periods, definition of infrastructure, assumptions and scenarios. This results in significant differences in the projected infrastructure demand as well as the required investment to meet such demand.

Table 2 Summary of projected financial requirements by different authors (in 2015 US$)

Source	Global Infrastructure requirement (annual)	Global Infrastructure requirement (total)	Estimate period	What is included
GCEC, 2014	$ 6 trillion/year	$96.5 trillion by 2030	2015-2030	New construction & maintenance for Transport, Water & waste, Energy & Telecoms
Bhattacharya et al., 2016	$ 5 trillion/year	$80.5 trillion by 2030	2015-2030	New construction & maintenance for Transport, Water supply & sanitation, Energy, & Telecoms
Ruiz-Nuñez. & Wei , 2015	$ 1.2 trillion/year	$8.1 trillion by 2020	2014-2020	New construction & maintenance for Transport, Water supply & waste, Energy, & Telecoms
Kennedy,& Morlot ,2013	$ 3.2 trillion/year	$19.2 trillion by 2020	2015-2020	New construction & maintenance for Transport, Water, Energy, & Telecoms
McKinsey & Company, 2013	$3.5 trillion/year	$62.1 trillion by 2030	2013-2030	New construction & maintenance for Transport, Water supply & waste, Energy, & Telecoms
Dulac, 2013	$ 3.2 trillion/year	$128.6 trillion by 2050	2010-2050	New construction & maintenance for road, railway and parking place

A study by The Global Commission on the Economy and Climate (GCEC) (2014) projects that the world will need to invest about $88.6 trillion in infrastructure by 2030 (i.e. $ 5.5 trillion per year). The study is based on a business-as-usual (BAU) scenario and assumes that there will be no new policy actions to address additional infrastructure which might be required to tackle the effects of climate change and the requirements for additional energy security. The projections were calculated at 2010 prices and derived from sectoral estimates provide by OECD (2006 and 2012), the International Energy Agency - IEA (2012), and the analysis by Climate Policy Initiative (The Global Commission on the Economy and Climate, 2014). The projection includes the investment for replacement, maintenance and construction for transport (road, rail, airport, and port), water supply and waste (for both human and agricultural use), energy (power generation, electricity transmission and distribution, fossil fuel supply chain, and energy end-use sectors) and telecommunications infrastructure (fixed-line telephony and data, mobile telephony and data, broadband mobile communications).

Bhattacharya et al (2016) estimate that between $75 trillion and $86 trillion (at 2015 prices) of investment is needed for new construction and maintenance of core infrastructure (including energy, transport, water supply & sanitation, and telecommunication) for the period 2015 to 2030. They made the calculation based on the average infrastructure investment spending in 2015 and assumptions of GDP growth and investment rates. The uncertainties in these assumptions are the major limitation of the report.

Ruiz-Nuñez and Wei (2015) estimate that the required resource to satisfy new infrastructure demand while still maintaining existing global infrastructure will amount to $1.1 trillion (US$ 2011) or 2.2 percent of current world GDP per year over the period 2014 and 2020. To estimate the infrastructure investment demand Ruiz-Nuñez and Wei (2015) adopted Fay's (2000) model and Yepes (2008) methodology to develop a model in which infrastructure investment requirement is estimated to satisfy the customer and producer demand for services given an expected GDP growth rate. The GDP growth rates between 2014 and 2020 were predicted from the average GDP growth rates of the previous five years.

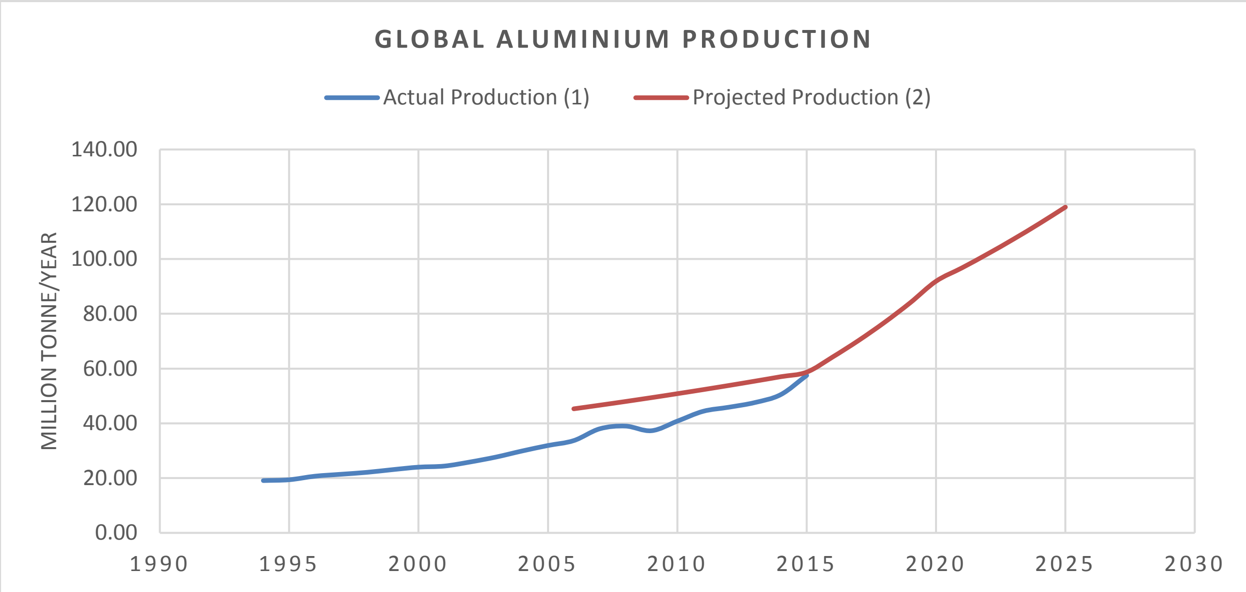
McKinsey and Company (2013) projects global infrastructure needs through combining independent estimates of future needs by sector, including those of the OECD, IEA, and Global Water Intelligence (GWI). The report forecasts that $57 trillion, at 2010 prices, in global infrastructure investment will be required between 2013 and 2030. This figure includes the investment for transport, power, water and telecommunications infrastructure, with roads and power accounting for almost half of the demand. Similar to the above studies, McKinsey and Company's report suggest that the infrastructure investment requirement up until 2030 is greater than the estimated value of today's infrastructure worldwide.

Similar studies were also conducted by Kennedy & Morlot (2013) and Dulac, (2013). While Kennedy & Morlot (2013) focus on a wide range of infrastructure categories (transport, energy generation, transmission and distribution, water, and telecommunication), Dulac, (2013) only calculates the needs for roads, railways and parking demands. As a whole, Kennedy, & Morlot (2013) forecast that the world will need an investment of $18.7 trillion for infrastructure by 2020. For the transport sector, Dulac (2013) estimates an investment of $120 trillion (US$ 2010) is required by 2050.

4 Aluminium

Aluminium's strength to weight properties and its resistance to corrosion make it an important material for the construction infrastructure and transport (trains and aircraft). Due to its light weight and electrical conductivity, aluminium is also widely in electricity transmission. Approximately 26% of aluminium production is used for the construction sector in 2016 (Statista.com, 2018). The demand for aluminium is expected to continue to increase to match with the exponential growth in global population, the increasing trend in globalization and urbanization. Menzie et al. (2010) project that aluminium consumption by 2025 is likely to reach 120 million tonnes per year, representing a compound growth rate of 4.1 % per year. The growth rate is expected to relatively slow in high-income countries, but remain rapid in low and middle income countries. At this growth rate, aluminium production will double after 15 years and triple after about 23 years. Figure 2 shows actual and predicted aluminium production from 1994 to 2025.

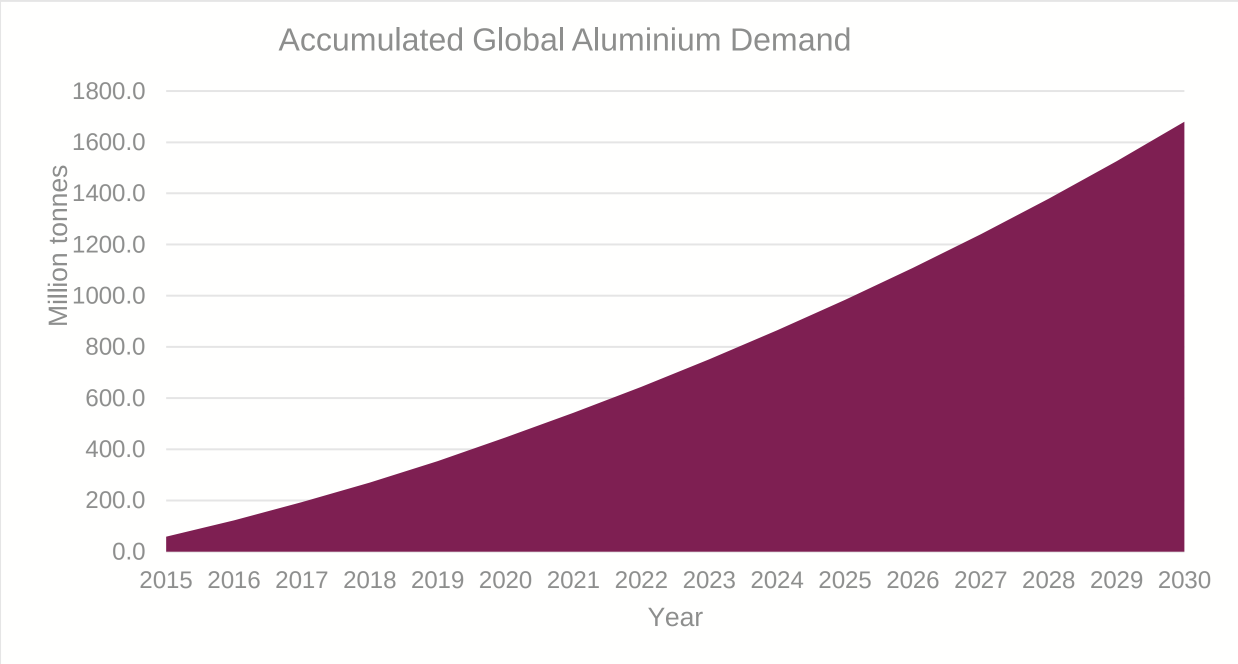
Figure 2 Global Aluminium Production between 1994 and 2025



Source: (1) US Geological Survey; (2) Menzie et al., 2010

Utizling the Menzie et al. (2010) projection for the period 2015 to 2025 and extrapolating to 2030 the resulting accumulated aluminium demand is given in Figure 3. To meet this projected demand, the world will need to produce about 1.7 billion tonnes of aluminium by 2030.

Figure 3 Accumulated global aluminium demand 2015-2030



Source: adapted from Menzie et al., 2010

Typically four tonnes of bauxite is required to produce a tonne of aluminium (Ashraf, 2014; Australianbauxite.com, 2017). This means to produce 1.7 billion tonnes of aluminium by 2030, the world will need about 6.8 billion tonnes of bauxite. The total global bauxite reserves are estimated to be about 27.8 billion tonnes (The Bauxite Index, 2017). If the aluminium demand keeps growing at 4.1% per year, there are no significant changes in aluminium production technologies and no new bauxite reserves are found, current known world reserves of bauxite are likely to be exhausted by 2055. This projection is based on current trends continuing unchanged, but substitution, changes in construction techniques, and exploitation of formerly uneconomic reserves are likely to prolong reserves of bauxite.

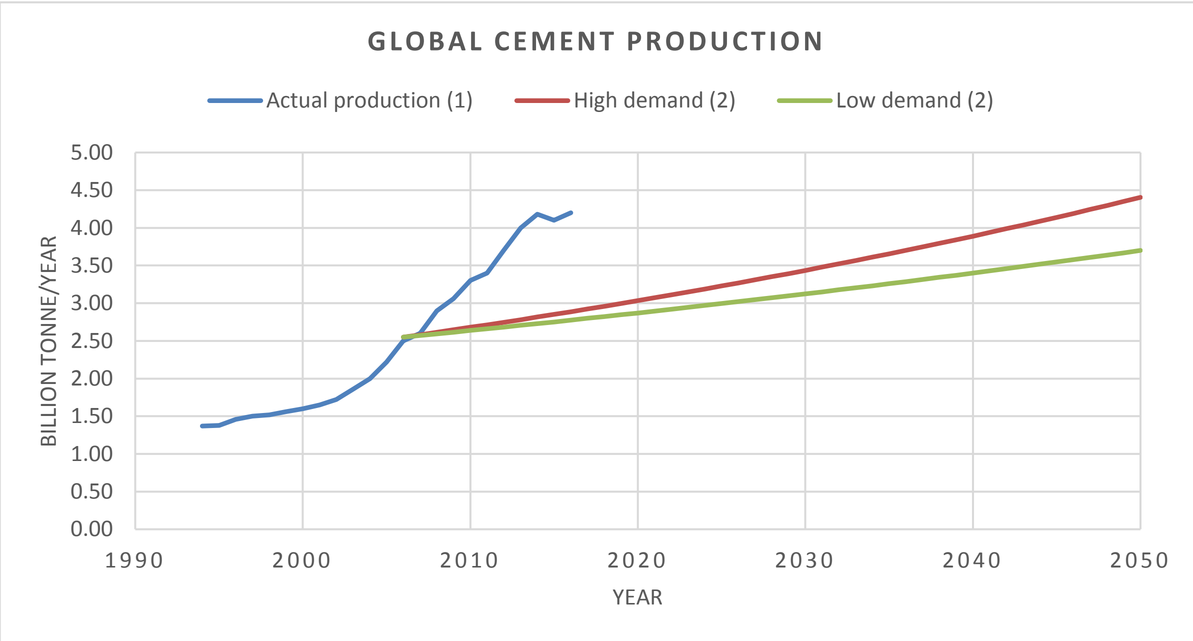
The production of a tonne of aluminium requires 72,000 kWh of energy (Rankin, 2012; Low-tech Magazine, 2014), 88 m^3 water (Zygmunt, 2007) and results in 21 tonnes of CO_2 (Rankin, 2012; Carbon Trust, 2011). To produce 1.7 billion tonnes of aluminium requires approximately 121,000 TWh of energy, 148 billion m^3 water and result in about 35 billion tonnes of CO_2. The annual average amount of energy required for aluminium production to 2030 is 5% of the entire global energy consumption in 2015 (Ritchie and Roser, 2017). The carbon emission resulting from aluminium production is about 2.2 billion tonnes per year to 2030, which is equivalent to about 6% of the global carbon emissions in 2015.

5 Cement

Cement is an essential component of concrete, a fundamental material used in buildings, bridges, dams and roads. IEA (2009) suggests a cement production road map up to 2050 with two scenarios in which global cement demand may increase on average by 0.8% to 1.2% per year between 2006 and 2050, reaching between 3.7 and 4.4 billion tonnes per year in 2050. At the high demand growth rate, cement production would increase by 50% after about 30 years and double after 56 years.

Figure 4 shows the actual and predicted global cement production between 1994 and 2050. The blue line presents actual cement production between 1994 and 2016 derived from USGS's database; the red and green lines show the range of cement demand projected by IEA (2010) between 2006 and 2050. Demand has in fact greatly exceeded IEA projections, possibly because IEA underestimated the growth of the cement market in emerging markets and developing countries. For instance, the projection suggests that China's cement production will peak in 2015 at nearly 1.7 billion tonnes per year, whereas USGS (2017) reported that actual cement production in China was approximately 2.4 billion tonnes in 2015 (i.e. 40% higher than the forecast). Unfortunately, we were unable to find other projections of global cement requirements.

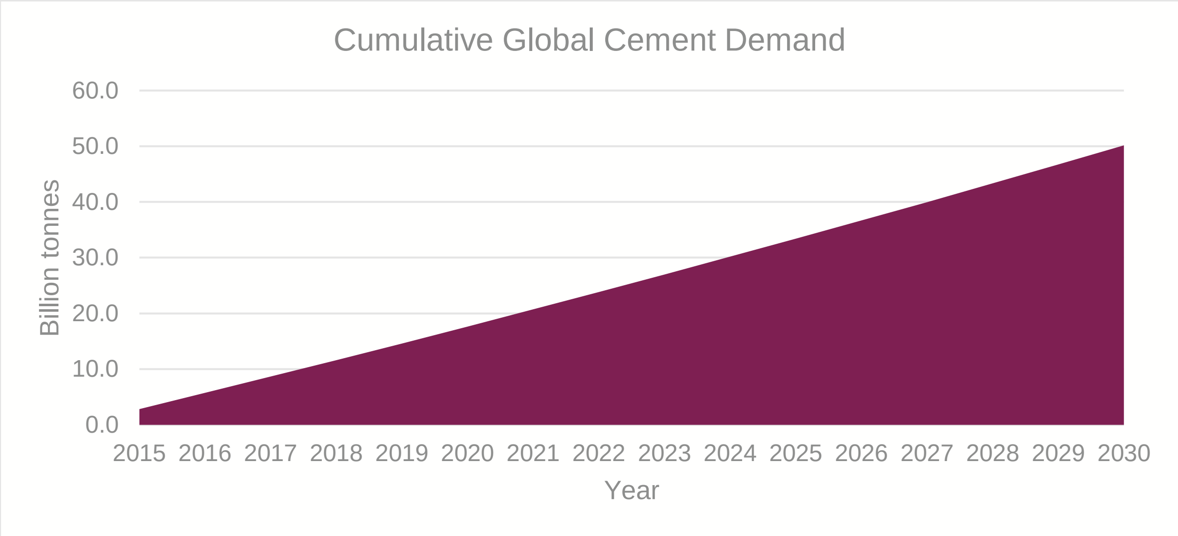
Figure 4 Global cement production between 1994 and 2050



Source: (1) US Geological Survey; (2) IEA, 2009

Adjusting IEA's estimate in the high-demand scenario for the period 2015 and 2030, the accumulated cement demand is calculated and shown in Figure 5. By 2030 the world is predicted to require the production of about 50 billion tonnes of cement.

Figure 5 Cumulative global cement demand 2015-2030



Source: adapted from IEA, 2010

Typically about 1.65 tonnes of limestone and 0.4 tonnes of clay are quarried for each tonne of cement produced (British Geological Survey, 2005). This means to produce 50 billion tonnes of cement by 2030, there will be a need for about 83 billion tonnes of limestone and 20 billion tonnes of clay (see table 3).

Table 3 Limestone and clay required to produce projected cement demand

Accumulated cement demand	Limestone per tonne of cement (*)	Clay per tonne of cement (*)	Limestone required	Clay required
(billion tonnes)	(tonnes)	(tonnes)	(billion tonnes)	(billion tonnes)
50.16	1.65	0.40	82.77	20.07

Source: (*) British Geological Survey, 2005

To produce a tonne of cement requires about 110 kWh of energy (GNCS, 2017; IEA-ETSAP, 2010) and 307 litres of water (Lafarge, 2011; World Steel Association, 2015), and 914 kg CO_2 are produced (GNCS, 2017; NRMCA, 2012). This means to meet the projected cement demand of 50 billion tonnes by 2030 about 5,518 TWh of energy, 15 billion m^3 of water will be required, and 46 billion tonnes CO_2 will be produced. Thus the annual average amount of energy required for cement production up until 2030 is 0.24% of the entire global energy consumption in 2015 i.e. 146,000 TWh, (Ritchie and Roser, 2017).

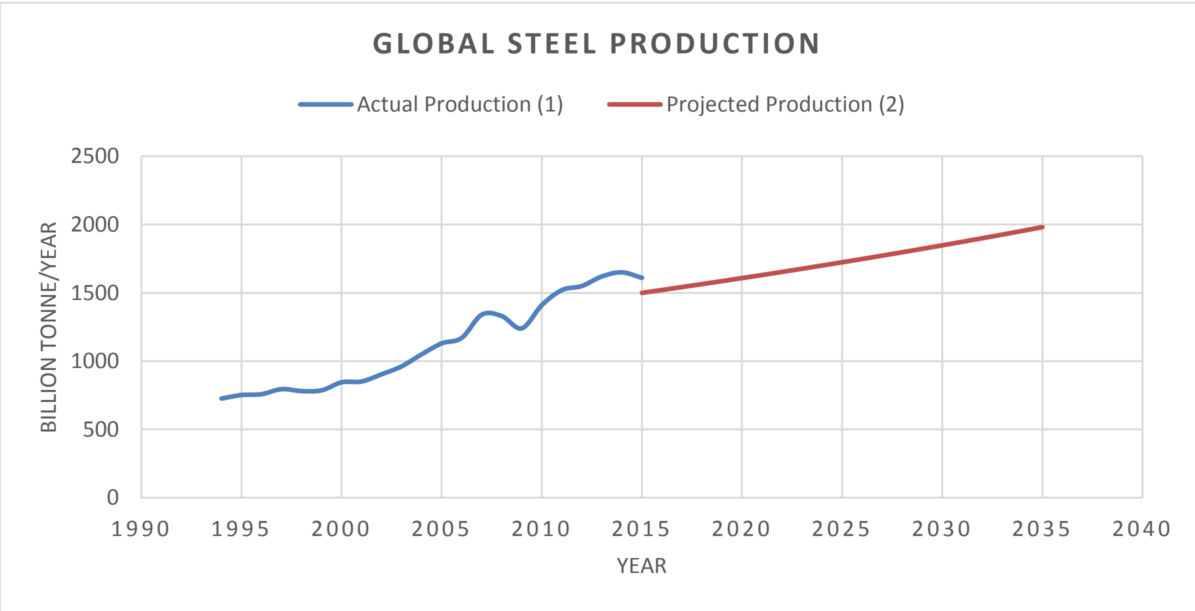
As a result, between 2015 and 2030, the cement industry will create 2.9 billion tonnes of CO_2 per year on average which is equivalent to 8.1% of the current global carbon emissions of 36 billion tonnes per year (Edgar, 2017). This share of carbon emission is similar to that reported by Andrew (2017) of 8% of global CO_2 emissions per year.

6 Steel

The world's steel consumption has more than doubled in the past twenty years, from 0.7 billion tonnes per year in 1994 to 1.6 billion tonnes per year in 2015 (USGS, 1996 & 2017). Steel demand is expected to grow at 1.4% per year, reaching about 2.0 billion tonnes per year by 2035 (Accenture, 2017). Construction is the largest steel-consuming sector, accounting for approximately 50% of global steel consumption (Lee and Dai, 2016).

Error! Reference source not found. shows global actual steel production from 1994-2015 (blue line) and predicted steel production to 2035 (red line) according to a study by Accenture (2017).

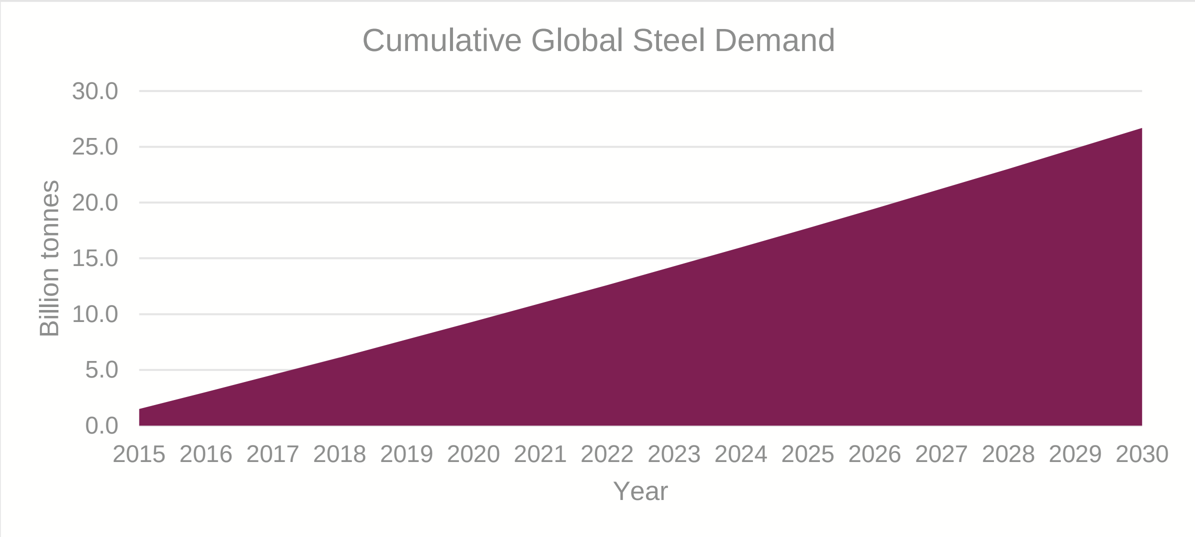
Figure 6 Global steel production between 1994 and 2035



Source: (1) US Geological Survey; (2) Accenture, 2017

By 2030 the world will need a total of about 27 billion tonnes of new steel produced (**Error! Reference source not found.**).

Figure 7 Cumulative Global Steel Demand 2015-2030



Source: adapted from Accenture, 2017

Producing 1 tonne of crude steel typically requires about 1.4 tonnes of iron ore (World Steel Association, 2016). To produce 27 billion tonnes of crude steel will require 37.4 billion tonnes of iron ore by 2030. According to The Statistics Portal (2017), world reserves of iron ore as of 2016 are approximately 170 billion tonnes. Therefore if steel demand keeps increasing at a rate of 1.4%, there are no significant changes in steel production technologies, and no new iron ore reserves are found, current known world reserves of iron ore may be exhausted by 2070. This projection is based on current trends continuing unchanged, but substitution, changes in construction techniques and exploitation of formerly uneconomic reserves are likely to prolong reserves of iron ore.

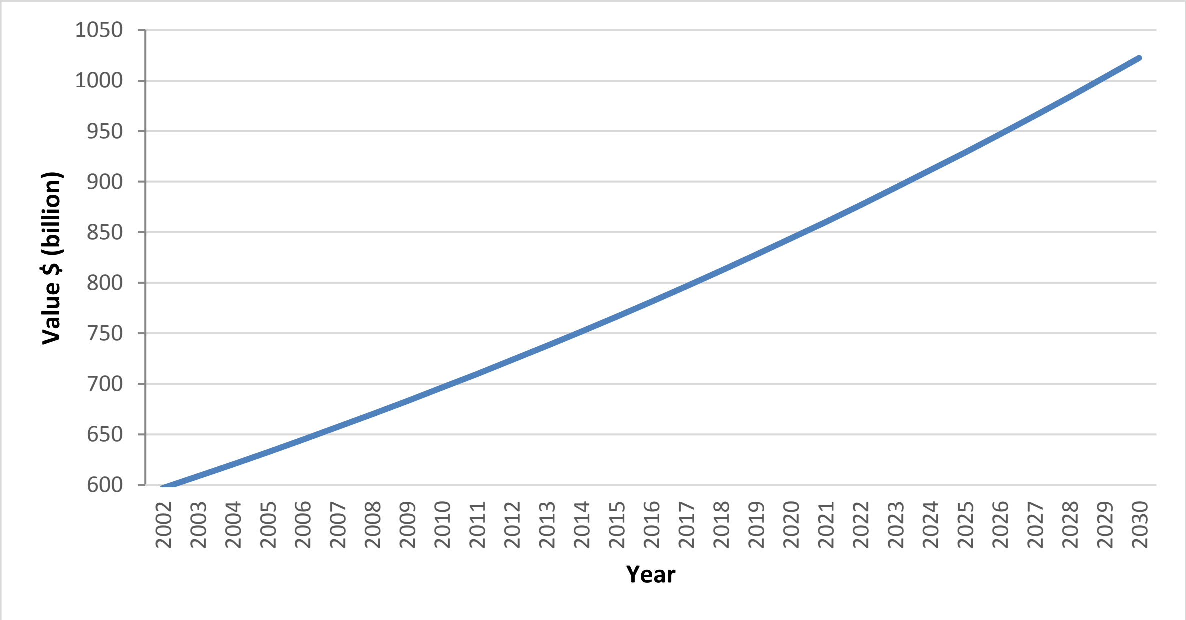
Typically in order to produce a tonne of steel requires about 5,700 kWh of energy (Horvath, 2013; Rankin, 2012) and 28.5 m^3 water (World Steel Association, 2015; Colla et al., 2017), and produces about 2 tonnes CO_2 (Horvath, 2013; Rankin, 2012). Thus, producing 27 billion tonnes of steel requires about 152,000 TWh of energy, 761 billion m^3 water, and results in about 53 billion tonnes of CO_2. The annual average amount of energy required for steel production to 2030 is about 7% of the entire global energy consumption, 146,000 TWh, in 2015 (Ritchie and Roser, 2017), and the annual carbon emissions from steel production to the year 2030 may amount to about 3.3 billion tonnes per year, which is equivalent to about 9% of the global carbon emissions of 36 billion tonnes per year in 2015 (Edgar, 2017).

7 Wood

The studies identified which project the requirement of wood do so in terms of the value of wood harvested or consumed, rather than the mass of wood. This measure has therefore been used in the report. The amount of energy required and carbon emissions produced as a result of wood production are not provided because of a lack of good quality studies, but the amount of water required to produce wood is estimated.

Turner et al. (2006) report that global wood consumption value increased from US$348 billion per year in 1958 to US$597 billion per year in 2002. They also project that the wood consumption will continue to increase at 1.9% per annum, reaching US$1,023 billion per year in 2030. With this growth rate, global wood production value will double by 2038 (see **Error! Reference source not found.**). The construction sector accounts for about 25% of the global wood consumption (Ebohon and Rwelamila, 2001).

Figure 8 Global wood production value between 2002 and 2030



Source: Turner et al., 2006

According to Turner et al. (2006), between 2015 and 2030 at total the world will need about 39.7 billion m^3 of round wood; 7.9 billion m^3 of sawn wood; 1.8 billion m^3 of veneer/plywood; 2.5 billion m^3 of particle board; and 1.5 billion m^3 of fibrewood.

To grow and process such an amount of wood, about 21.2 trillion m^3 of water is required (see table 4). The annual average requirement for this is 29% of the global water consumption in 2015 of approximately 4.5 trillion m^3 (World Water Exchange, 2016).

Table 4 Water required for wood production between 2015 and 2030

Type of Wood	Water required per m^3 (*)	Product demand	Water required
	(m^3)	x 1000 m^3	Billion m^3
Round wood	293	39,733,053	11,642
Sawn wood	580	7,921,641	4,595
veneer/ plywood	652	1,848,440	1,205
particleboard	847	2,524,682	2,138
Fiberwood	1093	1,494,787	1,634
Total			**21,214**

Source: (*) Schyns et al. (2017)

8 Human resource requirements

As requested, we attempted to estimate the human resource requirements (considering in this case only skilled engineers, rather than all labour requirements) to meet road construction needs until 2030. The assumptions made are presented in Table 3. We were unable to provide similar estimates for other infrastructure types due to a lack of reliable data.

Based on figures provided by Dulac (2013), by 2030 the world will need to construct an additional of 14 million paved road lane-km at a cost of $18.2 trillion. This will require about 17 million man-years of qualified engineer design input, or roughly 1.2 million person-years per year. This is about four times the total number of civil engineering jobs in the US in 2016 (which was 303,500; US Department of Labour, 2016)[5]

Table 3 Assumptions for estimating human resource requirements

Additional Road (lane-km)	14,000,000
Average construction cost / km ($ million)[1]	1.30
Total capital costs ($ million)	18,200,000
Planning and Design Cost[2]	10%
Avg. salary ($/year) [3]	43000
Overhead cost /labour cost [4]	150%
Total person-years (2015-2030)	17,438,140
Annual person-years	1,162,543

1. *Dulac, 2013*
2. *Hollar (2011) suggests that the preliminary engineering costs for highway projects on average are about 10.3% of capital costs.*
3. *Grant (2017) reports that the average salary for engineering graduates, by country, ranges from $6,379 to $79,243 per year. The average of this range, i.e. .approximately $43,000 per year, has been used here.*
4. *Assuming that overhead costs, including support staff, are about 150% of the salary of a fee earning engineer (http://web.mit.edu/e-club/hadzima/how-much-does-an-employee-cost.html*

5. *Here, civil engineers is defined as people who perform engineering duties in planning, designing, and overseeing construction and maintenance of building structures, and facilities, such as roads, railroads, airports, bridges, ports, channels, dams, irrigation projects, pipelines, power plants, and water and sewage systems.*

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