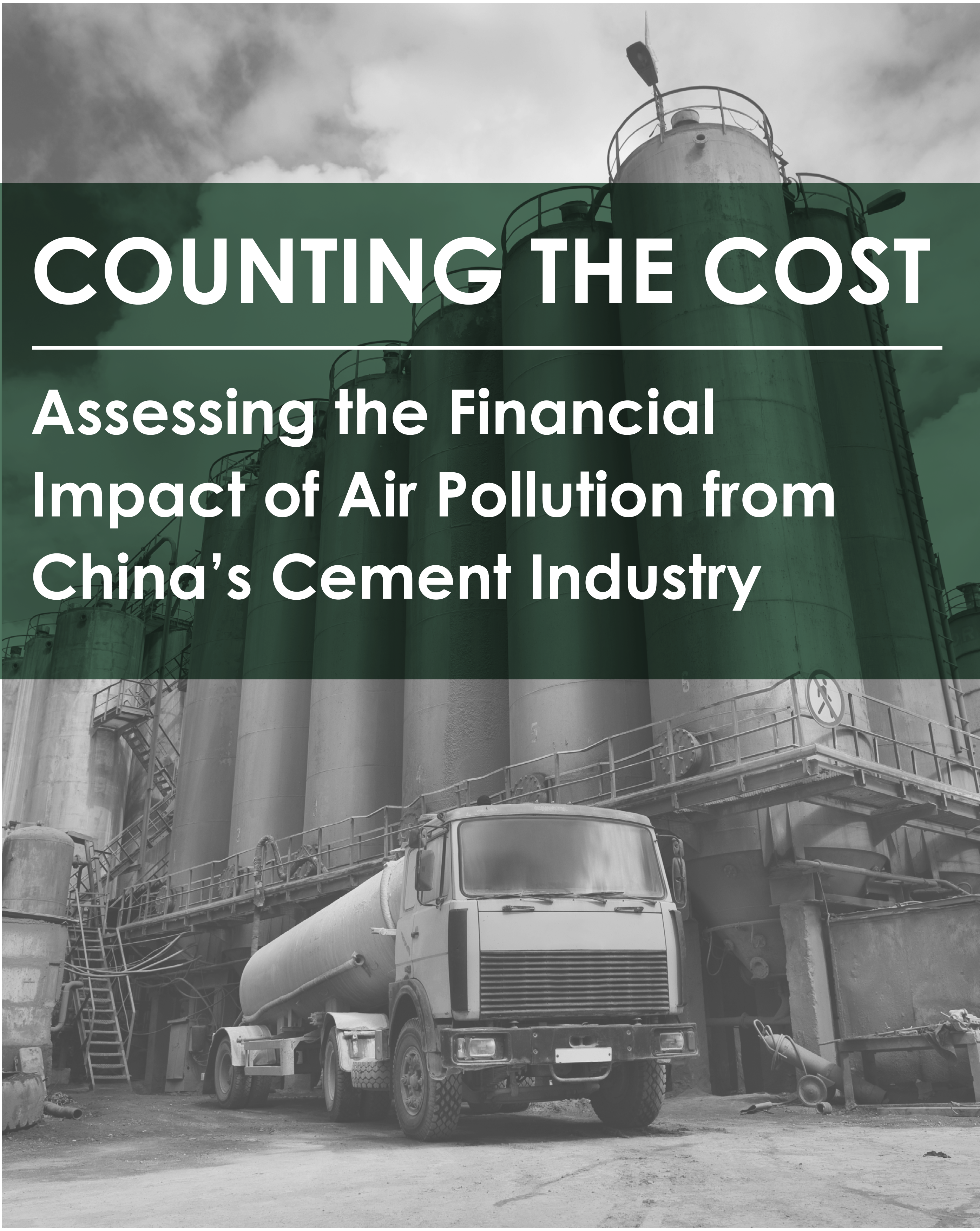

COUNTING THE COST

Assessing the Financial Impact of Air Pollution from China's Cement Industry

October 2015

Prepared by Trucost and ICCS (Innovation Center for Clean-air Solutions)

ICCS 清洁空气创新中心 Innovation Center for Clean-air Solutions

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DISCLAIMER

ABOUT THE RESEARCH PARTNERS

ICCS (INNOVATION CENTER FOR CLEAN-AIR SOLUTIONS)

Innovation Centre for Clean-air Solutions (ICCS) is an environmental think-tank focusing on promoting clean and sustainable development in China. With support from Energy Foundation, ICCS was founded in 2012 to act as the secretariat of Clean Air Alliance of China (CAAC), an international platform of think-tanks targeting at cleaning up China's air pollution via strengthened and systematic technical support on policy making and implementation at national and local levels. **www.cleanairchina.org**

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Trucost helps companies and investors to achieve success by understanding environmental issues in business terms. Our data-driven insights enable organizations to manage risks and identify opportunities for growth. We are the world's leading experts in quantifying and valuing the environmental impacts of operations, supply chains, products and financial assets. By putting a monetary value on pollution and resource use, we integrate natural capital into business and investment decisions.

With offices in Europe, the US and Asia, Trucost works with businesses worldwide to increase revenues, improve communications, meet marketplace expectations and comply with regulatory requirements. **www.trucost.com**

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MESSAGE FROM TRUCOST AND THE ICCS

China's rapid economic growth during the last three decades has been achieved at the cost of increasing natural resource demand, ecosystem degradation and environmental pollution. Today, these impacts constrain China's sustainable economic and societal development. TEEB for Business Coalition finds that the natural capital impacts of business are costing the global economy $7.3 trillion a year (equivalent to China's GDP in 2011) in terms of the economic costs of natural resource depletion and air, water and land pollution related health and social costs (TEEB, 2013). The UN-commissioned report also highlights that the cement manufacturing industry in Eastern Asia is ranked eighth highest of all region-sectors in terms of monetized natural capital impact. With more than half of the world's cement production coming from China, environmental impacts, business and investment risks are interwoven.

In response, China's key capital management challenge is to ensure that investment is managed in a way that balances short-term financial gain with long-term protection of the country's natural capital. Indeed, the newly founded China Green Finance Committee is leading the way to identify practical steps to achieve economic growth and environmental improvements through reform of China's financial system.

Against a backdrop of intensifying natural resource constraints, fueled by the resource demands of an increasingly affluent population, the ability to decouple investment returns from environmental cost will be critical. With support from Energy Foundation (China), Innovation Centre for Clean-air Solutions (ICCS) has partnered with natural capital expert Trucost to analyze and quantify the key environmental risks and opportunities of China's cement sector. In addition, the research has also evaluated potential benefits achieved through green technological interventions.

Through scientific and robust monetization of external costs, the joint research demonstrates how by embedding environmental indicators within traditional decision making investors can identify companies that are best positioned to succeed in a resource efficient, low-carbon economy, and manage risk from environmental laggards which threaten China's future sustainable growth. The report makes several important recommendations for investors, policy makers and companies.

EXECUTIVE SUMMARY

CONTEXT

China is home to the world's largest cement market, producing more than 58% of the world's total cement in 2013. Over the past 20 years, China's economy has increased tenfold with large-scale developments and infrastructure projects implemented by the Chinese Government driving rapid expansion of cement production.

However, like many other developing countries, China faces the challenge of attaining economic growth without compromising its future environmental, economic and social sustainability. The cement industry is one of the major contributors to air pollution and greenhouse gas emissions in China due to its size and high energy intensity supplied primarily through fossil fuels. These air emissions contribute to global climate change as well as much more localized impacts from air pollutants such as poor air quality damaging people's health and respiratory systems.

According to the Ministry of Environmental Protection, the cement industry in China contributed to 15-20% of $PM_{2.5}$ emissions (making it the largest contributor), 3-4% of SO_2 emissions (second only to the power industry) and 8-10% of NO_X emissions in the country. The World Health Organization concluded in 2014 that air pollution may now be the world's largest environmental health risk. The World Bank and the Development Research Centre for the State Council calculated the cost of mortality and health damages to the Chinese economy from air and water pollution to be $100bn-$300bn per year (RMB615bn – RMB1.9tn).

The external costs of cement manufacturing are increasingly creating business and investment risk through a variety of regulatory, reputational and market factors acting as cost internalization mechanisms. Policymakers and regulators have the ability to change the 'rules of the game' through raising the cost of certain activities, with significant implications for invested capital. Over the last decade, the Chinese Government has already made impressive efforts to transition towards a greener economy having passed over 40 regulations on greening the cement industry, including strict regulations on efficiency requirements on new cement plants to ensure old technologies are phased out. Despite setbacks, strengthening regulatory enforcement in the cement industry in China is on the cards and the future direction of travel is clear. The trend of regulatory change combined with the long time periods required before cement plant capital investments can be recovered (their lifespan usually exceeds 40 years) makes it crucial that plant modifications are carefully planned so as to ensure alignment with the long-term trends of the industry.

Reputational risks stem from negative public perception of a company's activities damaging brand value, whilst increasingly common public protests against expansion plans of cement companies pose a threat to the companies' 'license to operate' granted by social consent. Changing customer preferences towards goods with more sustainable production practices and supply chain initiatives create a market risk for companies that do not embrace this shift. For example, construction companies are likely to demand that cement companies produce lower carbon cement products in order to meet procurement and industry standards.

The implications of these risks to bottom lines are ever more important in a context where rising demand for infrastructure, particularly housing and transport, means that the demand for cement will continue to grow. Financial institutions need better data on the external cost exposure of companies in order to develop appropriate environmental assessments and reduce the risk of non-performing investments. They can do this through investing in 'best-in-class companies' that integrate external cost risks into decision-making. At the same time, there is scope for Chinese cement companies to capitalize on the growing market for more sustainable and resource-efficient business models.

METHODOLOGY

The following study by Trucost was commissioned by the Innovation Center for Clean-air Solutions (ICCS) to increase awareness of responsible investment among Chinese investors, policymakers and companies. By embedding environmental indicators within traditional decision-making, investors can identify those companies that are best positioned to succeed in a resource efficient economy, and manage risk from environmental laggards that threaten China's future sustainable growth.

The usefulness of integrating the most significant environmental factors into investment decisions was demonstrated through a pilot project evaluating the material environmental impacts of 32 publically traded cement production companies in Greater China. Their material environmental impacts create external costs, which were quantified and monetized. The monetization of external costs is a comprehensive tool to assess the magnitude of financial risks faced by companies by translating environmental impacts into a single monetary metric. It also enables the comparison of different types of impact that are not normally comparable (such as between different air pollutants) and across companies overall. As an integration tool, it can be used to measure and report overall impacts and associated costs relevant for a range of stakeholders important to a business' value creation.

The study's approach followed six distinct steps designed to establish the link between changes in the environment and respective changes in the wellbeing of societal groups such as local communities, employees, businesses and the wider society. The starting point of the assessment was to scope the boundaries for analysis according to the company's value chain and the most material environmental impacts, measured by appropriate key performance indicators (KPIs). The study focused on the production of clinker, which is responsible for the most material environmental impacts in the lifecycle of cement production. Air pollution was prioritized in this assessment because of its highly localized impact and heightened social and regulatory significance. Other material impacts (GHGs and water) are considered in the Appendices.

The quantification of KPIs and related impacts was conducted through primary and secondary data collection. Primary data collection refers to the use of actual, measured data. Generally the more company specific data, the better the results and usefulness for decision-making. In this assessment primary data from Annual and Sustainability Reports was prioritized. Where primary data was unavailable, the analysis used best available secondary data estimation techniques, including China-specific lifecycle assessments and academic peer reviewed literature. Finally, the results were sent to the 32 cement producing companies to provide them with an opportunity to review and improve their profile by providing additional primary data related to their clinker manufacturing operations.

The final step used monetization coefficients to enable data on emissions and resource use to be converted into a valuation of the impact this has on societal groups and their wellbeing, indicating the potential for a company's external risk to be translated into a risk for an investor or financier. The study concludes by exploring how financial institutions could integrate environmental considerations into equity valuation and corporate lending decisions to enable better risk management.

KEY FINDINGS

1. **The combined cement production of 32 publically listed cement companies representing 46% of China's total cement production was responsible for an external cost of $31,500m (RMB 195,400m) in 2013.** On average, 67% of cement companies' clinker and cement segment revenue and 43% of total company revenue could be at risk as the external costs of cement production become internalized through a range of drivers identified in this report.

2. **On average, 82% of the total external cost from air pollution is within cement companies' operational control.** This has direct implications for the management of this risk.

3. **$PM_{2.5}$ and mercury emissions account for the majority of external costs from cement production, together responsible for over $18,690m (RMB 115,800m).** Stakeholders should consider these as priority air pollutants for mitigation.

4. **If air pollution costs were internalized into clinker's trading price, it would trade 72% higher at an average of $79 (RMB 490) per metric ton of clinker.**
5. **Overall disclosure levels are low at 14% of environmentally relevant data points,** though disclosure within traditionally financially material metrics such as energy use is generally much higher. Investors should influence further disclosure as the financial relevance of external costs becomes more evident.
6. **Companies that disclose environmental data tend to have a lower than average emissions intensity** compared to other firms in China. However, it does not necessarily mean that they perform better overall.
7. **It is important to differentiate between external cost in absolute and in relative terms.** Absolute costs are driven by the total quantity of cement produced, whilst relative intensities (external cost/$m revenue) provide a way of comparing the efficiency of cement production by individual companies.

RECOMMENDATIONS

- **Financial institutions should adopt a robust approach to quantifying environmental risks and integrating their consideration into decisions.** Integrating external cost data into financial analysis is challenging for financial institutions due to the lack of comprehensive and comparable environmental impact data disclosures from companies, and the long term and unpredictable nature of some external costs. However, not integrating these means that the financial sector could be underestimating an important set of structural long-term risks it is exposed to. This study demonstrates the usefulness of quantifying portfolio, sector and investment level exposure by using external cost accounting techniques alongside a framework that considers the internalization of these external costs through a number of different risk drivers. This can help the financial sector reduce its risk and identify opportunities to capitalize on the transition to a more resource efficient and sustainable economy.
- **Financial institutions should use their influence to encourage companies to disclose the environmental impacts of their operations in a comprehensive and comparable manner.** The Shanghai and Shenzhen stock exchanges already have mandatory guidelines for listed companies regarding public disclosure. Most recently, the Hong Kong Stock Exchange (HKEx), where 10 companies assessed in this study are listed, has proposed to move ESG reporting to 'comply or explain' by the end of 2015. However, mandatory guidelines do not as yet mean reliable disclosures. In order for financial institutions to get a good understanding of environmental risks in their portfolios or loan books, acquiring more detailed granular data on sector exposure should be a priority. Three of the largest Western cement manufacturers – Holcim, Lafarge and CEMEX – have significantly higher rates of disclosure compared to their Chinese counterparts, although achieving these rates entails monitoring costs. For example, in 2014 CEMEX incurred a total investment of approximately $155m collecting and analyzing relevant emissions to meet US Environmental Protection Agency National Emission Standards for Hazardous Air Pollutants (NESHAP) for existing, new or reconstructed cement kilns in the US. As a by-product of its response to the NESHAP regulations the company has however also adopted a cost-effective implementation strategy for reducing emissions for each CEMEX US kiln. This has direct implications for investors who, by supporting companies in the improving measurement and management rates, benefit from reduced exposure to internalization risk.
- **Financial institutions and policymakers should encourage cement companies in China to meet or exceed best practice standards that minimize environmental costs.** Globally, technological advances have significantly decreased the environmental impacts of cement production, with efficiency improvements, use of cleaner fuels and abatement of air pollutants leading to lower impacts of production. However, there is still a huge opportunity for development. In China, cement companies lag behind the rest of the world on their implementation of lower impact production techniques including the use of renewable energy and alternative fuels (coal is still the main fuel), energy efficient techniques (average energy consumption of new dry process kiln production lines in China is 15-25% higher than the international average), and substitution of clinker for alternatives such as fly ash.

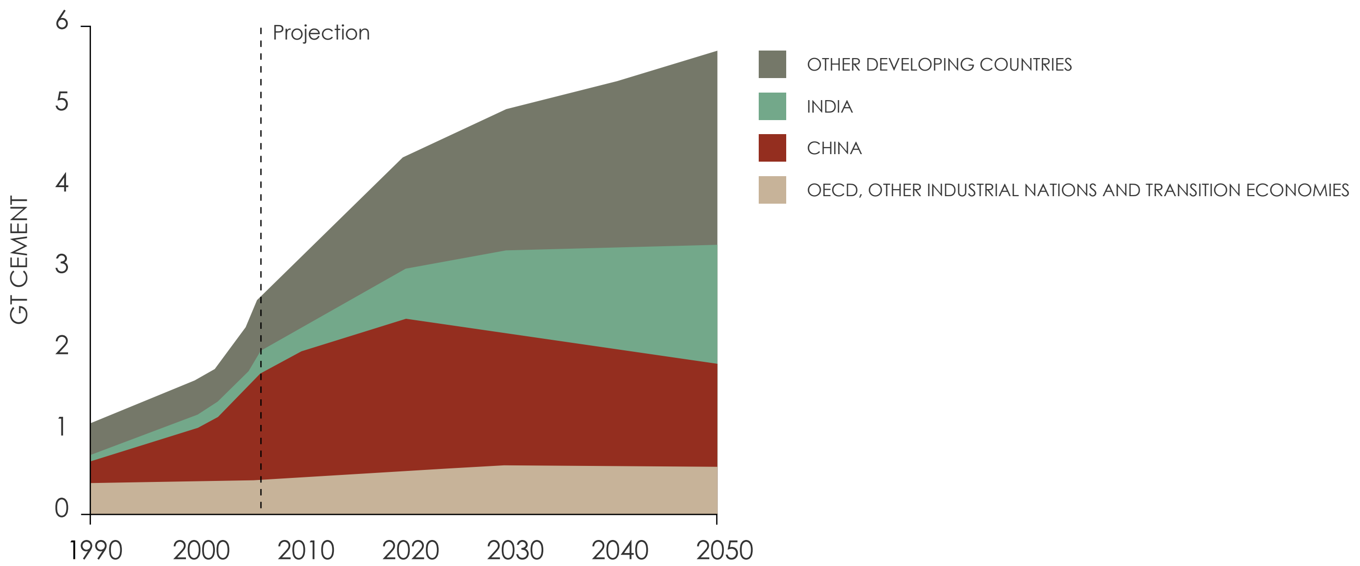
- **Policymakers should establish a working green finance system and mechanisms to mobilize private capital towards technologies that minimize the external cost of business. Better understanding the materiality of environment-related risks and the levels of exposure in different parts of the financial system will also help regulators manage scenarios that could result in financial instability.** China needs to transition toward a green and sustainable growth model. It is estimated that achieving national environmental goals during the 13th Five-Year Plan period (2016-20) will require an annual investment of at least US$320bn (RMB 2tn) into environmental protection, energy efficiency, clean energy, and clean transportation. China's cement sector, in particular, is estimated to require at least $45bn (RMB 280bn) of investment to undergo a green transformation in line with its broader targets. The government can only be expected to contribute around 10-15% of all green investment, while private capital will need to contribute the remaining 85-90%.
- **Companies and policymakers should supplement traditional cost-benefits analysis with monetized external costs to fully inform the business case for upgrading pollution abatement equipment.** Clinker production is the most impactful stage of cement production and the primary focus for any air pollutant abatement technology. Technologies to reduce PM include electrostatic precipitators and bag filters, which also reduce mercury emissions. NO_x and SO_2 emissions tend to be reduced as a by-product of optimizing the clinker burning process, with the main aim of reducing heat consumption, improving clinker quality and increasing the lifetime of equipment. NO_x can be tackled directly via the use of expert systems for kiln operations and low-NO_x burners, amongst others, whilst mercury can be targeted by reducing the amount of mercury in raw materials and fuels. The applicability of these technologies is site-specific and requires a careful assessment of associated costs and benefits.
- **Leading cement companies should respond to investor demands for integrated reporting by combining financial and quantified social and environmental externality data to holistically measure the value they create.** Holcim Group pioneered the use of integrated profit and loss (IPL) accounting in the cement sector in 2014 with the aim of focusing efforts on maximizing Holcim's financial, socio-economic and environmental value creation. The IPL confirmed that Holcim's overall value to society, taking into account its monetized socio-economic and environmental impacts, is significantly higher than the financial retained earnings of the company. Holcim's IPL experience demonstrates that leaders in the sector should consider quantified social and environmental profit and loss accounting to:
    - Improve visibility of social and environmental impacts, both at firm-wide operations level or specific operating units, such as a regional subsidiary
    - Identify risks through assessing the likelihood of internalization for each socio-environmental externality investigated in a range of scenarios
    - Support the development of sustainability valuation frameworks such as the Natural Capital Protocol, a major private-sector collaboration to provide businesses with standardized tools and metrics to identify their impact on natural capital
    - Complement existing reporting frameworks, such as the Global Reporting Initiative (GRI)
    - Encourage a shift away from superficial 'social responsibility' initiatives towards performance-driven sustainability by focusing on material socio-environmental issues as part of goal-setting, decision-making and performance evaluation
    - Demonstrate innovation in sustainability accounting and integrated reporting among mature sustainability leaders

1. DEFINING THE ENVIRONMENTAL RISKS FACING THE CEMENT SECTOR IN CHINA

SECTION 1 PROVIDES INVESTORS, COMPANIES AND POLICY MAKERS WITH AN OVERVIEW OF THE BUSINESS RISKS POSED BY THE CEMENT SECTOR'S GROWING ENVIRONMENTAL IMPACTS. Section 2 lays out a framework for evaluating environmental risks specific to the cement sector, and provides data on the performance of 32 publically listed cement companies in China. Section 3 provides investors, cement companies and policy makers with recommendations to improving environmental risk analysis and management in the cement sector in China.

China is home to the world's largest cement market, producing around 2.36 billion metric tons or 58.3% of the world's total in 2013 (Cembureau, 2014). Cement's primary use is in the production of concrete, a building and road construction material that can withstand varying environmental conditions, and the most used man-made material in the world. Over the past 20 years, China's economy has increased tenfold with large scale developments and infrastructure projects taken by the Chinese Government to satisfy unprecedented urbanization and industrialization growth, driving China's rapid expansion of cement production since the 1990s (Figure 1).

FIGURE 1: GLOBAL CEMENT PRODUCTION 1970-2050 (MILLION METRIC TONS)



SOURCE: INTERNATIONAL ENERGY AGENCY

However, like many other developing countries, China faces the challenge of attaining economic growth without compromising its future environmental, economic and social sustainability. The country's expansion has uplifted an estimated 660 million people out of extreme poverty, but it has also come at a significant but often invisible cost: outdoor air pollution is estimated to contribute to over a million premature deaths per year in China, more than 90% of its urban water bodies are thought to be polluted and it is also the world's largest producer of greenhouse gas (GHG) emissions (Cohen et al., 2005).

These external costs are increasingly creating business and investment risk through a variety of cost internalization mechanisms discussed in this report. The implications of this risk are ever more important in a context where rising demand for infrastructure, particularly for housing and transport, means that the demand for cement will continue to grow albeit at a slower pattern than in the last few years (International Cement Review, 2012; Global Cement Magazine, 2015).

1.1 ENVIRONMENTAL IMPACTS OF CEMENT PRODUCTION

The production of cement involves the consumption of large amounts of raw materials, energy and heat, and results in significant amounts of waste and gaseous emissions. The industry is one of the major contributors to air pollution and GHG emissions in China as a function of its size (China's housing market alone is worth around 15% of its economy) and high energy intensity supplied primarily through fossil fuels. Coal, the most polluting of fossil fuels, is used almost exclusively to fire cement kilns, as well as being widely used to generate the electricity needed by cement plants to power grinding mills, conveyers and other auxiliary equipment.

These air emissions contribute to global climate change – the cement industry in China is responsible for over 2% of global emissions – as well as much more localized impacts from air pollutants such as poor air quality damaging people's health and respiratory systems (PBL Netherlands Environment Assessment Agency, 2012). A 2014 World Health Organization (WHO) investigation concluded that air pollution may now be the world's largest environmental health risk, estimating that air pollution in China is responsible for the deaths of 40% of the 7 million people worldwide killed by air pollution annually. China also has among the highest rates of deaths per capita as a result of air pollution at 172 per 100,000 people (Asia Insurance Review, 2014). More recently, a study by the University of California, Berkeley (one of few to use primary data from Chinese air monitoring figures) estimated heart, lung and stroke deaths and found that about 1.6 million people in China die prematurely due to heavily polluted air mainly from small particles (South China Morning Post, 2015).

Particulate matter (PM), nitrogen oxides (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO) and GHGs are the primary emissions in the manufacture of cement. Small quantities of volatile organic compounds (VOCs), ammonia, and other pollutants may also be emitted. According to the Ministry of Environmental Protection, the cement industry in China contributed to 15-20% of $PM_{2.5}$ emissions (the largest contributor), 3-4 % of SO_2 emissions (second only to the power industry) and 8-10% of NO_x emissions in the country (MEP China, 2014). Cement production in China is also a major mercury pollution source from the raw feedstock materials and the use of fuels. Finally, the solid wastes that remain as a result of the production process are often disposed into water bodies or burned. Each impact is described in more detail in **Section 2 - Methodology.**

A PRIMER ON AIR POLLUTANT SOURCES AND MAJOR EFFECTS

Particulate matter (PM) is a complex mixture of extremely small particles and liquid droplets, made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles. The size of particles is directly linked to their potential for causing health problems. "Inhalable coarse particles" (larger than 2.5 micrometers and smaller than 10 micrometers in diameter) are found near roadways and dusty industries while "fine particles" refers to those found in smoke and haze which are 2.5 micrometers in diameter and smaller. The size of particles is directly linked to their potential for causing health problems, as they can penetrate deeply into sensitive parts of the lungs and cause or worsen respiratory disease, as well as aggravate existing heart disease.

Sulfur dioxide (SO_2) is one of a group of highly reactive gases, whose ingestion can cause an array of adverse respiratory effects including bronchoconstriction and increased asthma symptoms. It also leads to the formation of other sulfur oxides, which are a forming part of small particles. The largest sources of SO_2 emissions are from fossil fuel combustion at power plants (73%) and other industrial facilities (20%). When SO_2 combines with water, it also forms sulfuric acid, the main component of acid rain and a cause of deforestation.

Nitrogen oxides (NO_x) are a group of highly reactive gases with adverse respiratory effects including airway inflammation in healthy people and increased respiratory symptoms in those already suffering from asthma. The main sources of emission are vehicles, power plants and off-road equipment. In addition NO_x also contribute to the formation of ground-level ozone, when paired with volatile organic compounds, and fine particle pollution, both major contributors to respiratory diseases.

Volatile organic compounds (VOCs) are chemicals that enter the air as gases from many commonly used products. Cement typically contains VOCs such as tetrahydrofuran, cyclohexane, MEK, toluene, acetone, hexane, 1,1,1-trichloroethane. These chemicals are associated with short and long-term health effects.

Mercury is released into the environment through natural (for example volcanoes) and anthropogenic processes (fossil fuel combustion, cement production). It is a persistent toxic substance posing significant threats to public health and the environment and is classified as one of the top ten chemicals of major public health concern (WHO, 2013).

1.2 EXTERNAL COSTS AND INTERNALIZATION DRIVERS

The environmental impacts of cement production create an external cost by reducing the provision of clean air thus damaging people's health and wellbeing. These impacts can be viewed as an external cost of business activity, or 'externality', because the external cost is not included in the price that companies pay for environmentally damaging raw materials used by their activities such as coal, nor is it reflected in the price consumers pay for buying high-impact products such as cement. Instead, the environmental costs often fall on society.

The external costs of air pollution are not a new discovery for the Chinese Government. The China Green National Accounting Study Report showed that environmental pollution in 2004 amounted to a loss of national GDP of over 3%, while the Asian Development Bank and Tsinghua University in their National Environmental Analysis calculated that economic losses resulting from illness related to air pollution were 1.2% of national GDP, rising to 3.8% based on willingness to pay to remove such pollution (Green Finance Task Force, 2015). The World Bank and the Development Research Centre for the State Council calculated the cost of mortality and health damages to the Chinese economy from air and water pollution to be be $100bn-$300bn per year (RMB615bn – RMB1.9tn), excluding the long-term impact from severely affected infants and children (World Bank and DRCSC, 2014).

In an efficient market, these costs would be paid for by the polluter. In reality, a range of internalization drivers are acting to achieve this, including much current and expected future regulation, changing consumer preferences and extreme weather events. These drivers affect company balance sheets and income statements through increased costs and decreased revenue opportunities putting pressure on profitability. The internalization process can sometimes go as far as to result in 'stranded assets' — assets that have suffered from unanticipated or premature write-downs, devaluations, or conversion to liabilities (Caldecott et al., 2013). Understanding and navigating internalization factors is critical for financial institutions invested in the cement sector, in order to develop appropriate environmental assessments at a sector level.

REPUTATIONAL RISK DRIVERS

Reputational risks stem from negative public perception of a company's activities, damaging brand value and reducing sales. For example, public protests against the expansion plans of cement companies pose a threat to the companies' 'license to operate' granted by social consent. For example, the construction of Semen Indonesia's new cement plant in Rembang, Indonesia, has been delayed since 2014 due to protests by local residents and a non-governmental organization, the Indonesian Forum for the Environment (WALHI). Protestors claim that construction and operation of the cement plant could pose a threat to the ecosystem in the region (Global Cement, 2015a).

MARKET RISK DRIVERS

Changing consumer preferences towards goods with more sustainable production practices and supply chain initiatives create a form of market risk for companies that do not embrace this shift. Although the pace is slow, this change in consumer attitudes has resulted in the increase in initiatives for manufacturing green products. For example, construction companies are likely to demand that cement companies produce lower carbon cement products in order to meet procurement and industry standards.

POLICY AND REGULATION RISK DRIVERS

Policy and regulatory risks are related to more stringent legislation and/or voluntary commitments, such as the Chinese Government's ambitious air pollution reduction targets. Increased costs can also be associated with compliance or litigation, for example for exceeding pollution standards, or remediating polluted land. This category includes the risk of a loss or decline of subsidies for an industry that may impact its business model. As awareness of the environmental impacts increases, pressure to justify continued expenditure on environmentally damaging subsidies also increases.

In the cement sector, demand for outdated cement plants is likely to fall for a number of reasons spanning across more stringent emission standards, the rise in environmental compliance costs, reductions in overcapacity and the elimination of low-grade cement (Global Cement Magazine, 2015). In some cases investors can choose to divest from a company, such as Norway's Government Pension Fund Global (GPFG) removing investments in coal, oil sands, cement and gold mining on the basis that they face risk from regulatory action on climate change, as their business models are incompatible with the pledge by the world's governments to tackle global warming (NBIM, 2014).

CLIMATE RISK DRIVERS

These risks include adaptation and mitigation risks resulting from disruptions to vital infrastructure such as roads and transport caused by changing weather patterns and extreme weather events. Climate change may require increased investments in activities such as improved infrastructure, fuel-efficient technology, land-use and transport planning. The effects of climate change in the last few years in China have become increasingly apparent. The Intergovernmental Panel on Climate Change (IPCC) has warned that unchecked climate change will exacerbate erratic rainfall patterns, heat waves, droughts and other extreme events in China (IPCC, 2014).

RESOURCE DEPLETION RISK DRIVERS

These risks refer to the depletion of resources on which a company depends upon causing increased input costs or even site closures from to supply disruptions of different resources such as coal, raw materials and water.

The next section discusses the main drivers that may force cement companies to internalize the costs of the pollution and other external impacts they cause, potentially reducing long-term profitability.

1.3 EXPLORING POLICY AND REGULATION RISK DRIVERS

Regulatory changes are a key driver of internalization of external cost and asset stranding. In regulated markets, policymakers and regulators have the ability to change the 'rules of the game' through raising the cost of certain activities, with significant implications for invested capital (Caldecott et al., 2015). Examples include restrictions to use or outright bans (for example conservation areas, technological process phase out), establishment of tradable permit markets (for example, sulfur dioxide in the US) and imposition of taxes. Legal action such as fines and penalties for environmental incidents can also be significant.

REGULATORY FRAMEWORK GOVERNING CHINA'S CEMENT INDUSTRY

Because cement is costly to transport over land with only 7% of global production internationally traded, the domestic regulatory environment is the most relevant factor for cement producers. In China, the cement market is controlled by different Government institutions (WWF, 2008):

- National Development and Reform Commission (NDRC) sets the trends for the Chinese economy in a Five-Year Plan. It is one of the most powerful ministries in China as it controls some of the major governmental tools to steer the economy in specific sectors through the laws of investment
- Ministry of Construction
- Ministry of Environmental Protection
- Other important participants include the China Building Materials Industry Association, which is a partner of the NDRC for the development of industry policies

Over the last decade, the Government has already made impressive efforts to transition towards a greener economy having passed over 40 regulations on greening the cement industry, including strict regulations on efficiency requirements on new cement plants to ensure old technologies are gradually phased out.

Under China's 11th Five-Year Plan (2006-2010), there was a 19.1% fall in energy intensity per unit of GDP (Yuan et al, 2011). In the cement industry, the amount of energy required to produce a metric ton of cement fell by 41% (QEACBM, 2011) through cleaner modes of cement production. These efficiency measures reduce fuel and electricity use, in the process cutting air pollutants and greenhouse gases released by cement production. Regulatory measures have also been imposed to reduce air pollutants specifically.

The 12th Five-Year Plan (2011-2015) was even more ambitious than the preceding plan (UNEP, 2013). In 2010, the Ministry of Industry and Information Technology and other ministries issued a notice to carry out inspections to phase out overcapacity in the cement industry. For companies not meeting the requirements, banks were to stop issuing new credit and the National Land and the Resource Bureau was to stop approving new land permits, cutting electricity supplies if required. According to the Planning on Energy Saving and Emissions Reduction during the 12th Five-Year Plan issued by the State Council in 2012, 370 million metric tons of 'backward cement capacity' was to be phased out. As part of the 12th Five-Year Plan, energy consumption of cement production was also to be reduced to <93 Kg standard coal/metric ton cement.

The 12th Five-Year Plan also emphasized investment where ambitious green development plans are evident. For example, Energy Management Companies (EMCs), such as those that invest in energy reduction measures in the cement sector, could make a claim for 100% reimbursement of the VAT and a three-year income tax waiver, followed by a three-year half corporate income tax reduction (Ministry of Finance, 2010).

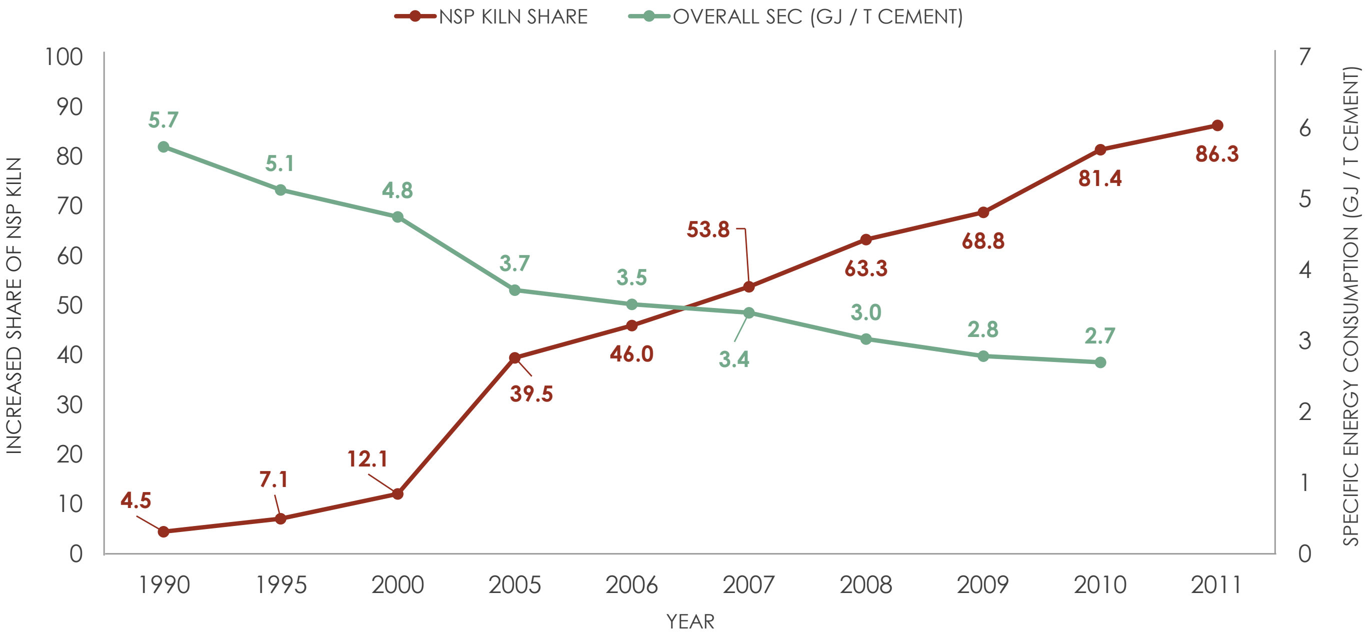
A PRIMER ON CEMENT KILN TYPES

The cement kiln is the world's largest piece of industrial equipment. There are two basic types of cement production processes and a number of different kiln types. It can be either wet or dry, depending on the water content of the material feedstock. The wet kiln process has much higher energy requirements due to the amount of slurry water that must be evaporated before calcinations take place. In China there are two main kiln types: shaft kilns and rotary kilns. With higher productivity and efficiency, rotary kilns dominated the cement industry in Western countries since the middle of the 20th century. Starting in the 1980s in China, however, small but easy-to-construct shaft kilns were built all over the country to meet the rapidly increasing demands of the construction industry, which by the mid-1990s accounted for 80% of production. The extremely rapid increase in the number of shaft kilns resulted in poor operating practices within the Chinese cement industry. At the end of the 1990s, China began to restrict construction of new shaft kilns and instead promoted precalciner kilns, which are the most advanced rotary cement kilns. Consequently, production from precalciner kilns increased rapidly and by 2013 it accounted for more than 90% of cement production (CMIIT, 2009, cited in Lei et al., 2011) **(Figure 2)**.

KILN TYPES

In 2002, only 16.8% of plants used dry process kilns, most relying on less efficient wet process rotary or vertical kilns, whereas today more than 90% of plants use dry process kilns, replacing 150 million metric tons of production capacity (CBMF, 2012).

FIGURE 2: CORRELATION BETWEEN ADVANCED PRECALCINER (NSP) KILN PRODUCTION SHARE AND IMPROVED ENERGY EFFICIENCY IN CHINESE CEMENT INDUSTRY



SOURCE: XU ET AL. 2014

CLINKER RATIO

Ordinary Portland cement is comprised of 95% clinker and 5% additives whilst 'blended cement' is the term for cement made from clinker that has been inter-ground with a larger share of one or more additives. Clinker can be substituted using cementitious substances such as coal fly ash from electric power plants, blast furnace slag from iron-making facilities, volcanic ash, and pozzolans such as rice husk ash and volcanic ashes (Huntzinger & Eatmon, 2008). These substitutes are natural or industrial by-products produced irrespective of their use in the cement industry, and their addition to cement prevents costs involved in landfilling of these by-products. Blended cements may have a lower short-term strength but a higher long-term strength, as well as improved resistance to acids and sulfates (Price et al., 2009)

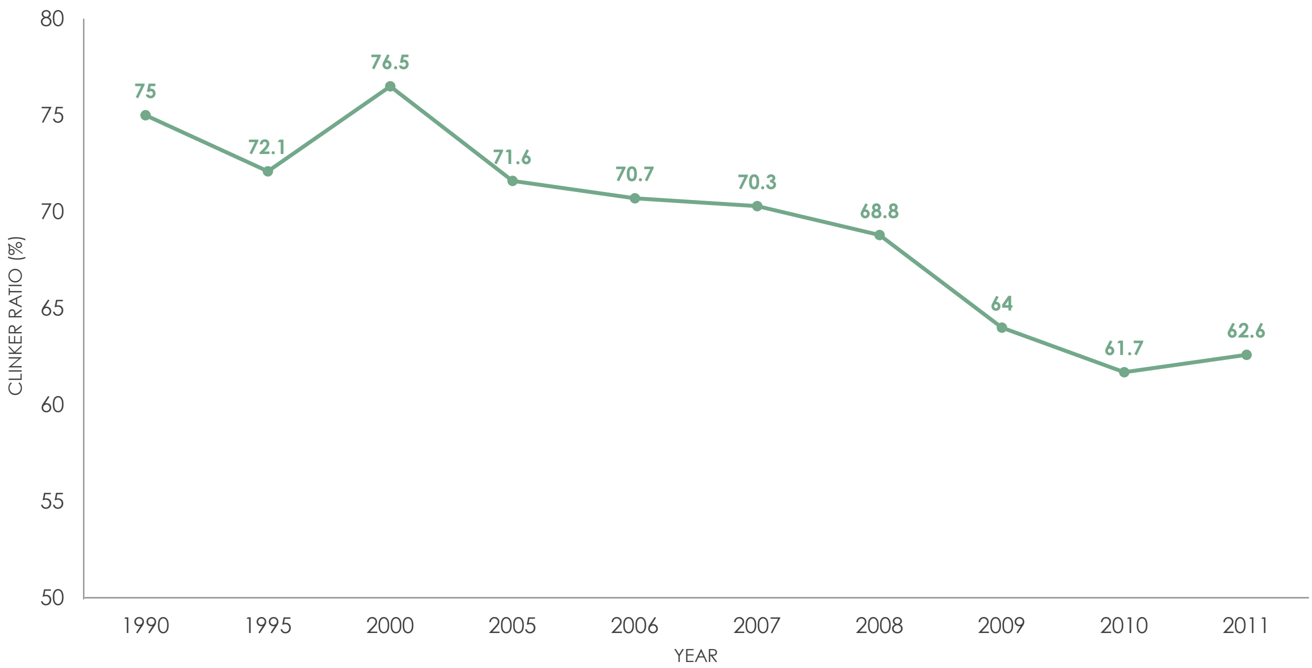
FIGURE 3: TYPES OF CEMENT FOR CONCRETE (BS EN 197-1)

CEM I PORTLAND CEMENT	Comprising Portland cement and up to 5% of minor additional components
CEM II PORTLAND-COMPOSITE CEMENT	Portland cement and up to 35% of other single constituents
CEM III BLASTFURNACE CEMENT	Portland cement and higher percentages of blastfurnace slag
CEM IV POZZOLANIC CEMENT	Comprising Portland cement and higher percentages of pozzolana
CEM V COMPOSITE CEMENT	Comprising Portland cement and higher percentages of blastfurnace slag and pozzolana or fly ash

SOURCE: BRITISH GEOLOGICAL SURVEY 2005

The clinker ratio is one of the most important factors, which determines environmental impacts per metric ton of final cement output. Reducing clinker amount in cement not only lowers direct environmental impacts during the clinker production stage but also reduces the indirect impact from virgin raw material requirement and impacts from mining and processing steps. The clinker ratio in China has reduced drastically over the years (Figure 3) (Xu et al., 2014).

FIGURE 3: FALLING CLINKER RATIO IN CHINESE CEMENT INDUSTRY



SOURCE: XU ET AL. 2014

WASTE HEAT RECOVERY

Investment into waste heat recovery (WHR) technology has also been high. On average, electric power accounts for up to 25% of the total operating costs of a cement factory. WHR, which utilizes residual heat in the exhaust gases generated in the cement manufacturing process, can provide low-temperature heating or generate up to 30% of overall plant electricity needs. This reduces operating costs and improves EBITDA margins[1] of cement factories by about 10-15% (IIP Network, 2015). In 2011, national energy efficiency regulation mandated WHR on all new clinker lines constructed after January 2011. Out of 865 WHR technologies installed across the world, 739 were installed in China by end of 2012 representing 6,575 MW of installed capacity (IFC, 2014; Global Cement, 2013).

TARGETING AIR POLLUTION

In July 2013, China's State Council approved the Air Pollution Prevention and Control Action Plan (2013-17) backed by US$277bn in total investments from the central government to fight air pollution. The initiative characterized as the strictest air pollution control measures ever adopted in China includes ten air pollution prevention and control measures (CCICED, 2014). As a capital- and coal-intensive sector suffering from overcapacity, the cement industry is likely to be affected through (CAAC, 2014):

- **Indicator 1:** Optimization and Adjustment of Industrial Structure, especially New projects control for overcapacity sectors, phasing out backward production capacity and relocation of heavy pollution enterprises with environmental upgrade
- **Indicator 2:** Clean Production, especially Cleaner production assessment and technology upgrades for key sectors
- **Indicator 4:** Small Coal-fired Boilers Treatment
- **Indicator 5:** Air Pollution Control for Industrial Sector, especially Industrial dust (PM) control and Industrial VOCs control
- **Indicator 6:** Urban Dust (PM) Control, especially PM control for construction area

[1] A measurement of a company's earnings before interest, taxes, depreciation, and amortization as a percentage of its total revenue

At the same time, in order to push forward industrial transformation and upgrades by formulation and amendments of major industrial emission standards, the Ministry of Environmental Protection, announced three emission standards of air pollutants, including **Emission Standard of Air Pollutants for the Cement Industry** (GB 4915-2013), **Standard For Pollution Control On Co-Processing Of Solid Wastes In Cement Kiln** (GB 30485-2013) and its supplementary standard **Environmental Protection Technical Specification For Co-Processing Of Solid Wastes In Cement Kiln** (HJ 662-2013).

The new standards specify tougher requirements for emission of PM and NO_x. Considering the technological progress in dust removal and de-nitration, the new standards set tougher PM emission limit at 30 mg/m^3 (for thermal equipment such as cement kilns) and 20 mg/m^3 (for ventilation equipment such as cement grinding mill), in comparison to 50 mg/m^3 and 30 mg/m^3 respectively according to ongoing standards (MEP, 2014). The NO_x emission limit is set at 400 mg/m^3 in comparison to the current 800 mg/m^3, in order to urge the cement producers to combine the process control (e.g., low NO_x burner, graded combustion in decomposing furnace, fuel replacement) with end-of-pipe control (SNCR is the currently available mature technology) of NO_x emissions. The new standards also set tougher requirements for control of odor and heavy metal pollution.

Considering the progress in upgrading de-nitration and dust removal facilities in established enterprises (for example newly built clinker production installations must install NO_x-removal equipment to treat emissions with no less than a 60% removal rate, as well as installing online real-time monitoring system and other highly effective pollution treatment equipment) and in light of the national policy of adjusting overcapacity and strengthening air pollution control, these standards have applied to newly constructed cement plants since 1 March 2014 and to existing plants since 1 July 2015. In accordance with No. 14 Announcement of MEP in 2013, special air pollution emission limits apply for companies based in three regions and ten city clusters, while local governments may extend the scope and set tougher requirements for enforcing the special emission limits.

It is estimated that after enforcing the new standards, the PM emission from the cement industry will be cut around 770,000 t (30.8%-38.5%) from the baseline of 2-2.5 million metric tons; the NO_x emission will be cut about 980,000 t (44.5%-51.6%) from the baseline of 1.9-2.2 million metric tons, effectively controlling the pollution load of HCl, HF, heavy metals, and dioxins, and meanwhile contributing to the reduction of GHG emissions (MEP China, 2014).

LEGAL ACTION, FINES AND PENALTIES

Cement producers anticipate that the new emissions limits will increase their operating costs, though some cement producers with best available technology are already able to meet these limits, protecting themselves from unexpected cost increase or resultant breach fines.

The imposition of fines is likely to have material implications for cement company profits. For examplein the United States, where the cement sector is the third largest industrial source of pollution, the Environmental Protection Agency started a coordinated, integrated compliance and enforcement strategy in 2008 to address Clean Air Act compliance issues at the nation's cement manufacturing facilities (EPA, 2015). A high-level review of cement plant settlements to date reveals important losses for cement companies in the US. These can serve as proxy to the Chinese cement industry.

- Ash Grove Cement Company agreed to pay a $2.5 million penalty and invest approximately $30 million in pollution control technology at its nine Portland cement manufacturing plants to resolve alleged violations of the Clean Air Act.
- In a Clean Air Act settlement with Holcim (US) Inc. (Holcim) and former owner St. Lawrence Cement Company, LLC, Holcim agreed to invest approximately $20 million or more to resolve violations of the Clean Air Act.
- CEMEX, Inc., the owner and operator of a Portland cement manufacturing facility in Lyons, Colo., agreed to operate advanced pollution controls on its kiln and pay a $1 million civil penalty to resolve alleged violations of the Clean Air Act (CAA).
- Essroc Cement Company agreed to pay a $1.7 million penalty and invest approximately $33 million in pollution control technology to resolve alleged violations of the Clean Air Act (CAA) at six of its Portland Cement manufacturing plants. Essroc also agreed to spend $745,000 to mitigate the effects of past excess emissions from its facilities.

GOING FORWARD

Despite considerable progress, China's cement firms remain less energy efficient than their Western counterparts and cause more stress on the local environment. The sector lags behind the rest of the world on its implementation of sustainable production techniques including the use of renewable energy (coal is still the main fuel), energy efficient techniques (average energy consumption of new dry process kiln production lines in China is 15-25% higher than the international average) and substitution of clinker for carbon efficient alternatives such as fly ash (UNEP, 2013).

This situation is typically attributed to a number of policy failures. For example, although Chinese regulations are seen as strict, they often lack stringent enforcement. This is particularly apparent in the cement sector where the local-level enforcement of environmental regulations is considered a long-standing issue (UNEP, 2013). There is often said to be a difference of interests between local and national authorities. As the world's most populous country, China faces governance challenges, including disparities between central government demands and action at the local level. In particular, local governments are often more focused on short-term economic growth rather than longer-term environmental concerns or broader national priorities. Ultimately, this results in underinvestment in environmental technologies and environmental damage (UNEP, 2013).

Evidence shows that Chinese cement companies are frequently in breach of regulatory standards. For example, a 2013 'Green Stocks Investigative Report' released in Beijing pointed out that 17 China-listed cement companies were in frequent violation of regulations on the discharge of gaseous pollutants, as well as not fulfilling their responsibilities to disclose discharge information (IPEA, 2013). Environmental campaigners were successful in engaging investors in these companies, some of which have reportedly conducted follow-up investigations into the environmental performance of listed cement companies in their investment portfolios.

In parallel, a lack of fiscal incentives or pollution taxes means firms are not sufficiently financially incentivized to reduce their pollution (UNEP, 2013). For example, the cement industry accounts for about 10% of China's national NO_x emissions but de-nitration technology is expensive – costing between $3.2-6.5 (RMB 20-40) per metric ton of production to install (NDRC, 2012). However, the profit in the cement sector is typically only $8.1 (RMB 50) per metric ton, so firms are unwilling to bear the cost (NDRC, 2012). There are very few subsidies for de-nitration technologies, meaning that NO_x emissions in the industry remain high.

Despite these shortfalls, the ambitious targets and achievements in the 11th and 12th Five-Year plan show a shift in the traditional model for development to a new model based on technological advancement and sustainability, setting standards and driving green investment in the sector (UNEP, 2013). Strengthening regulatory enforcement is also on the cards and the future direction of travel is clear. Moreover, the People's Bank of China is currently spearheading the drafting of the 13th Five-Year Plan (2016-2020) for the reform and development of China's financial sector. Green finance will be a key element of this plan (Green Finance Task Force, 2015), with the Green Finance Task Group presenting the most systemic set of policy recommendations pertaining to green finance to date.

The cost of a new cement plant is typically equivalent to around three years of turnover, ranking the industry among the most capital intensive. Approximately 30% of the industry's costs relate to energy, making it highly energy-intensive (Cembureau, 2015). The trend of regulatory change combined with the long time periods required before cement plant capital investments can be recovered (their lifespan usually exceeds 40 years) makes it crucial that plant modifications are carefully planned so as to ensure alignment with the long-term trends of the industry. Lock-in of this kind is expensive for society as a whole and ties up capital that could be deployed productively elsewhere.

1.4 EXPLORING MARKET RISK DRIVERS

The cement industry has grown in China due to large increases in demand for housing and transport infrastructure with construction firms and governmental institutions the cement market's main customer base. Many state-owned cement manufacturers have benefitted from government support and access to affordable capital, which has caused the sector to undergo a period of rapid growth with product quality and profitability lagging behind (FT Alphaville, 2014). For example, 25-30% of China's cement capacity is low-grade cement not used in other countries (UNEP, 2013). Buildings in China typically have a service life of only 30 years, while in the UK the average lifetime of a house is 132 years (UNEP, 2013).

Given the vital importance that infrastructure put in place to support future growth is as sustainable as possible, measures such as extending the average lifetime of buildings are likely to reduce cement demand by tens of millions of metric tons. China has already announced in 2013 that it would gradually phase out low-grade cement, lowering the country's cement consumption by 700-800 million metric tons per year (UNEP, 2014).

Market drivers are influenced by a wide range of additional factors, and many drivers are interlinked. Regulatory risk was discussed in the previous section, however future regulation (or anticipations thereof) also drives the market. The demand for mainstream cement is also likely to be reduced through regulations such as improved building standards. In a note assessing the key credit factors for the building materials industry, Standard & Poor's Ratings Services say that the focus on energy-efficient products and green building technologies is influencing the industry globally, and most competitive producers are making technological innovations to improve these aspects of their products and processes (S&P's Ratings Services, 2013). As such, Chinese producers that fail to grasp these opportunities risk losing market share.

1.5 EXPLORING REPUTATIONAL RISK DRIVERS

In China stakeholders are increasingly concerned about the environmental impacts of rapid industrialization and consumerism and take specific action to change a company's practices. Each year, local environmental protests have increased by 29% demonstrating the high levels of public concern related to the environment (Feng and Wang, 2012). In April 2015, Luoding City in Guangdong cancelled a plan to build a waste incinerator after it prompted a protest of around 10,000 people opposing site selection and citing that 'the nearby cement plant is already producing enough pollution, we don't need another polluter' (Global Cement Magazine, 2015). Environmental groups have also long campaigned to reduce sources of air pollution in China (Greenpeace, 2014).

Investors increasingly see the general sentiment towards polluters and negative publicity caused by such events as a potential risk to asset value. In a briefing following the release of Under the Dome, a 2015 documentary uncovering the causes of air pollution in China, Deutsche Bank pointed at the trend of social change: 'to our knowledge, this is the first time a video by an independent journalist has been allowed to cause such social impact; (…) it may have macro implications' before highlighting an expectation for pollution control to be an unprecedented focus of the Government over the next decade creating more investment opportunities for leading companies (Deutsche Bank, 2015).

Indeed, the reaction brought about by the documentary was immediately reflected on the Chinese stock markets, with shares in environmental industries such as pollutant treatment, air quality monitoring and green technology experiencing sharp gains shortly after the film's release (Bloomberg, 2015). Analysts at Jefferies stressed the significant investment opportunities in the low carbon space resulting from a "watershed" moment for China's environmental policy (FT Blogs, 2015).

Air pollutants growing at dangerous levels were also highlighted by BNP Paribas as a source of two main risks for China: the social risk as these emissions are harmful to human health, and the political risk from external pressure on the country to improve environmental performance (BNP Paribas, 2015). Nomura classified the Government's supportive attitude for environmental protection and related industries, and the public's heightened awareness of environmental issues, as defining factors for investor analysis (FT Blogs, 2015).

1.6 GREEN TRANSFORMATION IS THE NEW NORMAL

China's strategic decision to move away from a high pollution and resource intensive economy will clearly have implications both for existing assets, as well as the trajectory of future capital investment. Investing in technologies and infrastructure has to ensure it does not quickly become outdated or inappropriate from a regulatory or societal perspective (Caldecott and Robins, 2014).

The previous sections demonstrated the growing risk of changing consumer behavior, tougher regulations and legal action forcing cement companies to internalize the external costs of their business activities. Table 1 summarizes some of these risk drivers that can affect the operations and manufacturing of cement companies.

TABLE 1: OVERVIEW OF INTERNALIZATION DRIVERS OF EXTERNAL COSTS FOR CEMENT COMPANIES

RISK DRIVER	POTENTIAL IMPACT	EFFECT
Evolving social norms and customer behavior – Societal demand	Each year environmental protests have increased by nearly a third demonstrating the high levels of public concern related to the environment. High levels of public concern facilitates the passing of new stricter regulations and mobilizes investor awareness and valuation	Loss of license to operate Increase of operational costs from new regulations Higher cost of capital from investor reappraisal
Evolving social norms and customer behavior – Investor demand	Investors are increasingly appreciative of the risks stemming from high pollution and significant opportunities created in the low-carbon space	Loss of share value on the stock markets for the most polluting companies Higher cost of borrowing on the debt markets due to investor reappraisal of credit risk
Evolving social norms and customer behavior – Customer demand	As infrastructure and housing needs are reappraised towards sustainable long-term performance, demand for most types of low-quality cement may fall	Decrease in revenue opportunities from lower demand for most types of cement
Regulations and legal action – Restrictions/ bans, tradable permit markets, imposition of taxes	Implementation or existent schemes imply increased investment costs by the companies to improve the available technologies to reduce emissions. Fuels are a major contributor to the overall air pollution and GHG performance of a cement producer's emissions profile. Thus, the cost of electricity and fuel in all jurisdictions of company operations will be affected	Increase of operational costs from new regulations Potentially large scale stranded asset write-offs if current CAPEX is not aligned with the long-term trends of the industry
Regulations and legal action – Legal fines	Chinese cement companies are frequently in breach of regulatory standards and important legal fines are soon likely to follow	Experience of US cement company settlements reveals highly material implications from legal fines
Uncertainty related to introduction of new regulations	The risks from the uncertainty in the regulatory environment stem from the inability to properly quantify and develop capital expenditure scenarios, affecting the business response of the company	Decrease in revenue opportunities from lower demand for most types of cement

SOURCE: TRUCOST PLC 2015

2. ANALYZING ENVIRONMENTAL RISK: THE TRUE COST OF CEMENT IN CHINA

Section 1 provides investors, companies and policy makers with an overview of the business risks posed by the cement sector's growing environmental impacts. SECTION 2 LAYS OUT A FRAMEWORK FOR EVALUATING ENVIRONMENTAL RISKS SPECIFIC TO THE CEMENT SECTOR, AND PROVIDES DATA ON THE PERFORMANCE OF 32 PUBLICALLY LISTED CEMENT COMPANIES IN CHINA. Section 3 provides investors, cement companies and policy makers with recommendations to improving environmental risk analysis and management in the cement sector in China.

2.1 MONETARY VALUATION AS AN INTEGRATED SUSTAINABILITY TOOL

"At present, China's pricing system does not fully reflect the negative externalities of polluting projects and the positive externalities of green projects. Understanding how to restrict excessive investments in polluting sectors and incentivize private investments in green industries, as well as how to use limited government funding to leverage several times more in private investment, will be the key to promoting green economic growth and building an "institutional system for ecological civilization". This is also a major challenge that confronts China's economic restructuring."

From **Establishing China's Green Financial System (Green Finance Task Force, 2015)**

Conventional steps to measure and value economic performance such as Gross Domestic Product (GDP), investment performance, or traditional profit-and-loss statements and balance sheets do not reflect the full scale of environmental impacts caused by business leading to a lack of recognition of their true costs. As a result, most of the negative (or positive) impacts of cement production are not taken into full account in company decision-making. In parallel, the benefits of sustainability initiatives are often reported in corporate social responsibility reports, but not integrated in the core activities and business models of companies.

To bridge this gap and in order to understand the potential magnitude of risks to business profitability from the external cost of business activity, investors can use a technique called 'monetization of external costs'. This translates physical measures in terms of metric tons of air pollutants emitted, or cubic meters of water used, into the dominant language of business and economics: a monetary value expressing the damage caused to environment and society. In other words it is a representation of the potential value that companies would have to internalize if they were to become accountable for their impacts. It also enables the comparison between different types of impacts not normally comparable (such as across air pollutants) and facilitates comparison between companies. As an integration tool, it can be used to measure and report overall impacts and associated costs relevant for a range of stakeholders important to a business' value creation.

Monetization of external cost is gaining ground through initiatives such as the World Business Council for Sustainable Development (WBCSD) Guide to Corporate Ecosystems Valuation and the United Nations-led Economics of Ecosystems and Biodiversity (TEEB) which encourage businesses to assess the natural capital they depend upon. Leading investors are also increasingly collaborating to integrate natural capital considerations in their decision-making. More than 40 CEOs of banks, investors and insurers worldwide have signed the Natural Capital Declaration (NCD) establishing a commitment to change financial business models to reflect the materiality of natural capital for the sector. The primer on monetary valuation of external impacts below provides further insight.

A PRIMER ON MONETARY VALUATION OF EXTERNAL COSTS

The theoretical grounds for the monetary valuation of benefits delivered by ecosystems were laid in the 1960s, when the general notion that natural resources lacking well-defined property rights, were vulnerable to overexploitation was famously articulated in Hardin's Tragedy of the Commons (1968). Valuation proliferated in the 1990s as a growing number of scientists recognized the usefulness for decision makers of framing ecological concerns in economic terms (Gomez-Baggethun, de Groot, Lomas, & Montes, 2010). A particular milestone in the mainstreaming of the approach was an assessment by Costanza et al. (1997), constituting the first attempt to value global ecosystem goods and services. This study estimated that the entire biosphere delivered unpriced ecosystem service benefits of $33 trillion per year on average, or almost double the global gross national product at the time.

Due to the compatibility with existing economic structures, monetary valuation approaches are increasingly used around the world in decision-making and in facilitating policy formulation. Some of the leading examples of pioneering international ecosystem services studies since 2000 include the Millennium Ecosystem Assessment (MEA) of the state of the globe's ecosystems, and The Economics of Ecosystems and Biodiversity (TEEB). MEA concluded that rapidly growing resource needs have resulted in approximately 60 percent of the ecosystem services that support life on Earth – such as fresh water, capture fisheries, air and water regulation, and the regulation of regional climate, natural hazards and pests – to become degraded or used unsustainably. Unless addressed, these substantial and largely irreversible losses are likely to substantially diminish the anthropogenic benefits flowing from ecosystems (MEA, 2005).

A major collaboration gaining traction within the private sector is being developed by the Natural Capital Coalition with support from the International Finance Corporation, the International Union for Conservation of Nature and The World Bank, is the Natural Capital Protocol (Natural Capital Coalition, 2014). The objective is to create a harmonized accounting framework, providing businesses with standardized tools and metrics to identify their impact and reliance on natural capital (Natural Capital Coalition, 2014).

Investors across the globe are also increasingly scrutinizing the natural capital impacts of companies in order to manage risk and identify new opportunities in the transition to a resource efficient, lower-carbon economy. A recent survey by the CFA institute, a global association of investment professionals, found that almost three quarters of investment professionals use environmental, social and governance information when making investment decisions (CFA Institute, 2015). More than 40 CEOs of banks, investors and insurers worldwide have also signed the Natural Capital Declaration (NCD) establishing a commitment to change financial business models to reflect the materiality of natural capital for the sector. These managers are seeking responsible companies who are better governed and generate fewer environmental and societal costs, while providing superior returns. These companies are good investments – with less risk, greater opportunities and a more secure long-term license to operate.

2.2 PROJECT METHODOLOGY

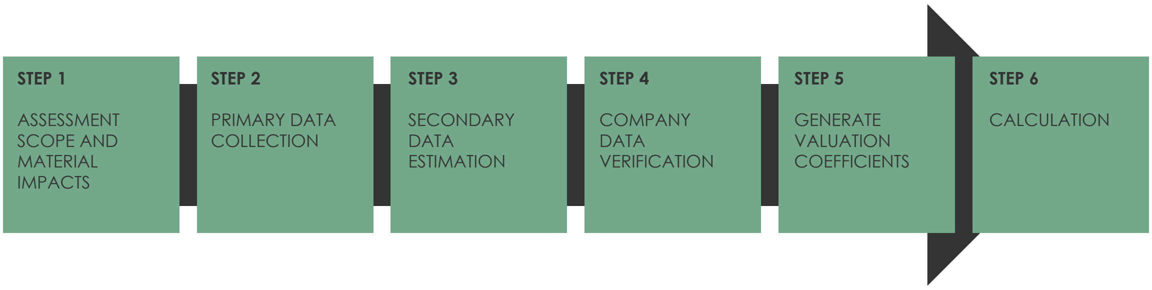
The usefulness of integrating material environmental factors in investment decision-making is demonstrated through a pilot project evaluating the environmental impacts of 32 publically traded cement production companies in Greater China. Their material environmental impacts were quantified and monetized to enable comparability and integration into business decision-making.

The end goal is to demonstrate that by embedding environmental indicators within traditional decision-making, investors can identify those companies that are best positioned to succeed in a resource efficient, low-carbon economy, and manage risk from environmental laggards which threaten China's future sustainable growth. Ultimately, this serves to increase awareness of responsible investment among Chinese investors, policy makers and other relevant stakeholders.

The calculation of external cost resulting from the environmental impacts of 32 publically traded cement production companies followed six distinct steps designed to establish the link between changes in the environment and changes in the wellbeing of specific societal groups, such as local communities, employees, businesses and the wider society **(Figure 5)**. The starting point of the assessment was to scope the boundaries for analysis according to the company's value chain and the most material environmental impacts measured by appropriate key performance indicators (KPIs) **(Figure 6)**.

For example, the energy used in manufacturing processes emits air pollutants, measured in metric tons. These pollutants could for example lead to acidification of freshwater systems resulting in the loss of fisheries, soil degradation, damage to forests and vegetation, corrosion of buildings, cultural monuments and materials. In turn, these environmental changes change the wellbeing of societal groups. Once the scope and boundaries of the assessment have been set, a clear picture of all the interconnected processes and environmental impacts was constructed. **Appendices A.1, A.2 and A.3 present the detailed Methodology.**

FIGURE 5: TRUE COST OF CEMENT, HIGH-LEVEL METHODOLOGY



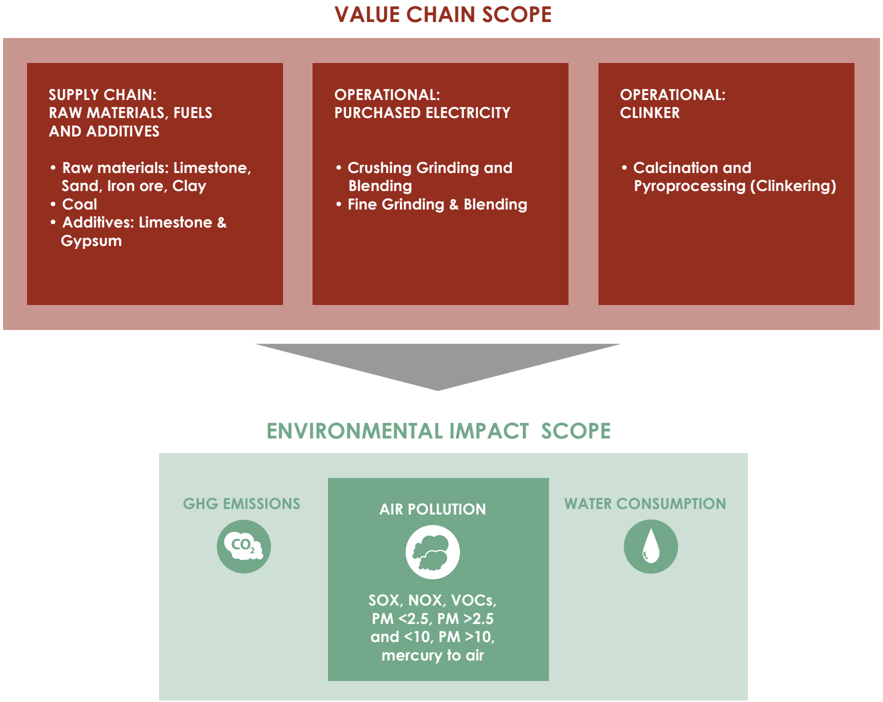
SOURCE: TRUCOST PLC 2015

2.2.1 PROJECT SCOPE AND BOUNDARIES

The value chain scope of this assessment focused on the production of clinker, which generates the most material environmental impacts in the lifecycle of cement production. Assessed are the raw material extraction, processing, and clinker manufacturing stages. Excluded are the finishing (fine grinding and blending of clinker for cement production) and packaging stages of cement production.

In line with best practice definitions, an environmental impact can be considered material if 'consideration of its value as part of the set of information used for decision-making, either by internal stakeholders or third parties relying on company disclosures, has the potential to alter that decision' (Natural Capital Coalition, 2014a). From an impact perspective, air pollution is increasingly considered the world's largest environmental health risk (Asia Insurance Review, 2014). Because of its highly localized impact, heightened social and regulatory significance, air pollutants were prioritized for this assessment, with other material impacts (GHGs and water) considered in Appendices.

FIGURE 6: PROJECT SCOPE



SOURCE: TRUCOST PLC 2015

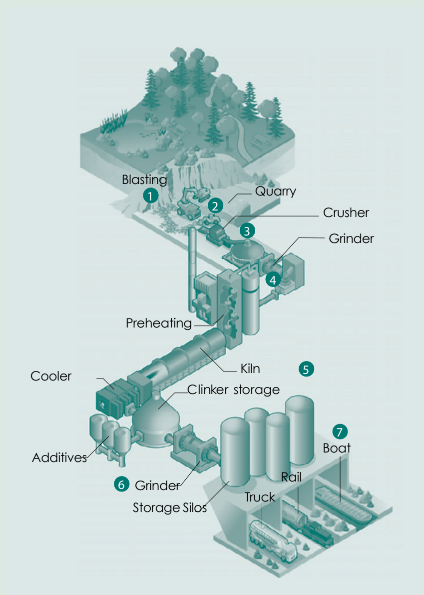
A PRIMER ON CEMENT PRODUCTION

Cement is produced from a feedstock of limestone, clay and sand, which provide the four key ingredients required: lime, silica, alumina and iron. Mixing these ingredients and exposing them to temperatures greater than 1,400 ˚C in a kiln causes chemical reactions that convert the partially molten raw materials into pellets called clinker. The clinker or kiln product is cooled and the excess heat is typically rooted back to the preheater units. After adding gypsum, the mixture is ground to a fine grey powder called Ordinary Portland cement, the most commonly used type of cement. It may also be combined with other active ingredients or chemical admixtures to produce other types of cement.

The manufacturing process is complex, involving a large number of materials with varying material properties, pyroprocessing techniques (for example wet and dry kiln, preheating, recirculation), and fuel sources (for example coal, fuel oil, natural gas, tires, hazardous wastes, petroleum coke).

The exclusion of the finishing and packaging stages of cement production also avoids the significant uncertainties around estimating a clinker to cement ratio, which is necessary for reliable projections of the clinker production. An additional complicating factor is that in some countries, including China, significant blending of clinker substitutes occurs when the concrete is mixed, rather than at the time of cement production.

FIGURE 7: MANUFACTURING PROCESS (IEA, 2009)



SOURCE: LAFARGE ANNUAL REPORT 2013

Large quantities of air pollutants are emitted from cement production, including SO_2, NO_x and PM, which result in significant regional environmental problems (Lei et al., 2011). Clinker production in cement kilns is the major source of most air pollutants in the cement production process. It is the sole source of SO_2, NO_x and VOCs emissions, with the emissions of these pollutants dependent on the fuel type being used. $PM_{2.5}$ and PM_{10} emissions are also of serious concern. They are more complex to quantifybecause besides kiln emissions, there are several other emission sources such as quarrying and crushing, raw material storage, grinding and blending, and packaging and loading. PM abatement efficiency also varies a lot between the different PM emission control technologies.

Mercury occurs naturally in the earth's crust and is released into the environment through both natural (e.g., volcano eruption, rock weathering, and forest fires) and anthropogenic processes (e.g., fossil fuel combustion, mining, and cement production). It is a persistent toxic substance posing significant threats to public health and the environment. The World Health Organization identifies it as one of the top ten chemicals or groups of chemicals of major public health concern (WHO, 2013).

Currently China is the world's largest emitter of mercury, accounting for over 50% of the world's total. Mercury is a trace element in the raw feedstock materials, and in the fuels (mostly coal), making the cement industry a major mercury pollution source. Despite the numerous ways that mercury finds its way into the air, coal combustion in industrial boilers and power plants remains the largest source of atmospheric mercury emissions in China, accounting for more than 50% of the total, with substantial additional contributions from non-ferrous metals smelting and cement production (CCICED, 2011).The mercury emissions from cement production are highly dependent on the mercury content of the raw material used and also the mercury content of the coal (CCICED, 2011).

2.2.2 PRIMARY AND SECONDARY DATA COLLECTION, ESTIMATION AND VERIFICATION

The quantification of KPIs and related impacts was conducted through primary and secondary data collection. Primary data collection refers to the use of actual, measured data. Generally the more company specific data the better the results and usefulness for decision-making. Secondary data estimation can be performed using Lifecycle Analysis (LCA) studies, academic research literature and input-output modeling. The choice of methodology was mainly driven by the aim of the study and data availability.

In this assessment primary data from Annual and Sustainability Reports was prioritized. However, where primary data is unavailable, the analysis used best available secondary data estimation techniques, including China-specific lifecycle assessments (LCAs) and academic peer reviewed literature (see Table 2 for an overview; Appendices for detailed methodology). Finally, the results were sent to the 32 cement producing companies to provide them with an opportunity to review and improve their profile by providing additional primary data related to their clinker manufacturing operations (Figure 8).

FIGURE 8: DATA COLLECTION HIERARCHY

1. COMPANY PUBLIC DISCLOSURE

- Annual Reports, Sustainability Reports

2. ESTIMATION METHODOLOGY

- **Lifecycle Databases:** Ecoinvent hosts the world's leading database of consistent, transparent, comprehensive and up-to-date Life Cycle Inventory (LCI) data
- **Scientific Journals:** Atmospheric Environment; Journal of Cleaner Production; Renewable and Sustainable Energy Reviews; Applied Energy
- **Other sources:** Ernest Orlando Lawrence Berkeley National Laboratory; CEMBUREAU; Cement Sustainability Initiative; Portland Cement Association

3. COMPANY PRIVATE ENGAGEMENT

Pre-populated data collection template sent to companies to invite them to review and improve their environmental profile by verifying disclosure and providing supplementary data

TABLE 2: OVERVIEW OF ESTIMATION METHODOLOGY

CATEGORY OF IMPACT	KPI: AIR POLLUTANTS FROM EACH KILN TYPE IN CHINA: PRECALCINER KILNS, SHAFT KILNS AND OTHER ROTARY KILNS	REGIONALIZATION	SOURCE
Operational	SO_X g/kg of coal combustion in specific kiln	China-specific	(Lei, et al., 2011)
Operational	NO_X g/Kg of coal combustion in specific kiln	China-specific	(Lei, et al., 2011)
Operational	VOCs g/Kg of coal combustion	Global average	(NETCEN, 2003; Stockholm Environment Institute , 2008; Argonne National Laboratory, 2012; EMEP / EEA, 2013; US EPA, 1995; NAEI, 2013)
Operational	$PM_{2.5}$ g/Kg cement production in specific kiln	China-specific	(Lei, et al., 2011)
Operational	$PM_{2.5\text{-}10}$ g/Kg cement production in specific kiln	China-specific	(Lei, et al., 2011)
Operational	$PM_{>10}$ g/Kg cement production in specific kiln	China-specific	(Lei, et al., 2011)
Operational	Mercury emissions to air mg/Nm^3 of flue gas production in specific kiln	Global average	(Renzoni, et al., 2010)

CATEGORY OF IMPACT	KPI: AIR POLLUTANTS FROM EACH KILN TYPE IN CHINA: PRECALCINER KILNS, SHAFT KILNS AND OTHER ROTARY KILNS	REGIONALIZATION	SOURCE
Indirect	**Quantity of raw material use**	Global average	**(Huntzinger & Eatmon, 2008)**
Indirect	**NO_x, SO_x, VOC, PM (all), Mercury emissions to air for Limestone**	Global average	**(Ecoinvent, 2015)**
Indirect	**NO_x, SO_x, VOC, PM (all), Mercury emissions to air for Clay**	Global average	**(Ecoinvent, 2015)**
Indirect	**NO_x, SO_x, VOC, PM (all), Mercury emissions to air for Sand**	Global average	**(Ecoinvent, 2015)**
Indirect	**NO_x, SO_x, VOC, PM (all), Mercury emissions to air for Iron Ore**	Global average	**(Ecoinvent, 2015)**
Indirect	**NO_x, SO_x, VOC, PM (all), Mercury emissions to air for Coal**	China-specific	**(Ecoinvent, 2015)**
Indirect	**NO_x, SO_x, VOC, PM (all), Mercury emissions to air for Electricity**	China-specific	**(Ecoinvent, 2015)**

2.2.3 MONETIZATION COEFFICIENTS

The final step involves the use of monetization coefficients to enable the conversion of data on emissions and resource use into a valuation of the impact this has on people and their wellbeing, assessing the potential for a company's external risk to be translated into a risk for an investor or financier. There are 3 stages to a monetization exercise:

- Quantifying the environmental footprint across 3 impact areas (air pollution, with GHGs and water consumption in Appendices) and 9 indicators that cover different types of emissions and resource use
- Estimating the likely environmental changes that result from these emissions or resource use based on local environmental context (for example, increase in the concentration of pollution)
- Monetizing the resulting change in people's wellbeing.

Several established techniques exist to assign a value to an environmental change and calculate the costs and benefits in monetary terms of a specific action. Techniques span from observing behavior on existing markets as a proxy (for example, how much is spent on aquatic recreational activities) to creating artificial markets by asking the population to estimate their willingness-to-pay for the existence of a wildlife habitat. The Appendices summarizes the different techniques that can be used.

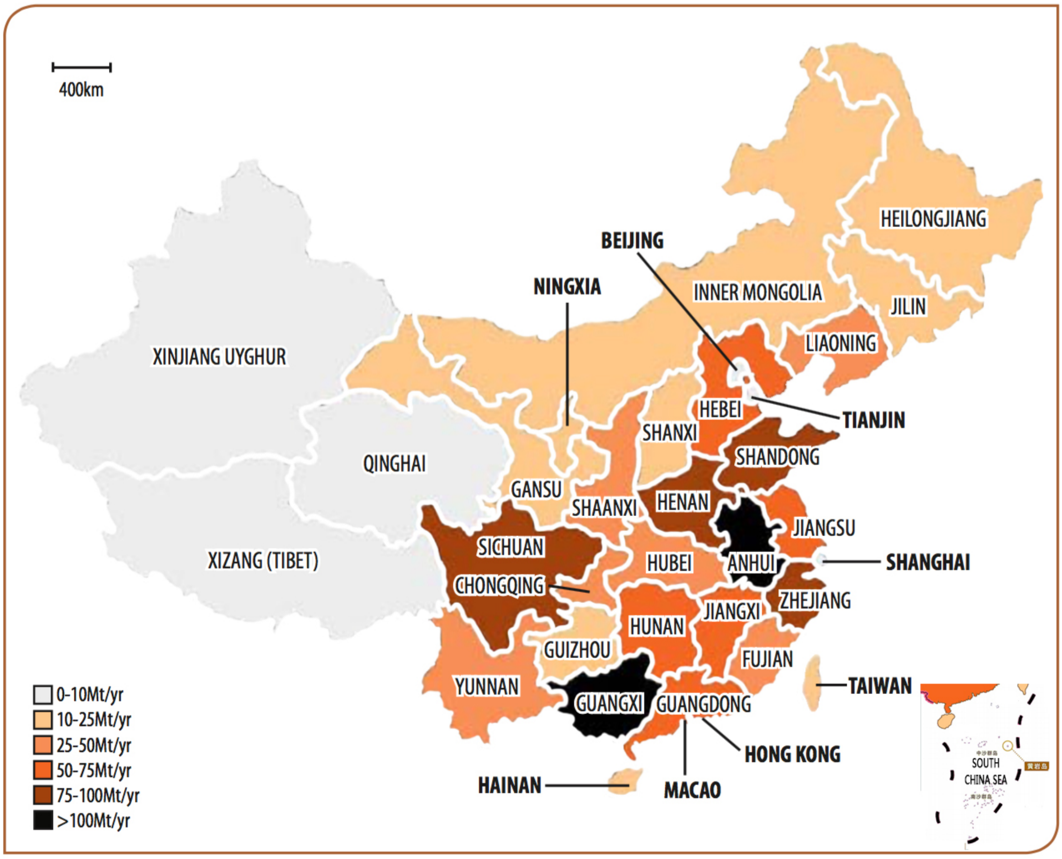
KEY CONSIDERATIONS IN MONETARY VALUATION

The monetization of external impact is inherently human-centric, with the values reflecting the impact of the environmental change on the wellbeing of the individual, society or business. This is so even in a context where the end-point is the environment. For example, the costs and benefits of a change in biodiversity are valued based on the services that biodiversity provides to society. This is consistent with the approach taken in the international Millennium Ecosystem Assessment, which focuses on contributions of ecosystems to human well-being while at the same time recognizing that potential for non-anthropocentric sources of value.

Valuations are most useful when analyzing the small, and smooth changes in the provision of environmental goods and services. Monetary valuations in general do not address the irreversibility of changes in the natural environment, tipping points or thresholds. While there has been much interest in valuing the totality of ecosystem services, such exercises have no economic meaning.

The local context where resources are sourced or emissions released is also important. A kilogram of air pollutant emitted in China has a different damage profile to the same air pollutant released in South Africa, due to differences in population density, income levels, average size of ecosystems, climatic conditions and others. For example, Henan and Shandong Provinces are among the top cement producers as well as among China's most densely populated (Figure 9). In those provinces, the damage profile of air pollution and the respective monetization coefficients would be higher.

FIGURE 9: INTEGRATED CEMENT CAPACITY IN CHINA IN 2015



SOURCE: GLOBAL CEMENT MAGAZINE 2015

2.3 BENCHMARK RESULTS: KEY FINDINGS

2.3.1 AGGREGATED FINDINGS

The combined cement production of 32 publically listed cement companies was 1,015 million metric tons of cement in 2013, equivalent to 46% of China's total cement production1 (Table 3). This generated clinker and cement segment revenues of $47,325m (RMB 293,200m) and total revenues of $74,008 (RMB 458,535). The production of clinker is the most intensive aspect of cement production. The estimated quantity of clinker produced in this period was 824 million metric tons.

TABLE 3: CEMENT COMPANIES INCLUDED IN ANALYSIS, 2013

ID NUMBER	TICKER	COMPANY NAME	COMPANY REVENUE FROM CEMENT ($M)	COMPANY REVENUE FROM CLINKER ($M)	TOTAL COMPANY REVENUE ($M)	CLINKER PRODUCTION (MILLION METRIC TONS)
1	914-HK	Anhui Conch	7,488	1,260	8,748	183.0
2	3323-HK	CNBM	9,269	2,277	18,995	219.5
3	1313-HK	China Resources	2,781	248	3,782	43.1*
4	000401-CN	Tangshan Jidong	2,183	235	2,536	54.1
5	1893-HK	China National Materials	1,580	-	3,346	19.3*
6	691-HK	China Shanshui	2,155	291	2,669	35.5*
7	900933-CN	Huaxin	2,113	155	2,580	32.0*
8	1136-HK	TCC	1,672	-	1,672	22.7*
9	2009-HK	BBMG	2,118	-	7,229	28.7*
10	1252-HK	China Tianrui	1,291	107	1,398	19.8*
11	600881-CN	Jilin Yatai	1,171	-	2,171	14.7
12	743-HK	Asia Cement	1,050	12	1,183	14.5*
13	000877-CN	Xinjiang Tianshan	1,024	-	1,277	14.7*
14	000789-CN	Jiangxi Wannianqing	766	37	997	12.9
15	600720-CN	Gansu Qilianshan	853	33	938	12.3*
16	2233-HK	West China	673	-	673	14.8*
17	002233-CN	Guangdong Tapai	565	8	616	9.8*
18	600449-CN	Ningxia Buliding Materials	518	-	679	11.1
19	000885-CN	Henan Tongli	509	131	646	12.9
20	600068-CN	China Gezhouba	767	-	9,608	10.4*
21	000672-CN	Gansu Shangfeng	160	240	407	12.3*
22	600425-CN	Xinjiang Qingsong	332	-	391	4.5*
23	000935-CN	Sichuan Shuangma	319	-	326	4.8*
24	600802-CN	Fujian Cement Inc	282	10	294	5.1
25	600318-CN	Anhui Chaodong	99	89	190	3.3*
26	600668-CN	Zhejiang Jianfeng	151	-	347	2.1*
27	600883-CN	Yunnan Bowin	6	-	6	0.1*
28	695-HK	Dongwu	58	0.4	58	0.8
29	000546-CN	Jinyuan Cement	12	-	14	0.2*
30	600539-CN	Taiyuan Lionhead	10	1	13	0.1*
31	600217-CN	Shaanxi Qinling	120	7	129	3.2
32	1312-HK	Allied Cement	90	0.4	91	1.2*
TOTAL			42,184	5,142	74,008	823.5

Note: * means estimated rather than disclosed quantity of clinker production

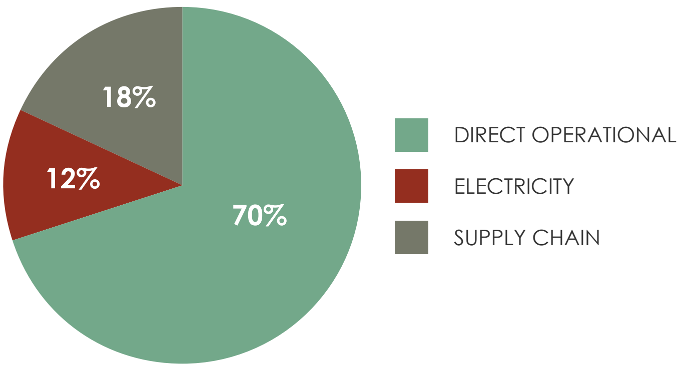
FINDING 1: The combined cement production of 32 publically listed cement companies equivalent to 46% of China's total cement production is responsible for an external cost of $31,500m (RMB 195,400m) in 2013. On average, 67% of cement companies' clinker and cement segment revenue and 43% of total company revenue could be at risk as the external costs of cement production become internalized through a range of drivers identified in this report.

Through the production of clinker for cement manufacturing and direct clinker sales, the 32 companies generated an external cost of $31,500m (RMB 195,400m), equivalent to 67% of their combined clinker and cement segment revenue. Revenues are normalized by clinker producing segments to avoid skewing results based on wider business activities. When the external cost of cement production is considered as part of total company revenue at risk, 43% of combined revenue could be at risk.
This indicates that the cement industry in China has a material exposure to the risk of internalization of external costs.

FINDING 2: On average, 82% of the total external cost from air pollution is within cement companies' operational control. This has direct implication for the management of this risk.

On average, 70% of total impact ($22,000m, RMB 136,400m) is related to companies' direct operations at the kiln level. Electricity is considered to be within companies' control, but the impacts are realized at the point of generation rather than site. If electricity is also included, this yields 82% of total impact within the cement companies' operational control. With such a significant proportion of impacts associated directly with company operations, individual companies have greater control over reducing these impacts, with technological and process adjustments within their own decision-making capabilities.

FIGURE 10: TOTAL EXTERNAL COST OF AIR POLLUTION OF 32 CEMENT COMPANIES IN CHINA, BY VALUE CHAIN PHASE, 2013

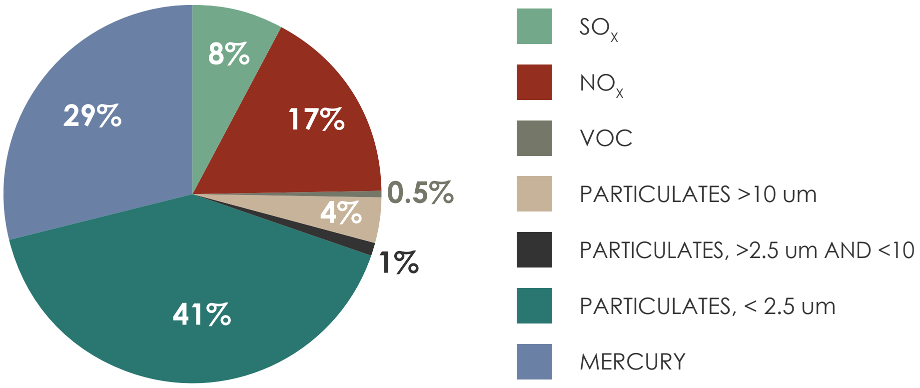


SOURCE: TRUCOST PLC 2015

FINDING 3: $PM_{2.5}$ and mercury emissions account for the majority of external costs from cement production, together responsible for over $18,690m (RMB 115,800m). Stakeholders should consider these as priority air pollutants for mitigation.

Within direct operational impacts, emissions associated with the combustion of fuel within the clinker kilns dominate, generating 85% of the external cost of clinker production, or $22,020 (RMB 136,450m). The remaining 15% is associated with the emissions related to the consumption of electricity. Particulate matter is the most dominant of the direct air pollutant impacts, with $PM_{2.5}$ ('fine particles', the smallest category of particulate matter) linked to 41% of the external cost of air pollution, or $10,780m (RMB 66,750m) across all companies (Figure 11). Mercury is the second most impactful air pollutant, associated with external costs of $7,920m (RMB 49,050m) across all companies.

FIGURE 11: AVERAGE EXTERNAL COST OF AIR POLLUTION PER METRIC TON OF CLINKER PRODUCED, DIRECT OPERATIONS, INCLUDING ELECTRICITY, 2014



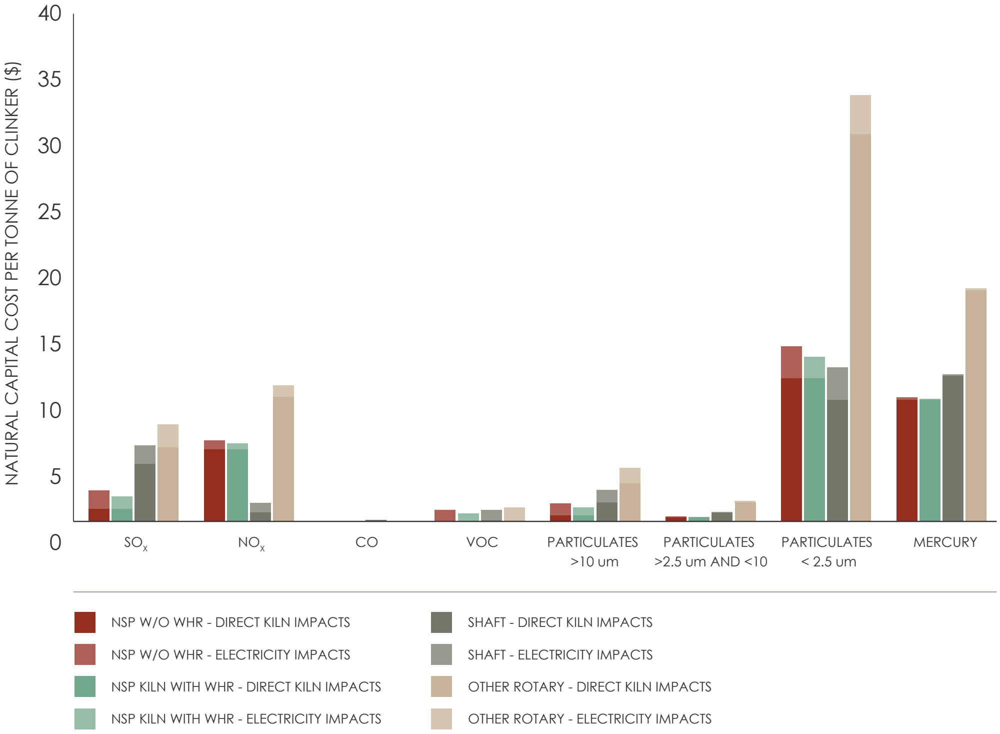
SOURCE: TRUCOST PLC 2015

The most impactful activity on site is the operation of cement kilns. Coal combustion in kilns releases particulate matter of different sizes, which is associated with cardiopulmonary conditions if inhaled by workers or local populations. Particulates account for between 41-51% of external costs of air pollution, depending on the type of kiln used. Coal combustion and the use of raw materials also release mercury, a persistent toxic substance posing significant threats to public health and the environment and classified as one of the top ten chemicals of major public health concern (WHO, 2013). Mercury accounts for between 26-40% of the total external cost of direct clinker kiln activity.

Precalciner rotary kilns have the lowest external cost from air pollutants of all types except for $PM_{2.5}$ (Figure 12). Precalciner kilns can function with or without waste heat recovery (WHR). While direct emissions are not reduced by WHR, the heat replaces electricity, and therefore precalciner kilns with WHR have a 32% lower air pollution impact from electricity, and 6% lower overall air pollution impact than precalciner kilns without WHR. This is mainly due to the reduction of SO_2, which tends to be significantly higher than NO_x emissions for electricity production in China as well as the rest of the world.

'Other rotary kilns' are the most polluting of all the kiln types, with almost 60% higher air pollution impact of the NSP with WHR. In precalciner kilns, approximately 70% of SO_2 is absorbed by reaction with calcium oxide while much less is absorbed in other rotary kilns and in shaft kilns (Lei et al., 2011). Compared to shaft kilns, rotary kilns produce much more NO_x because of their higher operation temperature and stable ventilation.

FIGURE 12: OPERATIONAL AND ELECTRICITY AIR POLLUTION EMISSIONS BY KILN TYPE, PER METRIC TON OF CLINKER



SOURCE: TRUCOST PLC 2015

FINDING 4: If air pollution costs were internalized into clinker's trading price, it would trade 72% higher at $79 (RMB 490) per metric ton.

The external cost of air pollution is equivalent to 72% of the average market trading price of clinker in 2013 ($46, RMB 286 per metric ton).

2.3.2 COMPANY LEVEL FINDINGS

Finding 5: Overall disclosure levels are low at 14% of environmentally relevant data points, though disclosure within traditionally financially material metrics such as energy use is generally much higher. Investors should influence further disclosure as the financial relevance of external costs become ever more evident.

The quantification of air pollution in this study was based upon a review of each company's annual and sustainability reporting. Where data was unavailable, impacts were modelled based on secondary sources such as lifecycle analysis data. To enhance the quality of data, companies were contacted to verify modelled data and provide primary data where available.

The overarching finding at the company level is the low level of primary data disclosure both through their annual reports and through the company engagement stage. A limited reporting rate of 14% across companies was calculated based on the number of environmentally relevant data points recorded as a proportion of the number of data points sought (Figure 13). The rates are color coded in the traffic light system, whereby the companies with highest disclosure are colored dark green, across the scale to red, which is used to represent zero data points recorded. This has implications for the assessment of individual company performance as well as for comparability across companies.

Disclosure rates are highest for the energy consumption category: fuel and electricity consumption and waste heat recovery. This may be related to the fact these metrics are traditionally considered to have a direct impact on financial profitability, with more than 30% of the industry's operating expenses relating to energy costs.

FIGURE 13: DISCLOSURE RATE ASSESSMENT (NOTE: DISCLOSED DATA HIGHLIGHTED IN GREEN)

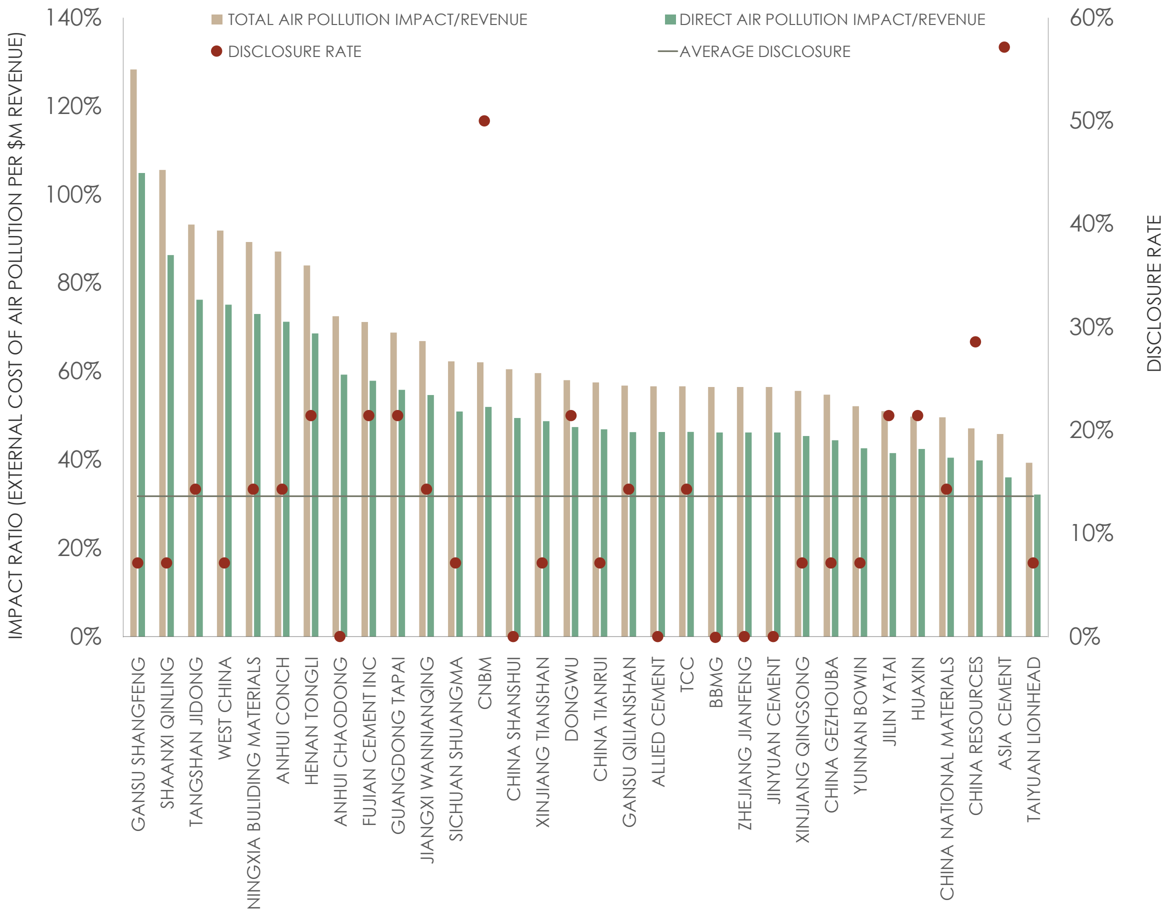
	GENERAL INFORMATION				ENERGY CONSUMPTION			WATER	GHG	AIR POLLUTANTS					
	CEMENT (TONNES)	CLINKER (TONNES)	CLINKER TO CEMENT RATIO	KILN TYPE	COAL CONSUMPTION	ELECTRICITY CONSUMPTION	"ENERGY RECOVERY (WASTE HEAT)"	WATER CONSUMPTION	GHG	NO_x	SO_2	VOCS	PM	MERCURY TO AIR	SUMMARY OF DATA POINTS DISCLOSED PER COMPANY
Asia Cement	■	■			■	■			■	■	■		■		57%
CNBM	■	■			■	■	■	■		■					50%
China Resources				■	■	■	■								29%
Huaxin					■	■	■								21%
Jilin Yatai	■	■					■								21%
Guangdong Tapai	■		■				■								21%
Henan Tongli	■	■					■								21%
Fujian Cement Inc	■	■					■								21%
Dongwu	■	■	■												21%
Anhui Conch	■	■													14%
Tangshan Jidong	■	■													14%
China National Materials			■	■											14%
TCC						■		■							14%
Jiangxi Wannianqing	■	■													14%
Gansu Qilianshan	■						■								14%
Ningxia Buliding Materials	■	■													14%
China Tianrui				■											7%
Xinjiang Tianshan	■														7%
West China	■														7%
China Gezhouba							■								7%
Gansu Shangfeng	■														7%
Xinjiang Qingsong				■											7%
Sichuan Shuangma	■														7%
Yunnan Bowin	■														7%
Taiyuan Lionhead	■														7%
Shaanxi Qinling		■													7%
China Shanshui															0%
BBMG															0%
Anhui Chaodong															0%
Zhejiang Jianfeng															0%
Jinyuan Cement															0%
Allied Cement															0%

SOURCE: TRUCOST PLC 2015

FINDING 6: Companies that disclose environmental data tend to have lower than average emissions intensity compared to other firms in China. However, it does not necessarily mean that they perform better overall.

The ten companies with the highest air pollution impact per metric ton of clinker show a lower average disclosure rate of 13%, while the ten with the lowest estimated external cost had a higher disclosure of 17% (Figure 14). For example, Asia Cement Holdings (745-HK) has the highest disclosure rate of 57%, and was associated with the second lowest air pollution impact intensity per unit of revenue. From all the companies reviewed, it has the lowest revenue at risk should the external costs of air pollution become internalized through environmental legislation or other mechanism. It is also associated with the lowest impact intensity per metric ton of clinker **(Figure 14)**.

FIGURE 14: IMPACT RATIO (EXTERNAL COST OF AIR POLLUTION PER $M REVENUE) AND DISCLOSURE RATE



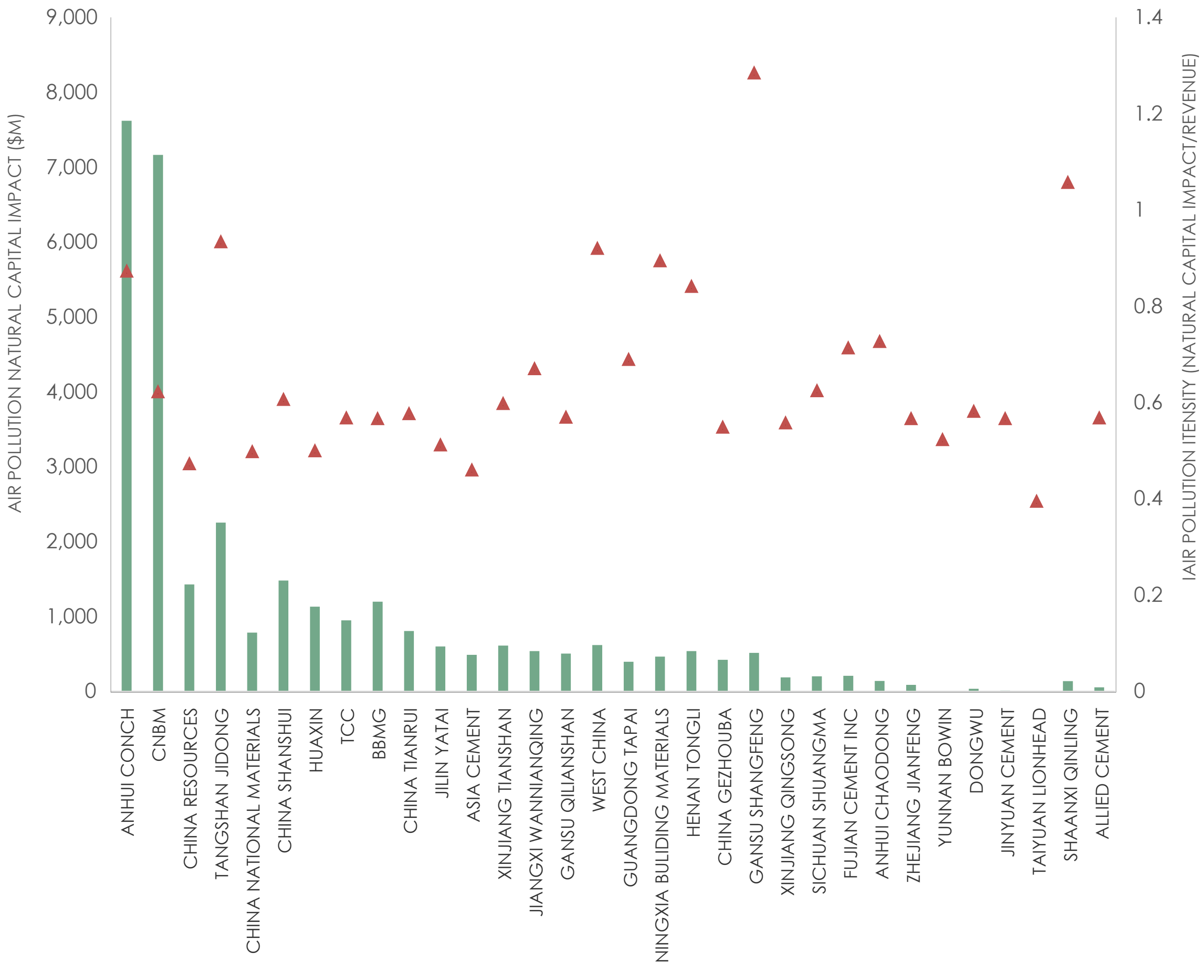
SOURCE: TRUCOST PLC 2015

Due to limited data disclosure across all companies, much of the air pollution quantification is based on modeled data allocated to each company based on clinker production, resulting in similar split of air pollution emissions. Overall, companies that performed better tended to be those that disclosed data on coal use, electricity use, waste heat recovery or actual emissions. However without providing environmental data, it is not possible to determine specific performance. Whilst this does not mean those companies perform better, it should serve as further incentive for these companies to monitor and report upon material environmental impacts, as it is likely that modeling their impacts may lead to overestimation.

Finding 7: It is important to differentiate between external cost in absolute and in relative terms. Absolute costs are a function of cement production, whilst relative intensities (external cost/$m revenue) provide a way of comparing the efficiency of individual companies.

The two largest cement manufacturers, Anhui Conch Cement Co Ltd (914-HK) and China National Building Material Company (3323-HK), produce almost 49% of the total clinker by all 32 companies reviewed. Figure 15 shows that while both companies are responsible for the largest external cost of air pollution in absolute terms (combined impacts represent 47% of the total of all companies' external cost), the intensity of production (external cost of air pollution per $m revenue) is higher for Anhui Conch Cement Co Ltd. China National Building Material Company has 62% of its revenue at risk should the air pollution external costs become internalized. This is 5% lower than the average intensity experienced within the sector.

FIGURE 15: TOTAL EXTERNAL COST OF AIR POLLUTION AND INTENSITY

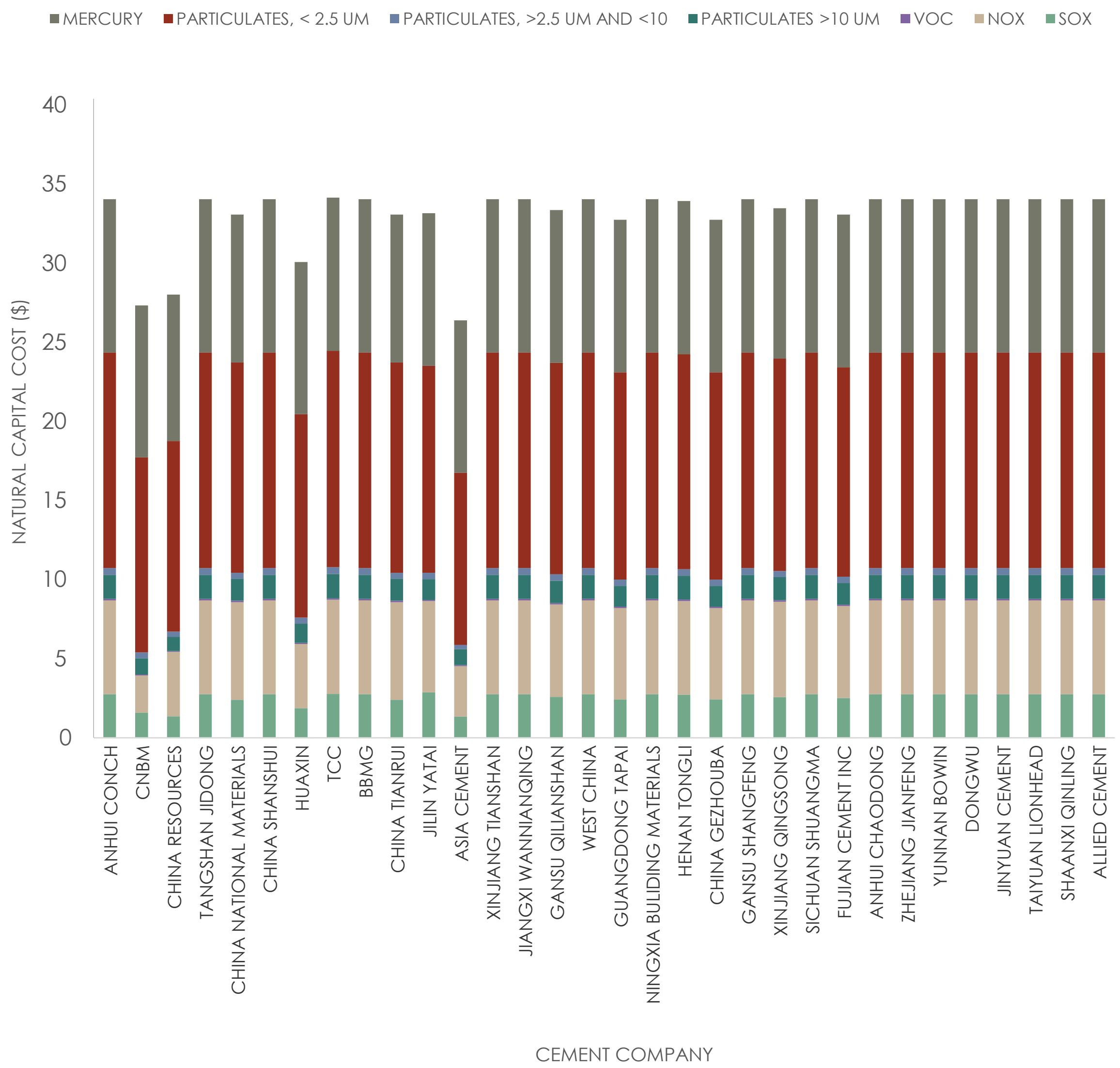


SOURCE: TRUCOST PLC 2015

Absolute impacts are linked to the total clinker produced by a company, with the majority impact associated with direct operational activity. Figure 16 normalizes this in air pollution impact per metric ton of clinker.

The variation in impacts per metric ton of clinker produced is related to the use of different kiln types. In the absence of company disclosure on kiln types, the average percentage split of different kilns used in China was applied to the company's clinker production. Three of the 32 companies reported that they only use precalciner kilns at their sites. China Resources Cement Holdings Ltd (1313-HK) has the lowest air pollution impact per metric ton of clinker from all the companies at an average of $28 per metric ton (RMB 174) (Figure 16), owing to its precalciner kilns, as well as a reported waste heat recovery replacing 1.8 million MWh of electricity use. The fact that this company ranks amongst the lowest emitters does not necessarily mean that it is a better performer overall because the most other companies are largely modeled. However, it does serve as an incentive for better disclosure across the board.

FIGURE 16: DIRECT AIR POLLUTION IMPACT PER TON CLINKER



SOURCE: TRUCOST PLC 2015

The predominant kiln type used within China is the precalciner rotary kiln, representing over 90% of kiln activity in the cement sector (Xu, et al, 2011). If the 32 companies all used precalciner kilns their total external cost would be reduced by $707m (RMB 4,380 million), or 3% of overall impact. If all companies performed at the level of best practice identified within the group, a total of $3,320m (RMB 20,590m) of external cost could be avoided, or almost 13% reduction.

3. MITIGATING THE RISK: RECOMMENDATIONS FOR INVESTORS, POLICY MAKERS AND COMPANIES

Section 1 provides investors, companies and policy makers with an overview of the business risks posed by the cement sector's growing environmental impacts. Section 2 lays out a framework for evaluating environmental risks specific to the cement sector, and provides data on the performance of 32 publically listed cement companies in China. SECTION 3 PROVIDES INVESTORS, CEMENT COMPANIES AND POLICY MAKERS WITH RECOMMENDATIONS TO IMPROVING ENVIRONMENTAL RISK ANALYSIS AND MANAGEMENT IN THE CEMENT SECTOR IN CHINA.

3.1 THE IMPORTANCE OF COMPREHENSIVE DATA DISCLOSURE

"The negative social and environmental impacts of companies' operations present material costs to investors, companies, and society that are not currently accounted for in a company's financial reporting."

(Sustainability Accounting Standards Board, 2015)

"Institutional Investors say businesses need to provide them with non-financial information that better outlines measurable risks to the company's performance or risk losing their potential investment."

(EY, 2015)

The disclosure of material sustainability information is important to investors, companies, regulators and the public for a number of reasons. The negative social and environmental impacts of companies' operations increasingly present material costs to a wide range of stakeholders but are not currently accounted for in a company's financial reporting (SASB, 2015). Disclosure of environmental impact allows communication of company performance, and in turn enables the assessment of risk of internalization of external costs. Investors also need context to help them understand to what extent reported financial information is indicative of future performance (SASB, 2015).

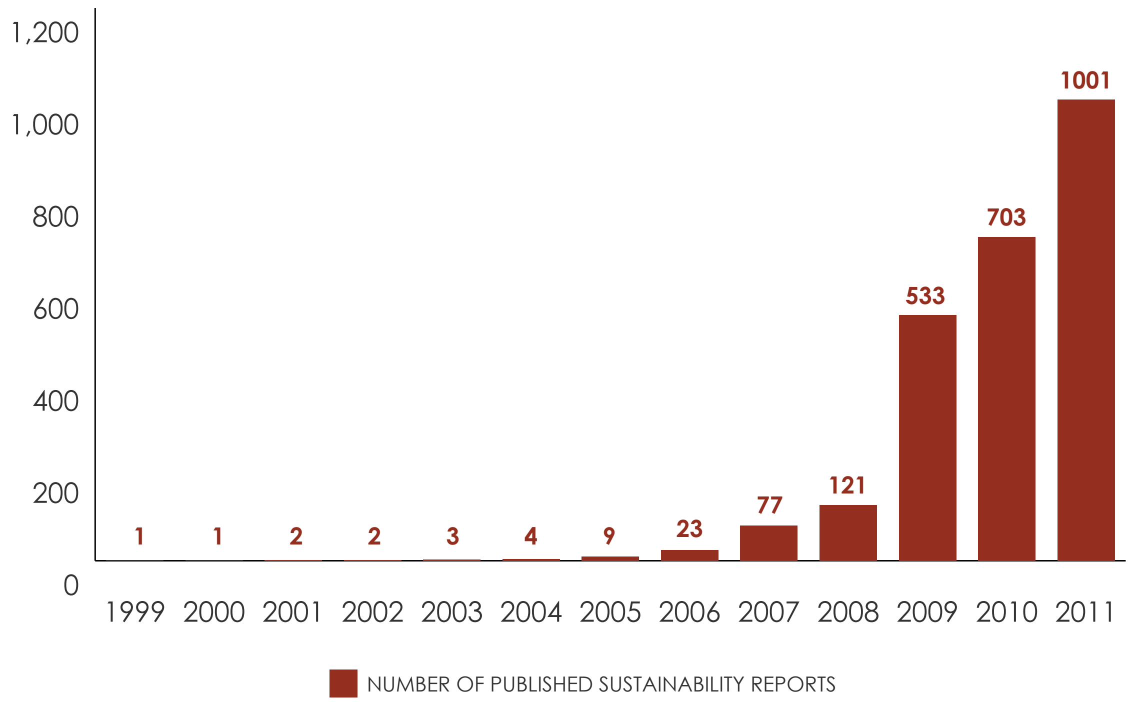
Investor demand for mandatory environmental and social disclosure is pushing ESG reporting into the mainstream. Seventeen countries already require some form of corporate sustainability disclosure (Ceres, 2014). A recent survey by the CFA institute found that almost three quarters of investment professionals use environmental, social and governance information when making investment decisions (CFA Institute, 2015). Of those, 38% said ESG performance is a proxy for management quality. A further 63% of survey respondents consider ESG in the investment decision-making process to help manage investment risks.

In a global institutional investor survey "Investment Rules 2.0", EY found clear evidence of growing investor reliance on non-financial information to draw conclusions on value and better inform and underpin their decisions (EY, 2015). At the same time, EY found that nearly two-thirds of investors are facing a deficit of the quality and type of non-financial information they want.

An ongoing letter campaign organized by the Principles for Responsible Investment (PRI), Ceres, and the UNEP-Finance Initiative (UNEP-FI) requests that the International Organization of Securities Commissions (IOSCO) work closely with regulators, stock exchanges, and other related parties to improve the disclosure of ESG information in the global marketplace. The campaign suggests that IOSCO take action in a variety of ways in order to bring about more consistent disclosure rules, develop accountability mechanisms, and help issuers and capital market influencers better understand the benefits of ESG disclosure.

In China, despite the increasing number of sustainable investments made globally, the concept of Socially Responsible Investing (SRI) has only been around for about a decade, due to growing concerns surrounding China's environmental crises and labor issues. In order to promote sustainability reporting, Government initiatives such as the Green Security Policy proposed by CSRC and MEP have significantly influenced the progression in CSR reporting. For example, from 2007 onwards the amount of sustainability reporting has increased significantly compared to earlier years (SynTao Sustainability Solutions, 2011). This is an implication of mandatory imposition from government (for example Green Security Policy) and stock exchanges initiatives (for example Shanghai and Shenzhen Stock Exchanges guidelines for sustainability reporting) which came into existence from 2006.

FIGURE 17: TREND OF SUSTAINABILITY REPORTING IN CHINA

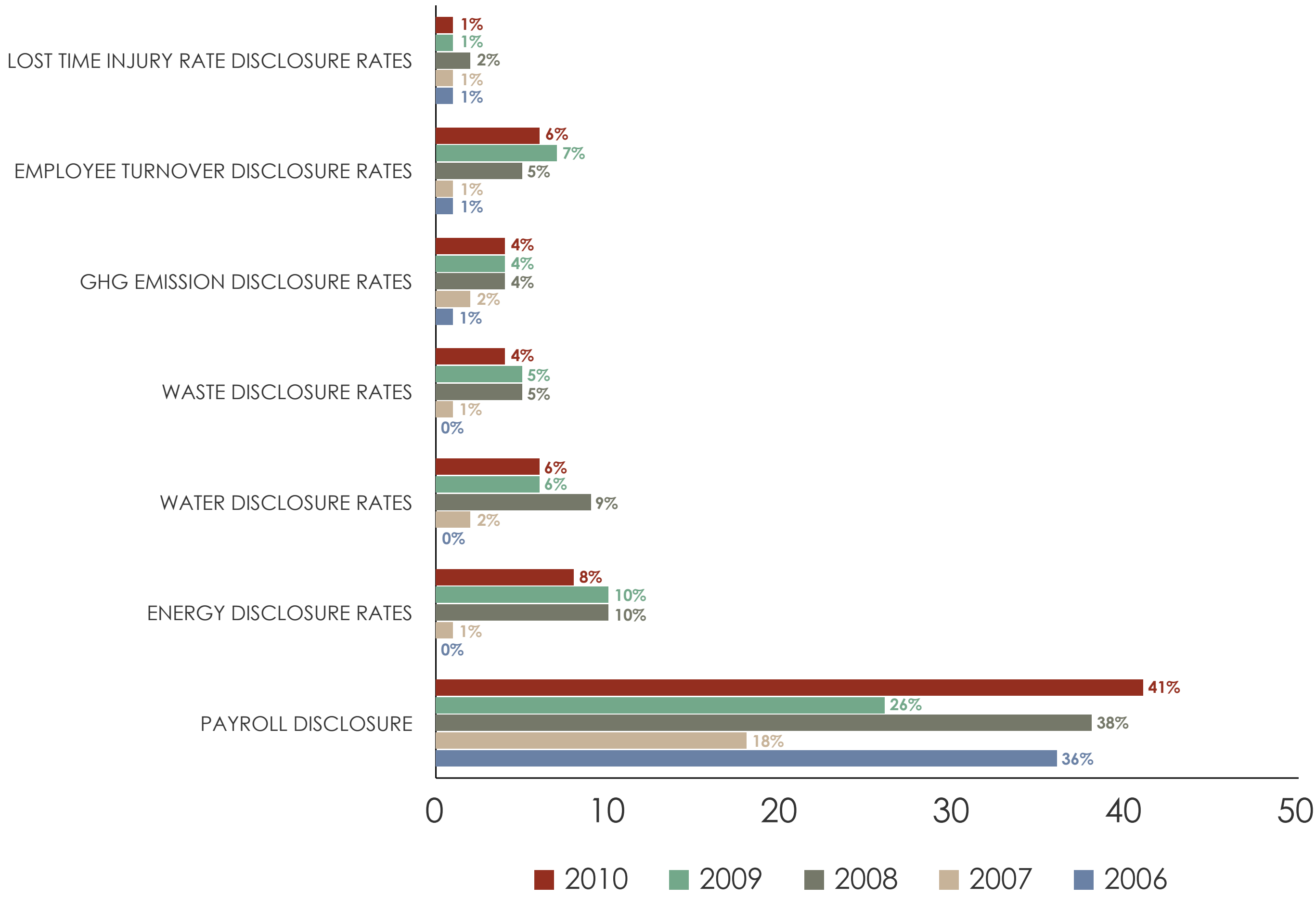


SOURCE: SYNTAO SUSTAINBILITY SOLUTIONS 2011

The Shanghai and Shenzhen stock exchanges already have mandatory guidelines for listed companies regarding public disclosure. An increasing trend has been observed for sustainability reporting amongst the listed companies from these stock exchanges from 2009. Most recently, the Hong Kong Stock Exchange, where 10 companies assessed in this study are listed, has adopted the key principles of the United Nations Principles for Responsible Investment (UNPRI) as part of its Investment Policy and Guidelines, and proposed to move ESG reporting to 'comply or explain' by the end of 2015.

However, mandatory guidelines do not as yet translate into comprehensive reporting. Research on disclosure rates in China by mid, large and mega- capitalisation listed on Chinese composite exchange shows that percentage disclosure for environmental indicators such as GHG emissions, waste generation, water consumption and energy consumption were negligible for 2006-07 period with some increases from 2008-10 (Aviva Investors, 2012) (Figure 18). However, this is comparatively less than that for the payroll disclosure rate. Though companies trading on Chinese exchanges such as the Shanghai Stock Exchange do not usually make the top headlines in terms of sustainability reporting and performance, the strong supervisory presence of the central government and the predominance of state-owned companies on such exchanges is expected to play a role in a fast turnaround for sustainability disclosure.

FIGURE 18: DISCLOSURE OF FIRST GENERATION SUSTAINABILITY INDICATORS FROM CHINESE STOCK EXCHANGES



SOURCE: AVIVA INVESTORS 2012

Significantly higher rates of disclosure at an average of 85% are evidenced with three of the largest Western cement manufacturers – Holcim, Lafarge and Cemex – compared to their Chinese counterparts (Figure 19). As with Figure 13, the disclosure rates are color coded whereby the companies with highest rates are colored dark green, across the scale to red used to represent 0 data points apparent. The companies note that these high levels are underpinned by substantial investments. For example, in its 2014 Sustainable Development Report, CEMEX noted that collecting and analyzing relevant emissions to meet US Environmental Protection Agency National Emission Standards for Hazardous Air Pollutants (NESHAP) for existing, new or reconstructed cement kilns in the US has come at a total investment of approximately $155m (Cemex, 2014). As a by-product of its response to the NESHAP regulations the company has however also adopted a cost-effective implementation strategy for reducing emissions for each CEMEX US kiln. This has direct implications for investors who, by supporting companies in improving measurement and management rates, benefit from reduced exposure to internalization risk.

FIGURE 19: DIRECT AIR POLLUTION IMPACT PER TON CLINKER

	GENERAL INFORMATION				ENERGY CONSUMPTION			WATER	GHG	AIR POLLUTANTS					
	CEMENT (TONNES)	CLINKER (TONNES)	CLINKER TO CEMENT RATIO	KILN TYPE	COAL CONSUMPTION	ELECTRICITY CONSUMPTION	"ENERGY RECOVERY (WASTE HEAT)"	WATER CONSUMPTION	GHG	NO_x	SO_2	VOCS	PM	MERCURY TO AIR	SUMMARY OF DATA POINTS DISCLOSED PER COMPANY
Holcim															93%
Lafarge															93%
Cemex															71%
Asia Cement															57%
CNBM															50%
China Resources															29%
Huaxin															21%
Jilin Yatai															21%
Guangdong Tapai															21%
Henan Tongli															21%
Fujian Cement Inc															21%
Dongwu															21%
Anhui Conch															14%
Tangshan Jidong															14%
China National Materials															14%
TCC															14%
Jiangxi Wannianqing															14%
Gansu Qilianshan															14%
Ningxia Buliding Materials															14%
China Tianrui															7%
Xinjiang Tianshan															7%
West China															7%
China Gezhouba															7%
Gansu Shangfeng															7%
Xinjiang Qingsong															7%
Sichuan Shuangma															7%
Yunnan Bowin															7%
Taiyuan Lionhead															7%
Shaanxi Qinling															7%
China Shanshui															0%
BBMG															0%
Anhui Chaodong															0%
Zhejiang Jianfeng															0%
Jinyuan Cement															0%
Allied Cement															0%

SOURCE: TRUCOST PLC 2015

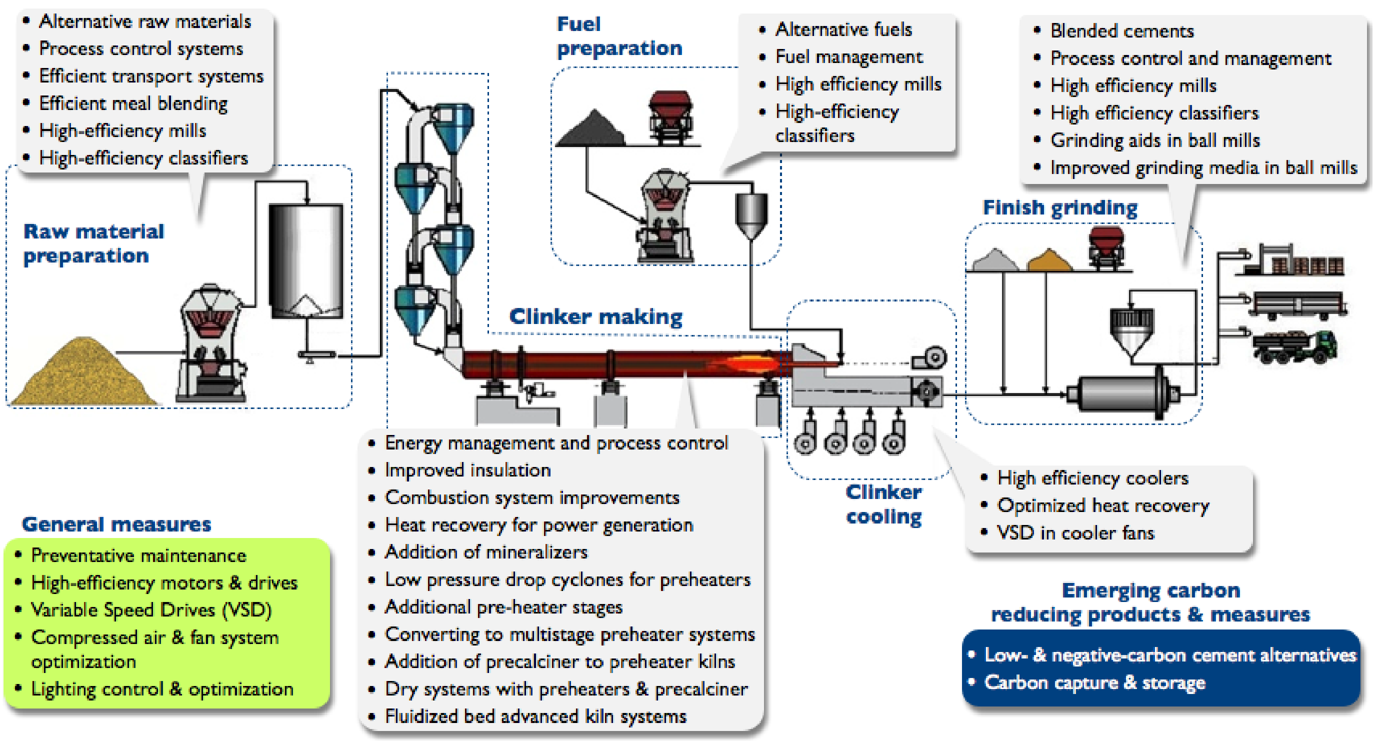
3.2 BEST PRACTICE POTENTIAL

Globally, technological advances have significantly decreased the environmental impacts of cement production, through efficiency improvements, use of cleaner fuels and abatement of air pollutants leading to lower impacts of production. However, there is still a huge opportunity for development. It is estimated that if all plants (globally) operating in 2012 were upgraded to best available technology, the global intensity of cement production could be reduced by 1.1 GJ/t of cement from an intensity of 3.5 GJ/t of cement (IEA, 2012), equivalent to a reduction of $9.3 (RMB 58) in external costs per metric ton of cement.

In China, cement companies remain less energy efficient than their Western counterparts and cause more stress on the local environment. The sector lags behind the rest of the world on its implementation of sustainable production techniques including the use of renewable energy (coal is the main fuel), energy efficient techniques (average energy consumption of new dry process kiln production lines in China is 15-25% higher than the international average), and substitution of clinker for efficient alternatives such as fly ash.

Clinker production is the most intensive process within cement production, and a range of technologies and mechanisms exist to improve practices (Figure 20). The following section focuses on some examples of good practices that could be implemented by the cement sector in China. More detailed technical specifications of opportunities are outlined in the Appendices.

FIGURE 20: SCHEMATIC OF BEST PRACTICE OPPORTUNITIES WITHIN CEMENT PRODUCTION



SOURCE: INDUSTRY EFFICIENCY TECHNOLOGY DATABASE 2015

Best available technologies often focus on GHG emissions, but many of these technologies are equally effective at reducing air pollutants. Energy efficiency and alternative fuels in particular offer alternatives to reliance on combustion of fossil fuels.

3.2.1 THERMAL AND ELECTRICAL EFFICIENCY

There is a vast range of thermal efficiencies and emissions profiles in cement kilns. Wet kilns are the least efficient with highest levels of energy consumption and air pollution. Best available technology includes precalciner kilns, which use multi-stage preheaters and precalciners to preprocess raw materials before they enter the kiln, and an air-quench system to cool the clinker product. Kiln exhaust streams from the clinker cooler and the kiln preheater system, contain useful thermal energy that can be converted into power and used onsite to reduce electricity requirements (IFC, 2014).

In China, over 90% of kilns are precalciner kilns, though opportunity exists to both upgrade older kilns and increase the use of waste heat recovery technology. Outdated technologies should be phased out because of low efficiency as such plants are commonly heavy polluters and the quality of the cement produced is often inferior (WWF, 2008).

Operational efficiency is also important, and machinery must be operated effectively and maintained correctly to ensure that the maximum potential savings are achieved. Though hard to measure, this is an important aspect of emissions management (WBCSD, 2009).

In addition to kilns, other equipment can also be upgraded to achieve better performance. The European cement industry cites installing state-of-the-art automation, process control technology and auxiliary equipment among the reasons for its 8% improvement in GHG emissions (Cembureau, 2013).

3.2.2 ALTERNATIVE FUELS

A wide range of waste materials can be used as fuel to replace coal, the dominant fuel source for the cement sector in China. In addition to reducing emissions to air from fossil fuel combustion and displacing waste to landfill, there is a financial benefit as waste materials can often be sourced for free, or for much lower cost than energy equivalent in coal.

Across the world, the use of alternative fuels ranges from 0% to 70% of total fuel requirements. Countries with better developed environmental legislation, law enforcement, waste collection and management practices tend to have higher use of alternative fuels (WBCSD, 2009). The benefits of using waste materials in place of coal are numerous. In China, cement plants are sometimes paid to receive the waste (Murray & Price, 2008).

CASE STUDY: HOLCIM ALTERNATIVE FUELS

Aware of the issues inherent in cement production, Holcim has reduced emissions per ton of product since 1990 by reducing the amount of clinker in cement through the use of carbon neutral components, the implementation of energy efficiency improvements and the use of innovative waste fuels to replace fossil fuels.

The company has created its own waste management brand, Geocycle, to collect refuse-derived fuel for generation of energy. Geocycle Asia collects waste from communities and industries within the region. These are then incinerated within the cement kilns at temperatures of up to 2,000 degrees Celsius, which is high enough to completely destroy any organic compounds and safely recycle inorganic compounds into clinker chemistry. The process works equally well for liquid waste, such as solvents or sludge from waste water plants, as it does with solid waste, such as plastics and rubber. Known as co-processing, this practice has a dual benefit of reducing reliance on fossil fuels and reducing waste which may otherwise be disposed at landfill or incinerated in a less efficient manner.

In India, a Holcim Group company Ambuja Cements Ltd (ACL) is working with local farmers to secure agricultural waste for input into its kilns, creating an additional revenue stream for farmers and reducing methane emissions associated with the organic decomposition of agricultural waste. This offers real business benefits to ACL by securing a future fuel source that is cheaper and less vulnerable to price fluctuation and security concerns.

3.2.3 AIR POLLUTANT ABATEMENT

Clinker production is the most impactful stage of cement production and the primary focus for any air pollutant abatement technology. Technologies to reduce PM include electrostatic precipitators and bag filters, which also reduce mercury emissions (Cemburau, 1997). NO_x and SO_2 emissions tend to be reduced as a by-product of Optimization of the Clinker Burning Process (OCBP), whose primary target is to reduce heat consumption, improve clinker quality and increase the lifetime of equipment. NO_x specifically can be tackled via the use of expert systems for kiln operations and low-NO_x burners, amongst others. Mercury, in particular, can be targeted by reducing the amount of mercury in the raw materials and fuels, although this is very difficult to accomplish. The best available technologies for reducing emissions at different stages of the cement manufacturing process are summarized in the Appendices.

The applicability of these technologies is site specific and requires a careful assessment of associated costs and benefits. For existing plants it can be more costly due to the replacement of equipment. Supplementing this analysis with the monetized external cost reductions adds an extra layer of analysis allowing decision-makers to maximize the financial as well as the environmental return on investment. Overall however air pollution can be approached from three different angles (Cembureau, 1997).

- Reducing inputs of precursors in the system to reduce precursor formation in the process. For example reducing mercury content in the raw material feed of the kiln will reduce the amount of mercury released in the form of vapor and particulates.
- Primary or integrated reduction measures based on modifying the manufacturing process. For example, optimizing clinker burning reduces flame and burning temperatures which result in reduced fuel consumption and reduced NO_x and SO_2 emissions. These measures are more challenging to implement as they may require trial and error to get optimized results but usually involve lesser costs than other abatement technologies. Usually it is also difficult to quantify reduction achieved with these measures.
- Secondary reduction measures are the most popular abatement measures as they are easier to implement, but are most costly. These measures use end point emission abatement where no modification is required in the process but a secondary cleaning unit applied in the exhaust gas. Although very high efficiency can be achieved using these measures, in most cases the limiting factor is high capital and operational costs.

CASE STUDY: LAFARGE MERCURY EMISSION REDUCTION

Lafarge, one of the world's leading cement manufacturers, has demonstrated several good practice activities to help reduce its environmental footprint. In order to achieve its challenging 'Sustainability Ambitions 2020', Lafarge has improved material and fuel sourcing, onsite processing techniques, and has invested in improved technologies to reduce air pollutants.

Mercury emissions are a highly damaging output of the cement industry. Lafarge has set itself a target of 30% reduction in mercury emissions per metric ton of clinker (the key base component of cement) by 2020 based on a 2010 baseline. Mercury is often found within the key raw materials required for cement production, so processing of the element is unavoidable. Improved procurement of raw materials and fuel achieved an initial 1% reduction of mercury emissions, but technological development was required to increase this further. Lafarge installed mercury abatement systems utilizing carbon injection technologies in two plants in 2013, which resulted in a ten-fold reduction of mercury emissions by year-end.

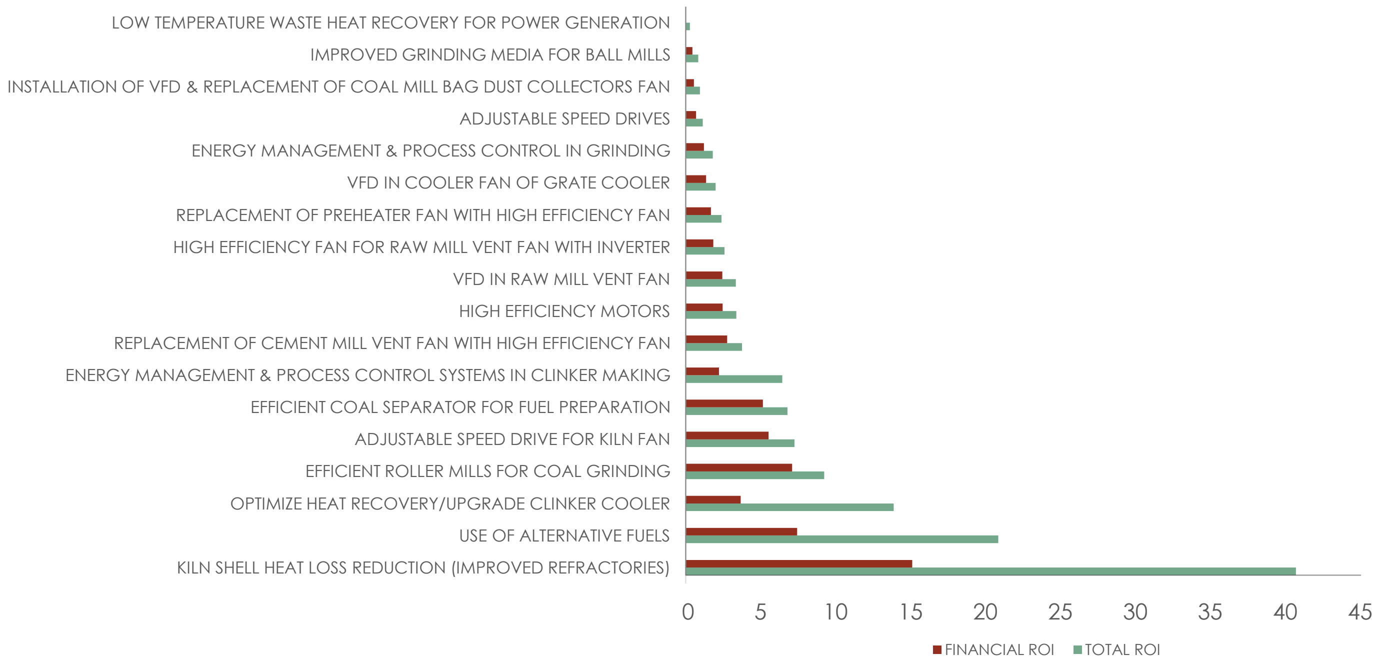
Lafarge has been able to communicate its improvements through its sustainability reporting and the Carbon Disclosure Project, highlighting its progress towards becoming a more sustainable manufacturer. It achieved a CDP score of 96/100 and was included in the Carbon Disclosure Leadership Index for France, showing its customers and investors the value of its achievements.

3.2.4 MONETIZING BEST PRACTICE POTENTIAL

A comprehensive review of energy efficiency improvements to NSP kiln cement plants in the Shandong Province in China identified 34 technologies and measures that offered reduction in fuel or electricity use compared to typically installed, lower efficiency technologies or measures in the cement making process (Price et al, 2009). Using their capital expenditure per metric ton of clinker and operational and maintenance cost changes throughout the lifetime of the technology, the review identifies 13 cost effective electricity-saving technologies and 6 cost-effective fuel saving technologies and measures that have not yet been fully adopted in the 16 surveyed cement plants in Shandong Province. The electricity-saving technologies all relate to improving the efficiency of motors and fans, fuel preparation and finish grinding, whilst the fuel saving include expanding the use of blended and limestone Portland cement and using alternative fuels in the cement kiln.

Despite their apparent cost-effectiveness, various reasons for non-adoption of these technologies were identified by the research, including age of the plant, overall staff knowledge and awareness of the existence of the technology, investor preferences and high initial capital costs despite the fact the payback period of the technology is short. Overlaying these measures with their associated monetized external cost savings adds an extra layer of analysis allowing decision-makers to maximize the financial as well as the environmental return on investment. It can also help build the case for prioritizing cement industry improvements.[2]

FIGURE 21: ANALYSIS OF AIR POLLUTION REDUCTION THROUGH ELECTRICITY- AND FUEL-EFFICIENCY OPPORTUNITIES IN THE CHINESE CEMENT INDUSTRY, PER METRIC TON CLINKER



SOURCE: ADAPTED FROM PRICE ET AL. 2009

[2] Conversion from RMB to $ was made at the 2009 rate of 6.84, given in the report. Capex costs were inflated to 2013 prices based on CPI

The analysis shows that the three investments with the largest overall returns (when both financial and external cost savings are taken into account) can be realized from fuel-saving measures. These are improved refractories, use of alternative fuels, and optimized heat recovery, which respectively deliver $41, $21 and $14 in overall returns per $1 investment.

The most cost effective fuel efficiency technology overall is to use better insulating refractories to reduce the heat losses through the shell of the kiln, where a fuel saving of 0.26GJ/ton clinker is alone associated with a $25 external cost return per $1 investment, equivalent to 61% of total return. The use of improved kiln-refractories may increase the reliability of the kiln and reduce downtime, which in turn reduces production costs and the energy needs during start-ups (Price et al, 2009).

Next, alternative or waste fuels can substitute traditional commercial fuels in a cement kiln and deliver $12 in external cost returns per $1 investment (61% of total returns). Improving heat recovery efficiency in the clinker cooler, which drops the clinker temperature from 1200°C down to 100°C, results in fuel savings that generate $9 in environmental ROI, or 69% of total returns. From an electricity-saving perspective, the greatest returns at $9 overall are generated by the adoption of efficient roller mills for coal grinding. Coal is widely used in the Chinese cement industry and is often prepared onsite, including crushing, grinding and drying. Roller mills can generally handle a higher throughput of coal, and though they involve a larger upfront investment, the operational costs can be up to 50% less than other mill types (Cembureau, 1997). Further opportunities exist within fuel and electricity-reduction technologies, and these are detailed in the Appendices.

The highest overall return on investment is achieved through product related measures such as the use of blended cement, which delivers $110 per $1 investment (63% of which are environmental returns). Using waste materials to create blended cements not only diverts waste to a high value application, but also creates cements that demonstrate higher long-term strength, as well as improved resistance to acids and sulfates. Their use is a particularly attractive efficiency option since the integration of clinker with other additives not only allows for a reduction in the energy used, but also limited capital costs usually related to extra storage capacity for the additives. The operational cost savings will depend on the purchase (including transport) costs of the additives, the increased electricity costs for (finer) grinding, the reduced fuel costs for clinker production and electricity costs for raw material grinding and kiln drives, as well as the reduced handling and mining costs.

3.3 IMPLICATIONS FOR INVESTORS

China needs to urgently transition toward a green and sustainable growth model. This was recognized in the Third Plenum of the 18th National Congress of the Communist Party of China, which calls for the establishment of 'a systematic and full-fledged institutional system of ecological civilization for the protection of the eco-environment' and 'a market-based mechanism that channels private capital investments to the protection of the eco-environment' (Green Finance Task Force, 2015).

The country's strategic decision to move away from a high pollution and high resource intensive economy and build an 'eco-civilization' will clearly have implications both for existing assets, as well as the trajectory of future capital investment (Caldecott and Robins, 2014). The shift is already well underway in China stemming from a serious concern over air pollution, a desire to reduce greenhouse gas emissions, and to reduce exposure to volatile international commodity markets. This has resulted in the massive deployment of non-fossil energy driven by new policy frameworks, falling technology costs, and the emergence of carbon pricing – trends which are set to grow. Increasing water scarcity could also adversely impact polluting sectors.

In order to fully implement a working green finance system and to mobilize private capital however, investors need quantitative tools to better inform investment decisions. One of many signs of progress is that a significant number of new industry bodies providing guidance have been established, including standards boards, councils, and various coalitions between industry, regulators, and international organizations. Investors are already implementing a range of responses to environment-related risks, but most fall into what can be understood as very preliminary risk assessments (Caldecott and Robins, 2014). For example, a standard progression of 'assessment/transparency/management' can be seen in the responses of financial stakeholders, but many are only taking initial steps towards proactively managing environment-related risks. Key mechanisms include stress testing, risk analysis, risk disclosure, and integrated reporting.

For financial institutions, identifying and pricing environment-related risks will improve risk management and hedging, potentially improving system resilience as well as portfolio performance (Caldecott and Robins, 2015). The analysis presented in this report has developed a framework to analyze environmental risks facing cement companies in China. It has qualitatively assessed the likelihood and severity of internalization risk, identified air pollution as a highly material risk facing companies, and used air pollution key performance indicators (KPIs) as the main elements to construct this assessment framework. Ultimately, it has demonstrated the usefulness of monetization of external impact as a comprehensive tool to assist investors with:

- Assessing the magnitude of the financial risks faced by companies
- Translating environmental impact into the language of business and economics
- Enabling the comparison between different types of impacts which are not normally comparable
- Facilitating comparison between companies

Continuously monitoring the evolution of external costs alongside the progression of internalization drivers provides a solid framework for investment appraisal. NO_x, SO_2 and particulate matter released during cement production are the pollutants of main concern. However, the actual emission factors per metric ton production depend on the emission abatement control deployed by the company. Investing in best available technologies considerably reduces these emissions.

As a result of applying a monetization framework, investors can use the results to inform setting higher risk premiums for assets more exposed to environment-related risks, this has the added benefit of shifting capital allocations away from sectors that could be considered environmentally unsustainable, and towards assets more aligned with China's vision for a cleaner and more sustainable economy. Table 4 provides a summary of possible responses by different stakeholders in the investment value chain.

TABLE 4: SUMMARY OF POSSIBLE INVESTOR RESPONSES

RELEVANT STAKEHOLDERS	POSSIBLE RESPONSES AS A RESULT OF EXTERNAL COST ANALYSIS
Fixed income investors	• Reassess required yields • Divest if necessary • Invest in green bonds
Ratings agencies	• Reassess company ratings
Equity investors	• Reassess required returns • Demand that management reduce environmental and regulatory risks • Divest if necessary
Bank loan assessments	• Reassess lending rates • Resell risky loans

3.4 IMPLICATIONS FOR COMPANIES AND POLICY MAKERS

Mobilizing the investments required to achieve national environmental goals depends on the successful establishment of a green finance system. It is estimated that achieving national environmental goals during the forthcoming 13th Five-Year Plan (2016-20) period will require an annual investment of at least US$320bn (RMB 2tn) into environmental protection, energy efficiency, clean energy, and clean transportation (Green Finance Task Force, 2015). China's cement sector in particular is estimated to require at least $45bn (RMB 280bn) of investment to undergo a green transformation in line with its broader targets (Rock, 2008). Given that the growth rates of government expenditure and fiscal revenue have both declined in recent years, the government can only be expected to contribute around 10-15% of all green investment, while private capital will need to contribute the remaining 85-90%. A better understanding of the materiality of environment-related risks and the levels of exposure in different parts of the financial system will also help regulators manage scenarios that could result in financial instability.

Equally, environment-related risks including the risk from asset stranding increasingly impact company strategy and the long-term viability of business models. Surveying more than 200 institutional investors about their views on non-financial information that better outlines measurable risks to company performance, EY found concerns over the potential impacts of stranded assets are on the rise. More than one-third of respondents actually took steps to reduce exposure in the last year (EY, 2015). Driven by social pressures, China has pledged to reduce pollution, limit carbon emissions, save scarce water and penalize companies that step out of line. Such plans could spell a surge in costs for some listed cement state-owned enterprises, which historically pay three times more in environmental penalties than their private sector counterparts, according to MSCI research (FT, 2015). Another source of rising costs for Chinese listed companies is likely to come from pressures to comply with carbon emissions standards, which are expected to force companies to invest in a range of mitigation technologies and abide by reduction regulations — or be fined.

As a result, firms that are able to manage growing environment related risks in a better way to secure a competitive edge over their peers. Monetization of external cost is a valuable tool to assist companies in their prioritization of limited resources available to manage the highest impact issues. EY'S 2015 institutional investors survey also found that investors are increasingly enthusiastic about the benefits of integrated reports, with a vast majority indicating they are "essential" or "important" (EY, 2015). The use of monetization of external cost in integrated reports was pioneered by cement company Holcim in 2014 (Holcim, 2014). In addition, those companies managing their external costs and disclosing this information may also benefit from better access to capital at a lower cost.

CASE STUDY: HOLCIM INTEGRATED PROFIT AND LOSS STATEMENT 2014

"We have to combine the financial and quantified externality data that can help us measure the value a company creates holistically. We also need data about the value we create, as the future belongs to those industries that can anticipate resource depletion and take corrective action. The business community must assess how much value it creates, as a measurement-led approach to sustainability will be the cornerstone of all businesses in the future."

Ajay Ambuja, CEO Ambuja Cements Ltd, India

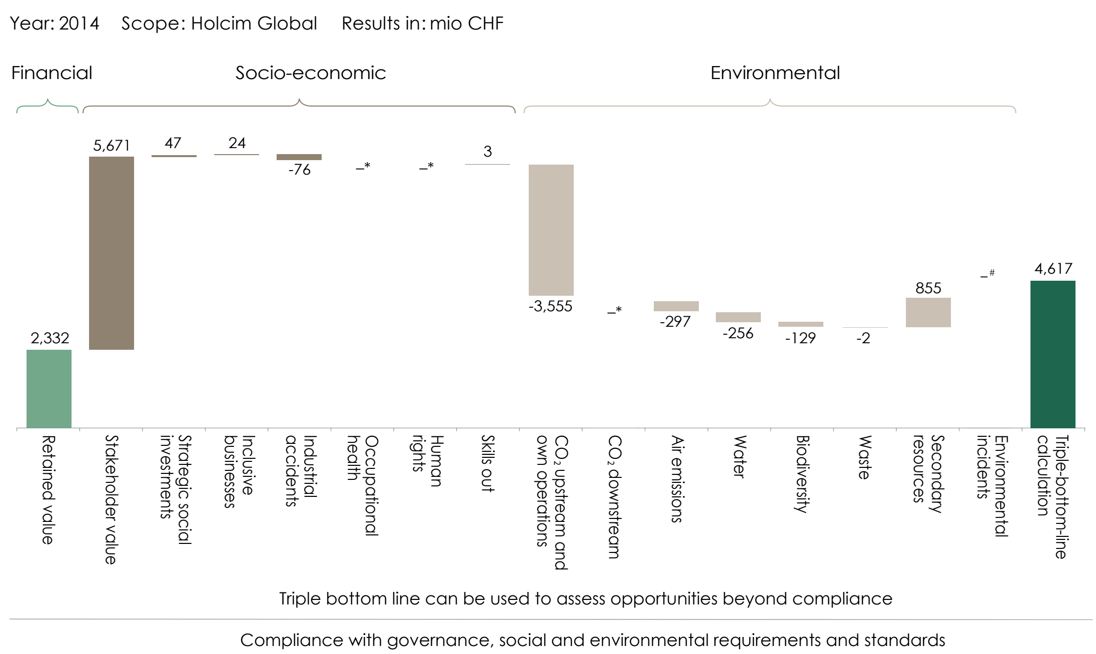
Holcim's pioneering integrated profit and loss (IPL) statement was published in 2014 with the aim of focusing efforts on maximizing Holcim's financial, socio-economic and environmental value creation. This was achieved through a quantification and monetization tool, raising awareness of the risks and opportunities posed by externalities and enabling decision-makers to compare options under different scenarios.

The IPL was initially piloted in 2013 by Ambuja Cements (ACL), a group company in India, estimating the positive and negative impacts of specific areas, such as water use and rainwater harvesting, carbon and other emissions, the use of alternative fuels and raw materials, and the estimated economic value added to society. The tool was used to identify where 1 US dollar invested would bring the highest societal return. The study specifically demonstrated that ACL could profitably maximize its "true value" by focusing its resources on reducing carbon emissions, water and further expanding its social engagements. With the increasing focus on "integrated reporting," the 2014 Group-wide IPL provides a basis for a discourse on how the company's resources and activities are impacting value. It is intended to allow businesses to think holistically about their strategy and plans, make informed decisions and manage key risks to build investor and stakeholder confidence and improve future performance.

The IPL confirmed that Holcim's overall value to society, taking into account the monetized impacts in the socio-economic and environmental domains, is significantly higher than the financial retained earnings of the company. Quantification methods used include a variety of sources, such as The Economics of Ecosystems and Biodiversity (TEEB) for natural capital accounting and the Social Return On Investment (SROI) Network for social impact analysis. The monetization coefficients for air pollutants in particular were retrieved from studies using the Impact Pathway Analysis to measure the relationship between the concentration of a pollutant and its impacts on affected receptors (social and environmental) and monetize the damages. This study is based on global assumptions, using global averages for emission factors, without taking into account the varied dispersion of air pollutants, differences in ambient air pollution levels or local specific factors.

In a 2015 briefing note on the topic Verdantix, an independent research and consulting firm, notes that Holcim's IPL experience demonstrated leaders in the sector should consider social and environmental profit and loss accounting to:

- Improve visibility of social and environmental impacts, both at firm-wide operations level or specific operating units, such as a regional subsidiary
- Identify risks through assessing the likelihood of internalization for each socio-environmental externality investigated in a range of scenarios
- Support the development of sustainability valuation frameworks such as the Natural Capital Protocol, a major private-sector collaboration to provide businesses with standardized tools and metrics to identify their impact on natural capital
- Complement existing reporting frameworks, such as the Global Reporting Initiative (GRI)
- Encourage a shift away from superficial 'social responsibility' initiatives towards performance-driven sustainability by focusing on material socio-environmental issues as part of goal-setting, decision-making and performance evaluation
- Demonstrate innovation in sustainability accounting and integrated reporting among mature sustainability leaders



* Not measured for 2014, but reflected, as we intend to measure in future IPLs. # No significant incidents in 2014.

SOURCE: HOLCIM 2014 - INTEGRATED PROFIT AND LOSS STATEMENT

GLOSSARY

TERM, ACRONYM OR ABBREVIATION	DESCRIPTION
Acidification	Changes in chemical composition of soil and surface water due to deposition of acidic chemical products of air pollutants like sulphur dioxide (SO_2), nitrogen oxides (NO_x) and ammonia.
Air-quench systems	A process used to rapidly cool clinker to improve quality of the product.
Bag filters	Air pollution control device used to reduce amount of particulates released in atmosphere from exhaust gas.
Calcination	Chemical process which leads to conversion at high temperatures of calcium carbonate (limestone, one of cement's key raw materials) into calcium oxides and carbon dioxide.
Carbon Disclosure Project (CDP)	An organisation based in the United Kingdom, which works with shareholders and corporations to disclose the greenhouse gas emissions of major corporations. CDP brings together institutional investors to focus attention on carbon emissions, energy usage and reduction – wherever companies and assets may be located.
Clinker	The final product of chemical transformations taking place in cement kiln. Raw materials like finely grounded limestone and clay is heated at temperature between 1400 - 1500 °C to form clinker.
Clinker ratio	Percentage of clinker compared to other non-clinker components in final cement composition. Reducing clinker amount in cement lowers direct environmental impacts during the clinker production stage, thereby reducing the indirect impact from virgin raw material requirement and impacts from mining and processing steps.
Co-processing	Process which is used in cement manufacturing for energy recovery and recycling of resources from waste materials. Mineral portion of the waste replaces virgin raw materials and energy content of waste replaces conventional fuel sources.
De-nitration	Removal of nitrogen compounds particularly NO_x from stream of exhaust gas.
Electrostatic precipitators	Air pollution control device used to separate particulates (especially of size below 10 micrometres) from a stream of exhaust gas. This works on the principle of applying charge to particles to separate them from main stream of gas and getting it deposited on oppositely charged electrodes.
ESG	Environmental, Social and Corporate Governance.
External cost of business (externality)	Costs of business activities borne by third parties who did not choose to incur them.
Fly ash	This is one of the residues generated by coal combustion. Fly ash is finely divided particles of ash entrained in flue gases resulting from the combustion of fuel.
Green finance / Socially responsible investing (SRI) / Sustainable investing	Investment strategies that shift capital flows towards entities that are best positioned to financially benefit from the long-term structural trends in the global economy, society and environment. A 'green finance system' in the Chinese context specifically refers to a series of policies, institutional arrangements and related infrastructure building that, through loans, private equity, issuance of bonds and stocks, insurance and other financial services, steer private funds toward green industry (Green Finance Task Force, 2015).
Input-output modelling or EEIO	Environmentally extended input-output model that maps the flow of inputs and environmental impacts through an economy.
Insulating refractories	Insulating materials which have chemical and physical properties to withstand exposure to very high temperatures.

TERM, ACRONYM OR ABBREVIATION	DESCRIPTION
Internalization driver	Market forces which can lead to privatization of the external cost to the creator e.g. carbon taxes leading to additional cost to companies releasing carbon dioxide.
Key performance indicators (KPIs)	Environmental impact categories for appraisal of the environmental performance of businesses, sectors and regions.
LCA	Life Cycle Analysis is a technique to assess the environmental aspects and potential impacts associated with the lifecycle of a product, process, or service, by compiling an inventory of relevant energy and material inputs and environmental releases and evaluating the potential environmental impacts associated with identified inputs and releases
Millennium Ecosystem Assessment	An initiative to access the consequences of ecosystem change on human wellbeing.
Monetization coefficient	Coefficients that translate physical measures in terms of metric tons of air pollutants emitted, or cubic meters of water used, into a monetary figure expressing the damage caused to the environment and society. In other words it is a representation of the potential value that companies would have to internalize if they were to become accountable for their impacts.
Natural capital	The finite stock of natural assets (air, water, land, habitats) from which goods and services flow to benefit society and the economy. It consists of ecosystems providing renewable resources and services, and non-renewable deposits of fossil fuels and minerals.
Precalciner rotary kilns	The most advanced rotary cement kilns which have additional unit “precalciner” where raw materials are heated before they are passed to main kilns. Precalciner rotary kilns are associated with the lowest external cost from air pollution emissions for all pollutant types except for $PM_{2.5}$.
Pyroprocessing	Chemical process taking place in kilns where raw material feed undergoes chemical transformation under high temperatures.
Stranded assets	Assets that have suffered from unanticipated or premature write-downs, devaluations, or conversion to liabilities and they can be caused by a variety of risks.
TEEB	The Economics of Ecosystems and Biodiversity (TEEB) is a global initiative focused on “making nature’s values visible”. Its principal objective is to mainstream the values of biodiversity and ecosystem services into decision-making at all levels. It aims to achieve this goal by following a structured approach to valuation that helps decision-makers recognize the wide range of benefits provided by ecosystems and biodiversity, demonstrate their values in economic terms and, where appropriate, suggest how to capture those values in decision-making
Waste heat recovery	Process which is used to recover heat from exhaust gases and surfaces with high temperatures. In case of cement manufacturing, gases released during chemical process are at high temperatures (250 °C to 400 °C) which can be used to generate electricity. Kilns based on latest technologies have designs which facilitate waste heat recovery.
Wet kilns	Early cement manufacturing kilns which used raw material feed in the form of slurry. These kilns are at a disadvantage as they requires a lot more energy for drying water used for mixing raw materials and require the kiln length to be much longer than dry kilns as more surface area is required for drying process.

REFERENCES

Ackerman, F., Stanton, E., 2010. The Social Cost of Carbon. Economics Review, 53. Stockholm Environment Institute, USA. Available at: http://www.paecon.net/PAEReview/issue53/AckermanStanton53.pdf

Ansar, A., Caldecott, B.L., and Tilbury, J. (2013) Stranded Assets and the Fossil Fuel Divestment Campaign: What does Divestment mean for the Valuation of Fossil Fuel Assets? Smith School of Enterprise and Environment, University of Oxford.

Argonne National Laboratory, (2012). Updated greenhouse gas and criteria air pollutant emission factors and their probability distribution functions for electric generating units , s.l.: Argonne National Laboratory .

Arrow, K., Revesz, R., Howard, P., Goulder, L., Kopp, R., Livermore, M., Oppenheimer, M., Sterner, T., 2014. Global warming: Improve Economic Models of Climate Change. Nature, comment. Available at: http://www.nature.com/news/global-warming-improve-economic-models-of-climate-change-1.14991

Asia Insurance Review, (2014). China: Air pollution costs the Chinese US$300 bln a year. 2 Apr 2014. Available at: http://www.asiainsurancereview.com/News/View-NewsLetter-Article?id=29820&Type=eDaily

Aviva Investors, 2012. Benchmarking the World's Composite Stock Exchanges, s.l.: s.n.

Bell, R., 2011. The "Social Cost of Carbon" and Climate Change Policy. World Resources Institute. Available at: http://www.wri.org/blog/2011/07/%E2%80%9Csocial-cost-carbon%E2%80%9D-and-climate-change-policy

Berkeley Energy & Resource Collaborative. (2014). China's 12th five -year plan: three years down, two to go. Available at: http://berc.berkeley.edu/china-12th-five-year-plan-three-years-two-go/

Bloomberg Business. (2014). China Smog at Center of Air Pollution Deaths Cited by WHO. Available at: http://www.bloomberg.com/news/articles/2014-03-25/tainted-air-kills-more-than-aids-diabetes-who-report-shows

Bloomberg Business. (2015). China's 'Inconvenient Truth' Yields Environment Billionaires. Available at: http://www.bloomberg.com/news/articles/2015-03-03/-under-the-dome-spawns-pollution-fighting-billionaires-in-china

BNP Paribas. (2014). Equities Research: APAC Environment Watch. For a cleaner sky: China strikes against emissions. 14 November 2014.

British Geological Survey, (2005). Cement Raw Materials. Available at: https://www.bgs.ac.uk/downloads/start.cfm?id=1408

Burtraw, D., Sterner, T., 2009. Climate Change Abatement: Not 'Stern' Enough? Available at: http://www.rff.org/Publications/WPC/Pages/09_04_06_Climate_Change_Abatement.aspx

Caldecott, B., Robins, N., (2014). Greening China's Financial Markets: The Risks and Opportunities of Stranded Assets. Available at: http://www.smithschool.ox.ac.uk/research-programmes/stranded-assets/Greening%20China's%20Financial%20Markets%20-%20Risks%20and%20Opportunities%20from%20Stranded%20Assets.pdf

Caldecott, B.L. and McDaniels, J. (2014). Financial dynamics of the environment: risks, impacts, and barriers to resilience. Working Paper Series, Smith School of Enterprise and Environment, University of Oxford.

Caldecott, B.L., Howarth, N. and McSharry, P. (2013) Stranded Assets in Agriculture: Protecting Value from Environment-Related Risks. Smith School of Enterprise and Environment, University of Oxford.

CAAC (Clean Air Alliance of China), (2014). Performance assessment measures for Air pollution prevention and control action plan. China Clean Air Updates, English Translation. Available at: http://www.cleanairchina.org/file/loadFile/62.html

CBMF. (2012). Statistical Analysis Report of Cement Production and Capacity 2011. China Cement, (3): pp.10- 12.

CCICED (China Council for International Cooperation on Environment and Development), 2011. Special Policy Study on Mercury Management in China. Annual General Meeting. Available at: http://www.cciced.net/encciced/policyresearch/report/201205/P020120529368288424164.pdf

CCICED (China Council for International Cooperation on Environment and Development), (2014). Performance Evaluation on the Action Plan of Air Pollution Prevention and Control and Regional Coordination Mechanism. CCICED Special Policy Study Report. Available at: http://www.cciced.net/encciced/policyresearch/report/201504/P020150413497618655390.pdf

Cembureau (1997) Best Available Techniques for the Cement Industry, Brussels: Cembureau.

Cembureau, (2013). The role of cement in the 2050 low carbon economy Available from: http://lowcarboneconomy.cembureau.eu/uploads/Modules/Documents/cembureau-brochure.pdf

Cembureau. (2014). Activity Report. Available at: http://www.cembureau.eu/sites/default/files/Activity%20Report%202014_website_1.pdf

Cembureau. (2015). Cement industry – main characteristics. Available at: http://www.cembureau.be/about-cement/cement-industry-main-characteristics

Cemex (2014). 2014 Sustainable Development Report. Building Resilient and Sustainable Urban Communities. Available at: http://www.cemex.com/SustainableDevelopment/files/CemexSustainableDevelopmentReport2014_s.pdf

Ceres (2014) Cool response: the SEC and Corporate Climate Change Reporting. Ceres. http://www.ceres.org/resources/reports/cool-response-the-sec-corporate-climate-change-reporting/view

CFA Institute, (2015). Environmental, social and governance (ESG) survey. June 2015. Available at: http://irrcinstitute.org/pdf/FINAL-CFA-ESG-Study-August-2015.pdf

CMIIT, (2009) cited in Lei et al., 2011. 2011. Lei, Y., Zhang, Q., Nielsen , C., & He, K. (2011). AN inventory of primary air pollutants and CO_2 emissions from cement production in China, 1990 - 2020. Atmospheric Environment, 45, 147-154. Available at: http://www.sciencedirect.com/science/article/pii/S1352231010008095#

Cohen, Aaron J., et al. (2005). "The global burden of disease due to outdoor air pollution". Journal of Toxicology and Environmental Health, Part A 68.13-14: pp. 1301-1307.

Costanza, R. et al., (1997). The Value of World's Ecosystem Services and Natural Capital. Nature, Volume 387, pp. 253-260.

Costanza, R., Fisher, B., Mulder, K., Liu, S., Christopher, T. (2007) Biodiversity and ecosystem services: A multi-scale empirical study of the relationship between species richness and net primary production. Ecological Economics. Vol. 61, pp. 478-491.

CSI, (2014). Water Impact Management. Available at: http://www.wbcsdcement.org/index.php/en/key-issues/water

CSI, 2014(b). Cement Production. Available at: http://www.wbcsdcement.org/index.php/about-csi/explore-cement?start=2

Dayaratna, K.D., Kreutzer, D.W., 2014. Unfounded FUND: Yet Another EPA Model Not Ready for the Big Game. Backgrounder #2897 on Energy and Environment. Available at: http://www.heritage.org/research/reports/2014/04/unfounded-fund-yet-another-epa-model-not-ready-for-the-big-game

Defra, (2015). Greenhouse Gas Conversion Factor Repository. http://www.ukconversionfactorscarbonsmart.co.uk/

De Groot, R., Brander, L., van der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, A., Hein, L., Hussain, S., Kumar, P., McVittie, A., Portela, R., Rodriguez, L. C., ten Brink, P., van Beukering, P. (2012) Global estimates of the value of ecosystems and their services in monetary units. Ecosystem Services. Vol. 1, no. 1, pp. 50-61.

Delft. (2010) Shadow Prices Handbook - Valuation and Weighting of Emissions and Environmental Impacts. CE Delft.

Desaigues, B., Ami, D. & Hutchison, M. (2006) Final report on the monetary valuation of mortality and morbidity risks from air pollution. Paris: NEEDS.

Desaigues, B., Ami, D., Bartczak, A., Braun-Kohlová, M., Chilton, S., Czajkowski, M., Farreras, V., Hunt, A., Hutchison, M., Jeanrenaud, C., Kaderjak, P., Máca, V., Markiewicz, O., Markowska, A., Metcalf, H., Navrud, S., Nielsen, J. S., Ortiz, R., Pellegrini, S., Rabl, A., Riera, R., Scasny, M., Stoeckel, M. -., Szántó, R. & Urban, J. (2011) Economic valuation of air pollution mortality: A 9-country contingent valuation survey of value of a life year (VOLY). Ecological Indicators. 11 (3), pp.902-910.

Deutsche Bank, (2015). Asia Equities Daily Focus: Asian Edition. Breaking News: Under the Dome. 1 March 2015. Available at: http://www.goldbullioncompany.co.th/wp-content/uploads/2014/01/Deutsche-Asia-Daily-20150303.pdf

Desaigues, B., Ami, D., Bartczak, A., Braun-Kohlová, M., Chilton, S., Farreras, V., Hunt, A., Hutchison, M., Jeanrenaud, C., Kaderjak, P., Máca, V., Markiewicz, O., Metcalf, H., Navrud, S., Nielsen, J.S., Ortiz, R., Pellegrini, S., Rabl, A., Riera, R., Scasny, M., Stoeckel, M.-E., Szántó, R., Urban, J. (2006) Final Report on the Monetary Valuation of Mortality and Morbidity Risks from Air Pollution. Deliverable RS1b of NEEDS Project.

EC. (2004) European Union System for the Evaluation of Substances 2.0 (USES 2.0). Prepared for the European Chemicals Bureau by the National Institute of Public Health and the Environment (RIVM). Bilthoven, The Netherlands (RIVM Report no. 601900005). Available via the European Chemicals Bureau, http://ecb.jrc.it

EC, 2006. Reference document on best available techniques for large combustion plants.

Ecoinvent, (2015). Record name: market for electricity, medium voltage, CN, (Author: Karin Treyer active). Version 3.0. (Author: Karin Treyer active).

Ecoinvent, (2015). Record name: market for gypsum, mineral, GLO, (Author: [System] inactive). Version 3.0. (Author: Karin Treyer active).

Ecoinvent, (2015). Record name: market for limestone, crushed, for mill, GLO, (Author: Guillaume Bourgault inactive). Version 3.0. (Author: Karin Treyer active).

Ecoinvent, (2015). Record name: market for sand, GLO, (Author: [System] inactive). Version 3.0. (Author: Karin Treyer active).

Ecoinvent, (2015). Record name: market for clay, GLO, (Author: [System] inactive). Version 3.0. (Author: Karin Treyer active).

Ecoinvent, (2015). Record name: market for iron ore, crude ore, 46% Fe, GLO, (Author: [System] inactive). (Author: Karin Treyer active).

Ecoinvent, (2015). Record name: hard coal mine operation, CN, (Author: Karin Treyer inactive). Version 3.0. (Author: Karin Treyer active).

EMEP / EEA, 2013. EMEP / EEA air pollution emission inventory guidebook - 2013 : Energy Industries, s.l.: EMEP / EEA.

EPA (US Environmental Protection Agency). (2015). Cement Manufacturing Enforcement Initiative. Available at: http://www2.epa.gov/enforcement/cement-manufacturing-enforcement-initiative#lawsuits

EPA, 2013. The Social Cost of Carbon. Available at: http://www.epa.gov/climatechange/EPAactivities/economics/scc.html

EPA, 2014. Emission Factors for GHG Inventories. Available at: http://www.epa.gov/climateleadership/documents/emission-factors.pdf

EY, (2015). Investment Rules 2.0: nonfinancial and ESG reporting trends. Global Institutional Investor Survey 2015

Fan, C. Cindy. (2006). China's Eleventh five -year plan (2006 -2010): From "Getting Rich First" to " Common Prosperity". Pp.708-723

Feng, J. and Wang, T. (2012). "The Dilemma of Environmental Protest" in Southern Weekend, November 29, 2012.

FT Alphaville. (2014). Contextualising China's cement splurge. Available at: http://ftalphaville.tumblr.com/post/100653486301/contextualising-chinas-cement-splurge

FT, (2015). Environmental, social and other risks stalk Chinese listed companies. Available at: http://www.ft.com/cms/s/3/5ea966f2-2ad3-11e5-acfb-cbd2e1c81cca.html#ixzz3fy6WClti

FT Blogs, (2015). Investors weigh impact of 'Under the Dome'. Available at: http://blogs.ft.com/beyond-brics/2015/03/04/investors-weigh-impact-of-under-the-dome/

Global Cement. (2013). China: First in cement. Available at: http://www.globalcement.com/magazine/articles/796-china-first-in-cement

Global Cement Magazine. (2015). The cement industry of China – 'A new normal'. July-August 2015 Edition. Available at: http://globalcement.com/pdf/eGCJulAug2015ns.pdf

Global Cement (2015a). LafargeHolcim to expedite merger process in Indonesia . Available at: http://www.globalcement.com/news/item/4030-lafargeholcim-to-expedite-merger-process-in-indonesia

Goedkoop, M. Spriensma, R. (2000) The Ecoindicator 99 - A Damage oriented method for Life Cycle Impact Assesment. Netherlands. Product Ecology Consultants.

Gomez-Baggethun, E., de Groot, R., Lomas, P. & Montes, C. (2010). The history of ecosystem services in economic theory and practice: From early notions to markets and payment schemes.. Ecological Economics, Volume 69, pp. 1209-1218.

Green Finance Task Force. (2015). Establishing China's Green Financial System. With forewords by co-convenors Pan Gongsheng, Ma Jun and Simon Zadek. The People's Bank of China & UNEP Inquiry: Design of a Sustainable Financial System.

Greenpeace. (2014). Reduce air pollution. Available at: http://www.greenpeace.org/eastasia/campaigns/air-pollution/

GRI/WBCSD, 2003. The GHG Protocol for Project Accounting. Available at: http://www.ghgprotocol.org/files/ghgp/ghg_project_protocol.pdf

Hendriks et al. Emission Reduction of Greenhouse Gases from the Cement Industry. Available at: http://www.moleconomics.org/files/sustainability%20documents/EmissionReductionofGreenhouseGasesfromtheCementIndustry.pdf

Holcim, (2014). Integrated Profit and Loss Statement 2014. Measuring our triple bottom line. Available at: http://www.holcim.com/uploads/CORP/Holcim_IPL_Final2.pdf

Howard, P., 2014. Omitted Damages: What's Missing From the Social Cost of Carbon. The Cost of Carbon Project, a joint project of the Environmental Defense Fund, the Institute for Policy Integrity, and the Natural Resources Defense Council. Available at: http://costofcarbon.org/files/Omitted_Damages_Whats_Missing_From_the_Social_Cost_of_Carbon.pdf

HSBC (2015). Green Bonds in China. Channeling funds to where they can help build a cleaner, modern economy.

IEA ETSAP. (2010). Energy technology systems analysis programme: Cement Production . IEA ESTAP .

IFC (2014) Waste Heat Recovery for the cement sector: Market and supplier analysis.

IFC. (2014). Waste Heat Recovery for the Cement Sector: Market and Supplier Analysis. Available at: http://www.ifc.org/wps/wcm/connect/a87be50044581e9889678dc66d9c728b/IFC+Waste+Heat+Recovery+Report.pdf?MOD=AJPERES

Industry Efficiency Technology Database (2015) Cement Available from http://ietd.iipnetwork.org/content/cement#technology-resources [Accessed 20/07/2015]

Institute for Industrial Productivity. (2015). Waste Heat Recovery. Available at: http://www.iipnetwork.org/62730%20WRH_Report.pdf2

International Cement Review. (2012). The cement industry in figures: An overview of global cement sector trends.
Available at: http://www.ficem.org/pres/THOMASARMSTRONG-LA-INDUSTRIA-DEL-CEMENTO-ENCIFRAS.pdf

International Energy Agency. (2012). Tracking Clean Energy Progress.

IPCC, 2007. IPCC Fourth Assessment Report: Climate Change 2007. Climate Change 2007: Working Group III: Mitigation of Climate Change. 2.4 Cost and benefit concepts, including private and social cost perspectives and relationships to other decision-making frameworks.

IPCC. (2014). Climate change impacts in China. Available at: http://wwf.panda.org/about_our_earth/aboutcc/problems/rising_temperatures/hotspot_map/china.cfm

IPCC, 2014. IPCC Fifth Assessment Report. Working Group III.

IPEA (Institute for Environmental and Public Affairs). (2013). Responsible Investment in Cement Industry: Still a long way to go. Phase I Green Stocks Investigative Report Releases in Beijing. Available at: http://chinawaterrisk.org/wp-content/uploads/2013/06/Responsible-Investment-in-Cement-Industry.pdf

IUCN. (2015) Table 6a - Number of animal species in each IUCN Red List Category by country. Table 6b - Number of plant species in each IUCN Red List Category by country. [Online] Available from: http://www.iucnredlist.org/about/summary-statistics [Accessed on: 06.06.15]

IWGSCC, (2010). Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis. Interagency Working Group on Social Cost of Carbon, United States Government. Available at: http://www.whitehouse.gov/sites/default/files/omb/inforeg/for-agencies/Social-Cost-of-Carbon-for-RIA.pdf

IWGSCC, (2013). Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis. Interagency Working Group on Social Cost of Carbon, United States Government. [online] Available at: http://www.whitehouse.gov/sites/default/files/omb/assets/inforeg/technical-update-social-cost-of-carbon-for-regulator-impact-analysis.pdf

Ke, J., McNeil, M., Price, L., Khanna, N. Z., & Nan, Z. (2013). Estimation of CO_2 emissions from China's cement production: methodologies and uncertainties. Ernest Orlando Lawrence Berkeley National Laboratory. Available at: https://china.lbl.gov/sites/all/files/6329_ep_cement_co2.pdf

Ke, J., Zheng, N., Fridley, D., Price, L., & Zhou, N. (2012). Potential energy savings and CO_2 emission reduction of China's cement Industry . Lawrence Berkley National Laboratory .

Kopits, E., (2014). The Social Cost of Carbon in Federal Rulemaking. National Center for Environmental Economics, U.S. EPA. Available at: http://www.hks.harvard.edu/m-rcbg/cepr/Papers/2014/SCC_HKS%20Energy%20Policy%20Seminar_03%2031%2014_forweb.pdf

Krukowska, E., (2014). Europe Carbon Permit Glut Poised to Double by 2020: Sandbag. Bloombert Business News. Available at: http://www.bloomberg.com/news/articles/2014-10-14/europe-carbon-permit-glut-poised-to-double-by-2020-sandbag-says

Lei, Y., Zhang, Q., Nielsen, C., & He, K. (2011). AN inventory of primary air pollutants and CO_2 emissions from cement production in China, 1990 - 2020. Atmospheric Environment, 45, 147-154.

Madlool, N.A., Saidur, R., Hossain, M.S., Rahim, N.A., (2011). A critical review on energy use and savings in the cement industries. Renewable and Sustainable Energy Reviews 15 (4), 2042-2060.

Marceau, M. L., Nisbet, M. A., & VanGeem, M. G. (2006). Life cycle inventory of portland cement manufacturing. Portland cement association .

Marquis, Christopher; Zhang, Jianjun; Zhou, Yanhua. (2011). Regulatory uncertainty and corporate responses to environmental protection in China. Pp. 39-63.

MEA (2005). Millennium Ecosystem Assessment. Ecosystems and Human Well-being, A Framework for Assessment, s.l.: Island Press.

MEP, (2014). MEP announces new emission standards for major industries -Efforts to implement the ten major measures against air pollution. Available at: http://english.mep.gov.cn/News_service/news_release/201401/t20140115_266434.htm

MEP. (2013). Emission standard of air pollutants for cement industry. GB 4915-2013. Available at: http://kjs.mep.gov.cn/hjbhbz/bzwb/dqhjbh/dqgdwrywrwpfbz/201312/t20131227_265765.htm

MEP. (2013b). Standard for pollution control on co-processing of solid wastes in Cement kiln. GB 30485—2013. Available at: http://kjs.mep.gov.cn/hjbhbz/bzwb/gthw/gtfwwrkzbz/201312/t20131227_265767.htm

MIIT. (2012). The 12th Five-Year Development Plan of Solar Photovoltaic Industry. (Only in Chinese)

Ministry of Finance. (2010). The Notice of the Ministry of Finance and the State Administration of Taxation on Issues Concerning the Value-added Tax, Business Tax and Enterprise Income Tax Policies for Promoting the Development of the Energy Services Sector. (Only in Chinese)

Motoshita, M., Itsubo, N., Inaba, A. (2010) Development of impact factors on damage to health by infectious diseases caused by domestic water scarcity. International Journal of Life Cycle Assessment. Vol. 16, pp. 65-73.

Murray, A & Price, L (2008). Use of alternative fuels in the cement manufacture: Analysis of fuel characteristics and feasibility for use in the Chinese cement sector.

Nathaniel, A., Fridley, D., & Nina, Z. (2009). China's Coal: Demand, Constraaints, and Externalities. Ernest Orlando Lawrence Berkley National Laboratory.

National Institute of Public Health and the Environment. (2004) European Union System for the Evaluation of Substances 2.0 (USES 2.0). Bilthoven.

Natural Capital Coalition (2014a). Developing the Protocol. [Online] Available at: http://www.naturalcapitalcoalition.org/natural-capital-protocol/developing-the-protocol.html

NAEI, (2013). Emission factors detailed by source and fuel. [Online] Available at: http://naei.defra.gov.uk/data/ef-all?q=78878 [Accessed 18 8 2015].

NETCEN, (2003). Emission factors programme Task 7 - review of residential & small-scale commercial combustion sources, s.l.: NETCEN.

NDRC. (2012). China's Cement Industry is Facing Dramatic Increase of Environmental Costs. Available at: http://www.ndrc.gov.cn/xxfw/hyyw/ t20120221_462710.htm (Only in Chinese)

Neuwald, 2004, cited by Huntzinger and Eatmon, 2008. Huntzinger, D. N., & Eatmon, T. D. (2008). A life-cycle assessment of portland cement manufacturing : comparing the traditional process alternative technologies. Journal of cleaner production, 1 - 8. Available at: http://sitemaker.umich.edu/deborah.huntzinger/files/inpress_jcphuntzinger_eatmon.pdf

Ni, Chunchun, (2009). China Energy Primer. Ernest Orlando Lawrence Berkeley National Laboratory. Available at: http://www.osti.gov/scitech/servlets/purl/979807-XSkUoh/

Norges Bank Investment Management. (2014). Responsible Investment Report. Available at: http://www.nbim.no/globalassets/reports/2014/2014-responsible-investment.pdf

OECD/IEA, (2007). Tracking Industrial Energy Efficiency and CO_2 Emissions. Available at: http://www.iea.org/publications/free-publications/publication/tracking_emissions.pdf

Olson, D. M., Dinerstein, E., Wikramanayake, E. D., Burgess, N. D., Powell, G. V. N., Underwood, E. C., D'Amico, J. A., Itoua, I., Strand, H. E., Morrison, J. C., Loucks, C. J., Allnutt, T. F., Ricketts, T. H., Kura, Y., Lamoreux, J. F., Wettengel , W. W., Hedao, P., Kassem K. R. (2004) Terrestrial Ecoregions of the World: A New Map of Life on Earth. BioScience. Vol. 51, no. 11, pp. 933-938.

PBL Netherlands Environmental Assessment Agency/EC. (2012). Trends in Global CO_2 emissions: 2012 Emissions. The Hague/Bilthoven. Available at: http://edgar.jrc.ec.europa.eu/ CO2REPORT2012.pdf

Pfister, S. (2011) Environmental evaluation of freshwater consumption within the framework of life cycle assessment. DISS. ETH NO. 19490. ETH ZURICH.

Pirrone et al., 2010. Global Mercury emissions to the atmosphere from anthropogenic and natural sources. Atmos Chem Phys (10), 6951-5964. Available at: http://www.atmos-chem-phys.net/10/5951/2010/acp-10-5951-2010.pdf

Price, L., Hasanbeigi, A., Hongyou, L., & Lan, W. (2009). Analysis of energy - efficiency opportunities for the cement industry in Shangdong province, China. Lawrence Berkeley National Laboratory .

Quantitative Economics Association of China Building Materials. (2011). "Review of Energy Consumption of China Cement Industry in the 11th Five-year Period" in China Cement, 1:30-35. (Only in Chinese)

Renzoni, R., Ullrich, C., Belboom, S., & Germain, A. (2010). Mercury in the cement industry . CEMBUREAU - CSI.

RFF (Resources for the Future), (2012). How Should Benefits and Costs Be Discounted in an Intergenerational Context? The Views of an Expert Panel. Available at: http://www.rff.org/RFF/Documents/RFF-DP-12-53.pdf

Rock, Michael. (2008). Using External Finance to Foster a Technology Transfer-Based CO_2 Reduction Strategy in the Cement and Iron and Steel Industries in China. WWF Macroeconomics for Sustainable Development Program, Beijing, China.

S&P's Ratings Services, (2013). Key Credit Factors For The Building Materials Industry.

SASB (Sustainability Accounting Standards Board). (2015). Materiality Assessment, Why is it Important?
Available at: http://www.sasb.org/materiality/materiality-assessment/

South China Morning Post, (2015). Air pollution killing 4,000 people a day in China, says US report. 14 Aug 2015. Available at: http://www.scmp.com/news/china/society/article/1849431/air-pollution-killing-4000-people-day-china-says-us-report

State Environmental Protection Administration of China. National Bureau of Statistics of China (2006). China Green National Accounting Study Report 2004.

Stern, N., 2006. Stern Review Report on the Economics of Climate Change. Cambridge: Cambridge University Press.

Stockholm Environment Institute , (2008). Foundation course on Air Quality management in Asia : Emissions, Stockholm: Stockholm Environment Institute .

SynTao Sustainbility Solutions, (2011). SynTao Sustainability Solution, 2011. Revealing China's ESG Issue, s.l.: s.n.

The Economics of Ecosystems and Biodiversity, (2010). Biodiversity, ecosystems and ecosystem services. The Economics of Ecosystems and Biodiversity: The Ecological and Economic Foundations.

TEEB (2013). Natural capital at risk: The top 100 externalities of business. Available at: http://www.naturalcapitalcoalition.org/projects/natural-capital-at-risk.html

Tol, R., 2011. The Social Cost of Carbon. Annual Review of Resource Economics, Annual Reviews, 3(1), p. 419-443.

UNEP, (2014). Valuing Plastic: The Business Case for Measuring, Managing and Disclosing Plastic Use in the Consumer Goods Industry. Available at: www.unep.org%2Fgpa%2FDocuments%2FPublications%2FValuingPlasticExecutiveSummaryEn.pdf&ei=w5G-VcSfGKnD7gbTho7oBQ&usg=AFQjCNEddPBnxZmo4etecpAhqIU3rZT_bg&sig2=LI-D63_6pYgYvuBkHZiF9Q&b-vm=bv.99261572,d.bGg

UNEP. (2013). China's Green Long March. Available at: http://www.unep.org/greeneconomy/Portals/88/Research%20Products/China%20synthesis%20report_FINAL_low%20res_22nov.pdf

US EPA , (1995). Emission factors & AP 42, compilation of air pollution emission factors , s.l.: US EPA.

Verdantix, (2015). Holcim innovates with "True Value" SE P&L Analysis. January 2015. Available at: https://home.kpmg.com/content/dam/kpmg/pdf/2015/06/holcim-true-value-analysis.pdf

WBCSD (2009) The Cement Sustainability Initiative: Cement Industry Energy and CO_2 performance.

WHO, 2013. Mercury and health Fact sheet N361. Available at: http://www.who.int/mediacentre/factsheets/fs361/en/

WHO, (2014). 7 million premature deaths annually linked to air pollution. Available at: http://www.who.int/mediacentre/news/releases/2014/air-pollution/en/

World Bank. Development Research Centre for the State Council. (2014). Urban China: Toward Efficient, Inclusive, and Sustainable Urbanization. Available at: https://www.worldbank.org/content/dam/Worldbank/document/EAP/China/WEB-Urban-China.pdf

World Bank Group, (2014). State and Trends of Carbon pricing. [online] URL: http://www.ecofys.com/files/files/world-bank-ecofys-2014-state-trends-carbon-pricing.pdf

World Cement, (2013). China Cement Industry Update. Available at: http://www.worldcement.com/asia-pacific-rim/08012014/China_cement_industry_update_569/

Worrell, E., Galitsky, C., and Price, L., (2008). Energy Efficiency Improvement Opportunities for the Cement Industry. Berkeley, CA: Lawrence Berkeley National Laboratory. http://ies.lbl.gov/node/402

WWF. (2008). A blueprint for a climate friendly cement industry. Available at: http://wwf.panda.org/about_our_earth/all_publications/?151621/A-blueprint-for-a-climate-friendly-cement-industry

Xu, J.-H., Fleiter, T., Fan, Y., & Eichhammer, W. (2014). CO_2 emissions reduction potential in China's cement industry compared to IEA's cement technology roadmap up to 2050. Applied Energy , 130, 592 - 602.

Yuan et al. (2011). "Energy Conservation and Emissions Reduction in China—Progress and Prospective" in Renewable and Sustainable Energy Reviews, 15(9):4334- 4347.

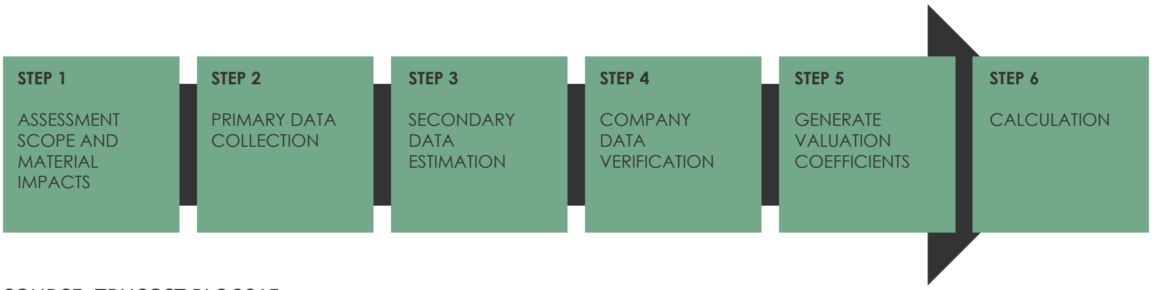
Zhang, Q. and R.Crooks (2012). Toward an Environmentally Sustainable Future toward an Environmentally Sustainable Future Country Environmental Analysis of the People's Republic of China. Manila: Asian Development Bank.

APPENDICES

A.1 QUANTIFICATION METHODOLOGY

The calculation of external cost resulting from the environmental impacts of 32 publically traded cement production companies followed six distinct steps designed to establish the link between changes in the environment and changes in the wellbeing of specific societal groups, such as local communities, employees, businesses and the wider society (Figure A1).

FIGURE A1: TRUE COST OF CEMENT, HIGH-LEVEL METHODOLOGY



SOURCE: TRUCOST PLC 2015

The value chain scope of this assessment focused on the production of clinker, which generates the most material environmental impacts in the lifecycle of cement production. Assessed are the raw material extraction, processing, and clinker manufacturing stages.

The quantification of KPIs and related impacts was conducted through primary and secondary data collection. Primary data collection refers to the use of actual, measured data. Generally the more company specific data the better the results and usefulness for decision-making. Secondary data estimation can be performed using Lifecycle Analysis (LCA) studies, academic research literature and input-output modeling. The choice of methodology was mainly driven by the aim of the study and data availability.

In this assessment primary data from Annual and Sustainability Reports was prioritized. Section A.1.1 outlines the primary data collection results. Where primary data was unavailable, the analysis applied best available secondary data estimation techniques, including China-specific lifecycle assessments (LCAs) and academic peer reviewed literature (outlined in Section A.1.2).

A.1.1 PRIMARY DATA COLLECTION

TABLE A1: PRIMARY DATA: CLINKER PRODUCTION

OVERWRITING APPROACH	COMPANIES
Clinker from company disclosure	1, 2, 4, 11, 14, 18, 19, 24, 28, 31
Clinker estimated from revenue, price and China-average clinker ratio	3, 6, 7, 8, 9, 10, 12, 15, 20, 22, 25, 26, 29, 32
Clinker estimated from cement production company disclosure, clinker for sales revenue and China-average clinker ratio	13, 16, 21, 23, 27, 30
Clinker estimated from cement production company disclosure and company clinker ratio disclosure	17
Clinker estimated from revenue, price and company clinker ratio disclosure	5

SOURCE: COMPILED BY TRUCOST FROM COMPANY PUBLIC DISCLOSURE

TABLE A2: PRIMARY DATA: OTHER KPIs

ID NUMBER	TICKER	COMPANY NAME	PRIMARY DATA POINT
1	914-HK	Anhui Conch	N/A
2	3323-HK	CNBM	• **Coal use:** Total volume of coal consumed (thousand tons of standard coal) • **Water:** Freshwater consumption of clinker production (ton water/ ton clinker); disclosed water multiplied by kiln factors to adjust for process water use • **Electricity:** Total volume of electricity consumed (thousand kWh), apportioned between electricity for clinker and electricity for cement making based on average percentage split required at each stage of the process • **NO_x:** NO_x emission of clinker production (kg/ton clinker) • **Waste heat:** 'The cement cogeneration quantity is 6,013,000,000 kWh, accounting for 23.3% of all electricity consumption'; subtracted from electricity use
3	1313-HK	China Resources	• **Coal use:** Standard coal consumption of clinker production (kg standard coal/ton clinker) • **Electricity:** Electricity consumption of cement (kWh/ton), apportioned between electricity for clinker and electricity for cement making based on average percentage split required at each stage of the process • **Kiln type:** All are NSP, adjusted to account for 100% NSP kilns • **Waste heat:** 'In 2013, the electricity produced by waste heat is 1,767,000,000 kWh'; subtracted from electricity use
4	000401-CN	Tangshan Jidong	N/A
5	1893-HK	China National Materials	• **Kiln type:** All are NSP, adjusted to account for 100% NSP kilns
6	691-HK	China Shanshui	N/A
7	900933-CN	Huaxin	• **Coal use:** Clinker coal consumption (kg/t) • **Electricity:** Power consumption (kWh/t), apportioned between electricity for clinker and electricity for cement making based on average percentage split required at each stage of the process • **Waste heat:** 25.4% of power generation; subtracted from estimated electricity use
8	1136-HK	TCC	• **Electricity:** Power consumption (kWh/t), apportioned between electricity for clinker and electricity for cement making based on average percentage split required at each stage of the process • **Water:** Cement water consumption (m^3/ton cement), adjusted per ton of clinker and multiplied by kiln factors to overwrite process water use
9	2009-HK	BBMG	N/A
10	1252-HK	China Tianrui	• **Kiln type:** All are NSP, adjusted to account for 100% NSP kilns
11	600881-CN	Jilin Yatai	• **Waste heat:** 433,000,000 KWh electricity generation; subtracted

ID NUMBER	TICKER	COMPANY NAME	PRIMARY DATA POINT
12	743-HK	Asia Cement	• **Electricity:** Intensity (kWh/ton clinker) derived from 2 disclosing companies within the group • **Coal use:** Intensity (tons/ton clinker) derived from 2 disclosing companies within the group • **GHG, PM, NO_x, SO_x:** ton/ton clinker. PM apportioned across different PM types based on estimation proportion within the group
13	000877-CN	Xinjiang Tianshan	N/A
14	000789-CN	Jiangxi Wannianqing	N/A
15	600720-CN	Gansu Qilianshan	• **Waste heat:** 187,000,000 KWh electricity generation; subtracted from estimated electricity use
16	2233-HK	West China	N/A
17	002233-CN	Guangdong Tapai	• **Waste heat:** 280,090,000.98 kWh electricity generation; subtracted from estimated electricity use
18	600449-CN	Ningxia Buliding Materials	N/A
19	000885-CN	Henan Tongli	• **Waste heat:** 375,380,000 KWh electricity generation; subtracted from estimated electricity use
20	600068-CN	China Gezhouba	• **Waste heat:** 297,390,000 KWh electricity generation; subtracted from estimated electricity use
21	000672-CN	Gansu Shangfeng	N/A
22	600425-CN	Xinjiang Qingsong	• **Kiln type:** 95 percent of capacity is NSP; adjusted proportion contributed by NSP to 95%
23	000935-CN	Sichuan Shuangma	N/A
24	600802-CN	Fujian Cement Inc	• **Waste heat:** 109,500,000 KWh electricity generation; subtracted from estimated electricity use
25	600318-CN	Anhui Chaodong	N/A
26	600668-CN	Zhejiang Jianfeng	N/A
27	600883-CN	Yunnan Bowin	N/A
28	695-HK	Dongwu	N/A
29	000546-CN	Jinyuan Cement	N/A
30	600539-CN	Taiyuan Lionhead	N/A
31	600217-CN	Shaanxi Qinling	N/A
32	1312-HK	Allied Cement	N/A

SOURCE: COMPILED BY TRUCOST FROM COMPANY PUBLIC DISCLOSURE

SULFUR DIOXIDE AND NITROGEN OXIDES

The burning of coal in cement kilns is the sole source of SO_x and NO_x emissions. SO_x and NO_x emissions factors were directly based on Lei et al. (2011) (Table A3).

TABLE A3: SO_X AND NO_X EMISSIONS FROM EACH KILN TYPE IN CHINA

KILN TYPE	SO_x (g/ kg of coal)	NO_x (g/kg of coal)
Precalciner Kilns	2.9	15.3
Other Rotary Kiln	12.3	18.5
Shaft Kiln	12.3	1.7

SOURCE: LEI ET AL. 2011

PARTICULATE MATTER

There are several sources of PM emissions besides kiln emissions, such as quarrying and crushing, raw material storage, grinding and blending, and packaging and loading. In addition, the abatement efficiency varies a lot between different PM emission control technologies (Lei et al., 2011). In this study unabated PM emissions reported by Lei et al. (2011) were adjusted for PM emission control technologies using the penetration level of available PM emission abatement technologies in China, the compatibility of abatement technology type with the underlying kiln type (for example vertical shaft kilns cannot be applied with electrostatic precipitators as there are chances of explosion and humid nature of exhaust gas) and actual PM reduction efficiencies (Table A4, Table A5).

TABLE A4: TYPICAL REMOVAL EFFICIENCY OF EACH TECHNOLOGY TYPE

PM ABATEMENT TECHNOLOGY	AVERAGE PARTICLE SIZE REMOVAL EFFICIENCY (% REMOVED) (EC 2006)		
	PM_2	$PM_{2.5-10}$	$PM_{>10}$
CYC	0	85	90
WET	99.5	99.9	99.9
BAG / Fabric Filters	99.6	99.9	99.95
ESP	98.3	99.95	99.95

SOURCE: EUROPEAN COMMISSION 2006

TABLE A5: PERCENTAGE REDUCTION IN PM EMISSION FOR EACH KILN CONSIDERING PREVALENT TECHNOLOGY PENETRATION LEVELS IN CHINA AND READJUSTED PM FACTORS (LIE ET. AL, 2011)

KILN TYPE	$PM_{2.5}$ % ↓	CALCULATION PM $_{2.5}$ (g/kg of clinker)	$PM_{2.5-10}$ % ↓	CALCULATION: PM $_{2.5-10}$ (g/kg of clinker)	$PM_{>10}$ % ↓	CALCULATION: PM $_{>10}$ (g/kg of clinker)
Precalciner Kilns	99.02	=26.3*(100-99.02)% = 0.26	99.92	=35*(100-99.92)% =0.03	99.95	=84.6*(100-99.95)% =0.04
Other Rotary Kiln	96.43	=19.4*(100-96.43)% = 0.69	99.52	=29.2*(100-99.52)% =0.14	99.68	=87.5*(100-99.68)% =0.28
Shaft Kiln	95.26	=4.6*(100-95.26)% =0.22	99.25	=8.3*(100-99.25)% =0.06	99.51	=28.8*(100-99.51)% =0.14

SOURCE: TRUCOST CALCULATIONS USING LEI ET AL. 2011 AND EUROPEAN COMMISION 2006

VOLATILE ORGANIC COMPOUNDS

The burning of coal in cement kilns is the sole source of VOCs emissions. A factor of 0.030006 g VOC/kg coal was calculated by Trucost on the basis of meta-analysis of different sources (EEA, 2013; NAEI, 2013; NETCEN, 2003; US EPA, 1995; Stockholm Environment Institute, 2008; Argonne National Laboratory, 2012). The default emission factors derived from these sources were analyzed for outliers and the mean value was calculated representing default emissions from coal combustion.

MERCURY EMISSIONS

The mercury emissions from cement production are highly dependent on the mercury content of the raw material used and also the mercury content of the coal (CCICED, 2011). The kiln-specific volume of gas emissions are calculated as per Renzoni et al. (2010) using kiln-specific heat consumption, calcination factor and normalization factor to 10% oxygen. An average mercury emissions factor from flue gases of 0.02 mg/nm^3 was then applied corresponding to an emission factor of around 0.035 g/t cement (Renzoni, 2010). The resulting values were triangulated with the 0.065 – 0.1 g/mg cement production provided by Pirrone et al. (2010).

A.1.3 OTHER MATERIAL IMPACTS: GHG EMISSIONS ESTIMATION

Cement manufacturing accounts for roughly 5% of all human-generated greenhouse-gas emissions (Earth Institute, Columbia University, 2012). Approximately half of all CO_2 emissions from cement production originate from the core calcination process where the conversion of raw materials takes place forming lime and carbon dioxide. The remaining amount results from energy usage during the production process where overall emissions are heavily dependent on the type of fuel used (for example coal, fuel oil, natural gas, petroleum coke and alternative fuels).

Additional factors influencing the quantity of CO_2 emitted include the electricity intensity of clinker and cement production and the CO_2 emissions profile of the electricity consumed. Grinding is the largest electricity demand in the cement industry.

Currently about 100 kWh/t of cement is consumed in rotary kilns for grinding raw materials, at the kiln and for grinding cement (OECD/IEA, 2007).

The use of alternative fuels in the cement industry offers an opportunity to reduce production costs, dispose of waste and in some cases reduce CO_2 emissions and fossil fuel use. Cement kilns are well-suited for waste combustion because of their high process temperature and because the clinker product and limestone feedstock act as gas-cleaning agents. Used tires, wood, plastics, chemicals and other types of waste are co-combusted in cement kilns in large quantities.

Overall emissions are also heavily dependent on the clinker to cement ratio (hereafter referred to as the 'clinker ratio'), which tends to vary between 0.7 – 0.95 metric tons of clinker per metric ton of cement depending on the types of cement produced. Generally, cement types are defined by the quantity of clinker substitutes used by weight. Within each blended cement type, different grades are identified based on the percentage of clinker substitutes used. For example, a clinker ratio of 0.95 represents 100% production of Portland cement with 5% gypsum added, while lower values are achieved by increasing the share of blended cement types.

The amount of clinker needed to produce a given amount of cement can be reduced by the use of supplementary cementitious materials such as coal fly ash, slag, and natural pozzolans such as rice husk ash and volcanic ashes (Neuwald, 2004, cited by Huntzinger and Eatmon, 2008). The addition of these materials into cement not only reduces the amount of material landfilled, but also reduces the amount of clinker required per metric ton of cement produced. Therefore cement substitutes may offer reduction in environmental impacts and material costs of construction. European cement manufacturers derived 3% of their energy needs from waste fuels in 1990 going up to 17% in 2005, with further increases since then (OECD/IEA, 2007). Cement producers in Belgium, France, Germany, the Netherlands and Switzerland have reached average substitution rates from 35% to more than 70% of the total energy used.

OPERATIONAL GHG EMISSIONS FROM CALCINATION

Operational GHG emissions from calcination are calculated by first applying a China-specific emission factor for calcination. The EF of 550kg CO_2/t clinker is taken from Cui and Liu (2008, cited in Lei et al., 2011) who followed the approach recommended by the Intergovernmental Panel on Climate Change (IPCC) and calculated the EFs based on the typical practices of the cement industry in China. This value was triangulated with the EF of 547kg kg CO_2/t clinker calculated by Ke et al., (2013) and other China-specific CO_2 EFs falling within the same range (Boden et al., 1995; Cui and Liu, 2008; He and Yuan, 2005; NDRC, 2004; Wang, 2009; Worrell et al., 2001; Zhu, 2000, cited by Lei et al., 2011).

OPERATIONAL GHG EMISSIONS FROM FUEL USE AT KILN

Operational GHG emissions from the kiln fuel use were calculated by converting a China-specific kiln-specific heat requirement (GJ/t clinker) to coal (t coal/t clinker) using a China-specific conversion factor (22.394 GJ/t coal). A China-specific GHG emissions factor from coal was then applied to calculate the GHG emissions from coal use at each type of kiln (2,337 kg CO_2e/t coal) (Table A7). The final EF was derived by summing GHG emissions from coal use at each kiln type, weighted by the percentage prevalence of each kiln type in cement production in China (Table A6, Figure A2).

TABLE A6: CONVERSION FROM HEAT REQUIREMENT TO GHG EMISSIONS PER TYPE OF KILN

KILN TYPE	HEAT INTENSITY (GJ/t clinker)[1]	CALCULATION: COAL INTENSITY[2] (t coal/t clinker)	CALCULATION: GHG INTENSITY[2] (t CO_2e/t clinker)	KILN TYPE % CONTRIBUTION IN 2012[3]
Precalciner Kilns	3.54	0.158	369	90.4%
Other Rotary Kiln	5.06	0.226	528	2.5%
Shaft Kiln	3.92	0.175	409	7.1%

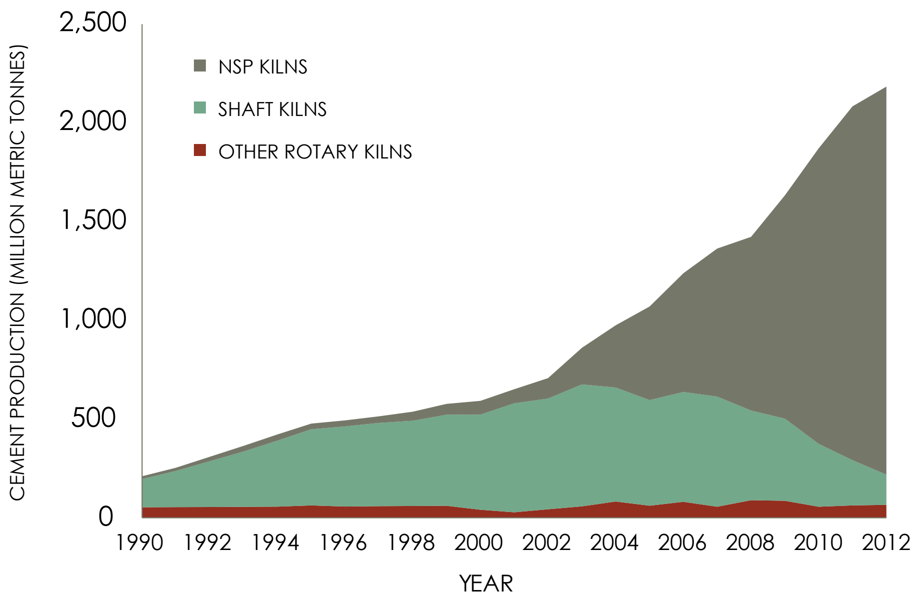
SOURCE: [1]LEI ET AL. 2011; [2]TRUCOST CALCULATIONS; [3]XU ET AL. 2014

TABLE A7: CONVERSION FROM TONNES COAL TO CO_2e FROM COAL COMBUSTION

	% Breakdown of coal production (China Energy Databook, 2006)[1]	CO_2 (Kg/ short ton) (EPA, 2014)[2]	N_2O (g/ short ton) (EPA, 2014)[2]	CH_4 (g/short ton) (EPA, 2014)[2]
Anthracite	76.50%	2602	40	276
Bituminous	19.00%	2325	40	274
Lignite and Brown coal	4.50%	1389	23	156
Calculation: Weighted sum of respective GHG quantities per ton of coal and the % breakdown of coal production per coal type	NA	2494	0.039	0.27
Calculation: Conversion to CO_2e using Global Warming Potential factors	NA	=2494*1 = 2494	= 0.039*25 = 0.981	= 0.27*298 = 80.5
Calculation: Conversion from short tons to metric tons (1.1023 short ton = 1 metric ton)	NA	2263	0.890	73.052

SOURCE: [1]NI 2009; [2]US EPA 2014

FIGURE A2: CEMENT PRODUCTION IN CHINA FROM DIFFERENT TYPES OF KILNS 2012



SOURCE: ADAPTED FROM XU ET AL. 2014

There are two potential limitations to the calculation of GHG emissions from fuel use at kiln that must be noted. Calculations include emissions from coal use only with the rest of the fuels sources excluded to reflect the fact that on average, 99% of fuel supply during clinker production is through coal. In addition coal emission factors are based on prevalence of different coal types to production in 2006, as it was problematic to find a more updated data source.

OPERATIONAL GHG EMISSIONS FROM ELECTRICITY USE

The China-specific electricity consumption per kiln type (Table A7) was weighted by the percentage prevalence of each kiln type in cement production in China (Figure A2) to derive a weighted average electricity intensity per metric ton of cement (96.3612 kWh/t cement). This was then converted to electricity intensity per ton of clinker (95.438 kWh/t clinker) and multiplied by a China-specific GHG emissions factor from electricity 1kWh = 0.84377 kg CO_2-Eq (Ecoinvent, 2015) (Table A9, Table A10).
The results were triangulated using other factors reported in literature (Table A11).

TABLE A8: AVERAGE ELECTRICITY INTENSITY FOR CEMENT PRODUCTION IN CHINA

KILN TYPE	CALCULATION: AVERAGE POWER INTENSITY FOR EACH KILN TYPE (KWh/ t cement production)[1]	% CONTRIBUTION IN 2012
Precalciner Kilns	95.8	90%
Other Rotary Kiln	118	3%
Shaft Kiln	96	7%

SOURCE: [1]PRICE ET AL. 2009 [2]XU ET AL. 2014

TABLE A9: AVERAGE ELECTRICITY USE IN KILN TYPES IN CHINA, 2006

KILN TYPE	ELECTRICITY INTENSITY[4] (kWh/t cement)	MAPPING
Vertical Shaft Kin - Mechanical	96	Shaft Kiln
Vertical Shaft Kin-Improved	75	Excluded (outlier)
Rotary Kan - Shaft Pre-heater	121	Other Rotary kiln
Rotary Kiln -Cyclone Pre-heater	119	Other Rotary kiln
Rotary Kiln - NSP ≤ 2000 tpd w/o WHR	111	Excluded (outlier)
Rotary Kiln - NSP 2000-4000 tpd w/o WHR	96	NSP
Rotary Kiln - NSP 4000-6000 tpd w/o WHR	95	NSP
Rotary Kiln - NSP ≥ 6000 tpd w/o WHR	94	NSP
Rotary Ifiln - NSP 2000 - 4000 tpd w/WHR	97	NSP
Rotary Ifiln - NSP 4000 - 6000 tpd w/WHR	97	NSP
Rotary Kiln -Wet	114	Other Rotary kiln

SOURCE: PRICE ET AL. 2009

TABLE A10: BREAKDOWN OF ELECTRICITY FACTOR INTO CONSTITUENT PARTS

	SHARE OF TOTAL ELECTRICITY CONSUMPTION (%), (MADLOOL ET AL., 2011)	CALCULATION: ELECTRICITY ALLOCATION PER STAGE (kWh/t cement)
Mines, crusher and stacking	2%	1.93
Re-claimer, raw meal grinding and transport	24%	23.13
Kiln feed, kiln and cooler	29.3%	28.23
Coal mill	6.7%	6.46
Cement grinding and transport	30.7%	29.58
Packing	2%	1.93
Lighting, pumps and services	5.3%	5.11

SOURCE: MADLOOL ET AL. 2011 *An average value for each kiln type was calculated excluding any outliers

TABLE A11: REVIEW OF ELECTRICITY USE IN CEMENT PRODUCTION

FACTOR	SOURCE
110 – 115 KWh / t cement	Lei et al., 2011
100 KWh / t cement	IEA, 2007
Current best practice is thought to be around 80 – 90 KWh / t of clinker	Sathaye et al., 2005 and FLSmidth, 2006
93.1 KWh/ t cement for 2012 at clinker ratio 72% and 68.6 Kwh / t clinker	GNR Database
90 – 150 Kwh / t cement In a dry process, the electricity consumption share is 38% for cement grinding, 24% for raw material grinding, 22% for clinker production including grinding of solid fuels, 6% for raw material homogenisation, 5% for raw material extraction and blending, and 5% for conveying, packing and loading	IEA ESTAP , 2010

A.1.4 OTHER MATERIAL IMPACTS: WATER USE ESTIMATION

Although the sector's water footprint is relatively small compared to other sectors, actions must be taken to manage the industry footprint on water, mostly at local level, where individual facilities and activities have a direct impact. Companies have to understand and manage the quantities of water withdrawn, as well as the quality and quantity of water released, with particular attention in water-stressed areas where much of cement production takes place.

Cement production requires water for cooling heavy equipment and exhaust gases, in emission control systems such as wet scrubbers, as well as for preparing slurry in wet process kilns although this process is progressively being phased out and replaced by modern, more efficient dry processes, thus bringing significant reduction in water usage (CSI, 2014). Water generally evaporates in the process. Discharged water can be affected by high temperatures, altered acidity or the presence of solids. Quarry dewatering can have impact on the river basin depending on the point of discharge. The aggregates business (and ready-mix to a lesser extent) also requires significant quantities of water.

Water use can be evaluated in terms of process water and non-process water. Process water refers to water that is used in a manufacturing or treatment process or in the actual product manufactured, for example to make raw meal slurry in the wet process and in the semi-dry process (although few plants employ the semi-dry process). Non-process (cooling) water is used as a method of heat removal from components and consists of water used for contact cooling (such as water sprayed directly into exhaust gases and water added to grinding mills), non-contact cooling (such as engine or equipment cooling), cement kiln dust landfill slurries, and dust suppression.

Water consumption factors for cement manufacturing were taken directly from study on US plants by Marceau et al. (2006) for process water, but adjusted for non-process water to account only for non-process water relating to 'Contact cooling water' and 'Non-contact cooling water', excluding water relating to 'Road dust suppression', 'Non-road dust suppression', 'Other laboratory and grounds', 'CKD landfill slurry' and 'Other'. Average water consumption factors are used for Verticle Shaft and Other Rotary Kilns, with Specific factor available only for Precalciner kilns (Marceau et al., 2006) (Table A12). The original quantities of water reported in kg/t cement were adjusted to m^3/tonne clinker using a clinker ratio of 0.95 (Table A12, Table A13).

TABLE A12: WATER CONSUMPTION PER KILN TYPE

KILN TYPE	CALCULATION: PROCESS WATER USE (m^3/ t clinker)	CALCULATION: NON PROCESS COOLING WATER (m^3/ t clinker)	CALCULATION: NON PROCESS OTHER WATER (m^3/ t clinker)
Precalciner	0.01	0.55	0.07
Average	0.09	0.71	0.08

SOURCE: MARCEAU ET AL. 2006

TABLE A13: NON-PROCESS WATER USE

WATER	WET	LONG DRY	PREHEATER	PRECALCINER	AVERAGE*
	Kg/ t of cement				
Contact cooling water	4	111	82	73	68
Non-contact cooling water	480	791	859	405	544
Road dust suppression	18	25	75	19	28
Non-road dust suppression	6	7	7	4	5
Other Laboratory and grounds	1	0	5	13	8
CKD landfill slurry	10	0	0	0	2
Other	2	94	<1	24	27
Total*	521	1028	1028	537	682

SOURCE: MARCEAU ET AL. 2006 *For Precalciner type kiln, water use data was directly used but was averaged for other types of kiln

A.1.5 OTHER OPERATIONAL DATA

TABLE A14: CEMENT TO CLINKER RATIO REPORTED FOR CEMENT PRODUCTION IN CHINA

YEAR	REPORTED VALUE	SOURCE
2005	72.9[a] , 71.6[b]	a - Ke, Zheng, Fridley, Price, & Zhou, 2012
2006	70.6[a], 70.7[b]	b - Ke, McNeil, Price, Khanna, & Nan, 2013
2007	70.3[a,b]	c - Xu, Fleiter, Fan, & Eichhammer, 2014
2008	68.8[a,b]	
2009	65.8[a] , 64[b]	
2010	62[c], 61.7[b]	
2011	63[c], 62.6[b]	

SOURCE: COMPILED BY TRUCOST

A.1.6 SUPPLY CHAIN QUANTIFICATION: AIR POLLUTION, MERCURY, GHG, WATER USE ESTIMATION

The quantity of raw materials required for the production of a ton of clinker (Table A15) was multiplied by global average emission factors for each impact category (Ecoinvent, 2015). For each material, lifecycle inventories were evaluated to obtain emissions associated with 1 kg of each material made available in the market place. Since the sourcing location for Chinese cement is unspecified, global average emissions from production of each material were assumed (Table A16, Table A17).

TABLE A15: AVERAGE AMOUNT OF RAW MATERIAL REQUIRED IN CEMENT PRODUCTION

RAW MATERIAL	GLOBAL AVERAGE RAW MATERIAL REQUIREMENT PER 0.95/t CLINKER[1]	GLOBAL AVERAGE RAW MATERIAL REQUIREMENT PER 1/t CLINKER[2]
Limestone	1.41	1.484
Clay	0.139	0.146
Sand	0.034	0.036
Iron Ore	0.015	0.016
Clinker	**0.95**	**1.00**

SOURCE: [1]HUNTZINGER & EATMON, 2008 [2]TRUCOST CALCULATIONS

TABLE A16: ECOINVENT INVENTORY RECORDS USED FOR GLOBAL AVERAGE EMISSIONS FROM RAW MATERIALS

RAW MATERIAL	RECORD NAME
Limestone	Market for limestone, crushed, for mill, GLO, (Author: Guillaume Bourgault inactive)
Sand	Market for sand, GLO, (Author: [System] inactive)
Clay	Market for clay, GLO, (Author: [System] inactive)
Iron Ore	Market for iron ore, crude ore, 46% Fe, GLO, (Author: [System] inactive)
Electricity	Market for electricity, medium voltage, CN, (Author: Karin Treyer active)
Coal	Hard coal mine operation, CN, (Author: Karin Treyer inactive)

SOURCE: COMPILED FROM ECOINVENT VERSION 3.1 2014

TABLE A17: EMISSIONS FROM MATERIAL USE FOR 1 KG OF RESPECTIVE RAW MATERIAL PRODUCTION

KPI	UNIT	LIMESTONE	SAND	CLAY	IRON ORE	ELECTRICITY	COAL
Water (Lake, river, unspecified natural origin and well, in ground)	m^3 (10-4)	2.2	14.3	0.1	0.3	27.1	35.0
Mercury to Air	Kg (10-11)	6.4	35.2	9.3	29.8	2780.0	444.0
GHG (GWP 100a)	kg CO_2-Eq (10-3)	2.2	10.1	4.8	6.6	844.0	877.0
NO_x	Kg (10-6)	50.9	75.2	51.6	158.0	3480.0	517.0
VOC	Kg (10-6)	8.6	12.8	8.3	26.1	60.7	36.5
SO_x	Kg (10-6)	6.1	37.6	8.5	20.7	7700.0	4210.0
PM (sum of all categories)	Kg (10-6)	181.0	20.9	9.4	2900.0	1690.0	1270.0
particulates >10 µm	Kg (10-6)	121.0	9.7	3.3	1450.0	981.0	415.0
particulates, >2.5 µm and <10	Kg (10-6)	48.0	3.9	1.5	1300.0	90.5	97.5
particulates, < 2.5 µm	Kg (10-6)	11.9	7.3	4.6	152.0	618.0	753.0

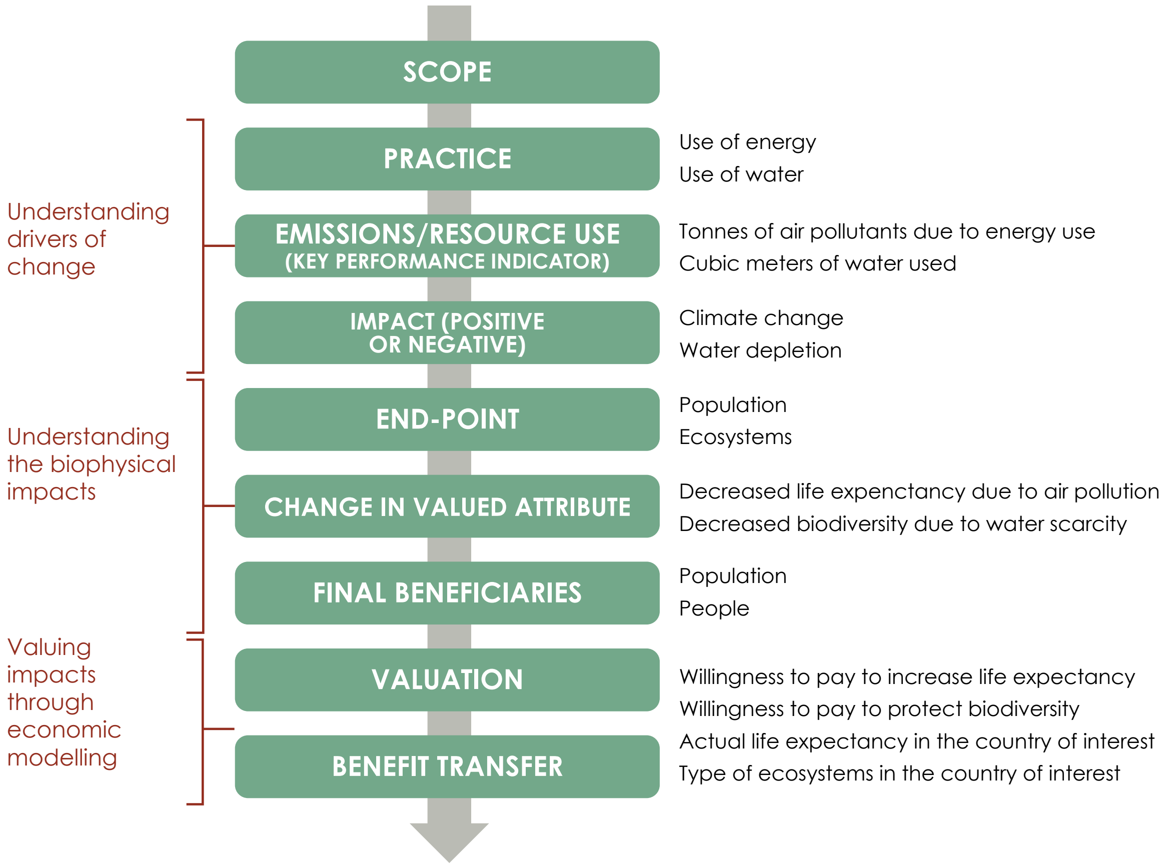
SOURCE: COMPILED FROM ECOINVENT VERSION 3.1 2014

A.2 MONETIZATION METHODOLOGY

A.2.1 FRAMEWORK FOR ASSESSMENT

Monetization coefficients enable the conversion of data on emissions and resource use into a valuation of the impact this has on people and their wellbeing. There are 3 steps to a valuation exercise: understanding and quantifying the environmental footprint across 3 impact areas (air pollution, GHGs and water) in biophysical terms; estimating the likely environmental changes that result from these emissions or resource use based on local environmental context (for example, from increases in the concentration of pollution); and finally converting the biophysical metrics into monetary terms that reflect the change in wellbeing of specific beneficiaries from the change in valued attribute (Figure A3).

FIGURE A3: OVERALL FRAMEWORK



SOURCE: ADAPTED FROM KEELER ET AL. 2012. EXAMPLES PRESENTED ALONGSIDE FRAMEWORK ARE FOR ILLUSTRATIVE PURPOSES ONLY

UNDERSTANDING AND QUANTIFYING DRIVERS OF CHANGE

The first step is to understand the drivers of change by devising appropriate key performance indicators (KPIs) that measure their extent. For example, energy use in manufacturing processes could lead to global warming or acidification, through the emission of greenhouse gases and other pollutants measured in metric tons.

KPIs and related impacts can be quantified through primary and secondary data collection. Primary data collection refers to the use of actual, measured data. Generally the more company specific data the better the results and usefulness for decision-making. Secondary data collection can be performed using lifecycle (LCA) studies, academic research and input-output modelling. The choice of methodology is mainly driven by the aim of the study and data availability.

UNDERSTANDING THE CONSEQUENCES OF IMPACTS

The second step is to understand the consequence of the impact to a specific end-point, the primary receptor of the impact – society, the environment, or the business itself. Each impact can have several end-points. For example, water depletion (negative impact) can affect society (end-point 1) through lack of drinking water and decreased food supply, and the environment (end-point 2) through decreased water availability to sustain fauna and flora. It can also affect the business itself (end-point 3) through increased water scarcity in a specific location.

Impacts are quantified in biophysical terms. Examples of metrics, or 'valued attributes', could include changes in life expectancy or changes in species richness due to the emission of pollutants. Biophysical models are used to estimate these metrics, basedon a thorough literature review adapted to reflect local conditions. For example, the extent to which water pollution impacts society through decreased life expectancy depends on local social and environmental factors such as the access to drinking water and pollutant dispersion based on hydrological patterns.

The choice of valued attribute is informed by both the scope and requirements of the study and as importantly by how it feeds in step 3 – economic modelling. One limitation of some valuation frameworks is that biophysical (step 2) and economic modelling (step 3) are conducted in isolation, leading to a discrepancy in metrics. For example, water quality metrics are often not connected with what the society values - recreational tourists do not value the concentration of phosphorus or other water pollutants, but rather water clarity (Keeler, et al., 2012).

VALUING IMPACTS IN MONETARY TERMS

The third step consists of converting the biophysical metrics into monetary terms that reflect the change in wellbeing of specific beneficiaries from the change in valued attribute caused by business activities. Regardless of the end-point (step 2: society, the environment or the business itself), valuation itself is inherently human-centric. Costs and benefits are thus human-centric, even in the case where the end-point is the environment. For example, the costs and benefits of a change in biodiversity are valued based on the services that biodiversity provides to society. This is consistent with the approach taken in the international Millennium Ecosystem Assessment, which focuses on contributions of ecosystems to human well-being while at the same time recognizing that potential for non-anthropocentric sources of value.

The change in wellbeing approach (also known as damage, or social cost method) is in most cases a preferred alternative to three alternative value perspectives that include market pricing and marginal cost of abatement (Table A18). This is because it tends to best reflect the true scale of the impact caused, measuring the change from the perspective of those affected by the change in environmental quality. It also reflects a wide range of business risks including regulatory, community unrest and license to operate, consumer pressure and future market demand. Recent initiatives that aim to standardize practices in valuation tend to also focus on changes in wellbeing mainstreaming it into the business world. These include the World Business Council for Sustainable Development (WBCSD) – Guide to Corporate Ecosystem Valuation; the Economics of Ecosystems and Biodiversity (TEEB) - for Business Report; and the Natural Capital Protocol being developed by the Natural Capital Coalition.

Market pricing, which includes prices currently paid for business such as carbon tax, or water consumption permit charges, has the advantage of being easily accessible. Carbon pricing schemes are also steadily increasing in terms of their global reach and theoretically provide the flexibility to reduce emissions at the lowest cost across the economy. However, given that most environmental impacts are non-market ('external costs') prices for the majority of impacts are mostly unavailable, whilst prices in markets that do exist (such as the EU Emission Trading Scheme) are often driven by political factors rather than supply and demand of environmental services. The cost of abatement approach refers to the private cost incurred by a business to reduce impacts, for example the cost incurred by a cement company to invest in abatement technology to reduce air pollution. Comparison across emitters is also difficult because costs of abatement depend on the existing technology installed and the options for improvement which are different for different businesses, segments and over time.

TABLE A18: REVIEW OF ALTERNATIVE VALUE PERSPECTIVES

	MARKET PRICE	MARGINAL ABATEMENT COST	SOCIAL COST
DEFINITION	Paid by businesses	Private cost of reducing impacts	Change in human wellbeing
USES	Carbon tax, water consumption permit price	Cost of reducing air pollution by changing fuel type	Reduction in quality of health
ADVANTAGES	• Easily accessible • Reach of carbon pricing for example steadily increasing • Emissions trading provides flexibility to reduce emissions at lowest cost across economy	• Based on known actual costs of existing reduction efforts, making them valuable tools for shaping policy, investment and forecasts	• A true measure of impact • Used by policy makers for regulation • Reflect wide range of business risks • A number of recent initiatives based on this
LIMITATIONS	• Most impacts are non-market • Does not reflect scale of impact on people • Price in existing markets driven by political factors Market volatilities make price comparisons hard	• Does not reflect scale of impact on people • Costs vary across businesses and overtime. Comparison is difficult	• Contingent on assumptions • Contingent on discount rates and equity weighting

Several techniques exist to assign a value to a change in wellbeing of specific beneficiaries from a business action (Table A18). These span from observing behavior on already-existing alternative markets as a proxy, for example how much is spent on aquatic recreational activities reflecting, or creating artificial markets by asking population their willingness-to-pay for the existence of wildlife habitat. Secondary valuation methods rely on primary monetary valuations that are conducted in another location. Therefore, the primary monetary value is adjusted to better reflect the local value at the secondary location based on a number of factors, for example, population density or the amount of forest cover. Secondary valuations are conducted where there time and data constraints means a primary valuation is not possible or practical.

TABLE A19: MONETARY VALUATION TECHNIQUES

NAME	DEFINITION	EXAMPLE	LIMITATIONS
Secondary monetary valuation methods			
Benefit (Value) Transfer	The transfer of values from one location or context to another	Recreational benefits of forest in Brazil to a similar forest in Peru	Calculations can only be as accurate as the original study
Primary monetary valuation methods			
Revealed Preferences - **Market Price**	The value of environmental goods or services are directly observed in markets	The value of timber traded between companies	The true economic value may not be observed in the market
Revealed Preferences – **Hedonic Pricing**	Observed change in property prices due to environmental changes	The proximity of a lake to a house that affects its price	Not all environmental changes affect property prices
Revealed Preferences – **Travel Cost Method**	This sums the value of the cost incurred travelling to a site	The cost of travel, entrance fees and the value of time when visiting a park	This assumes that the trip takes place for a single purpose
Stated Preferences – **Contingent Valuation**	Asks for respondents to state their willingness to pay or accept for environmental changes	Surveying residents on how much they are willing to pay to not develop a local park	There can be large differences between willingness to pay and accept compensation
Stated Preferences – **Choice Modelling**	A questionnaire that is designed to elicit the most desired attributes of a good or service by presenting combinations	A survey on a plan to improve drinking water, looking at reliability, quality, disruption etc…	The aspects or consequences of the trade-offs may not be well understood
Cost Based Methods	Values the damage or the replacement cost of environmental goods or services	The cost of replacing a forest that filters water with a water treatment plant	Costs are not always an accurate measure of benefits received

SOURCE: COMPILED BY TRUCOST FROM VARIOUS SOURCES INCLUDING SPURGEON ET AL. (2011) AND KING ET AL. (2000)

Trucost chooses valuation techniques based on data availability and suitability. Trucost has been consistent in its application of valuation techniques across all end-points. For example, the change in life expectancy has been valued the same regardless of whether it is caused by malnutrition due to water depletion, or by the inhalation of air pollutants.

Value is highly contingent on local conditions. In order to estimate costs or benefits in a context when no study exists, Trucost relies on secondary valuation value transfer method. In this method, the goal is to estimate the economic value of ecosystem services or impacts by transferring available information from completed studies, to another location or context by adjusting for certain variables. Examples include population density, income levels, and average size of ecosystems to name just a few.

Best practice guidelines for value transfers have been set out by UNEP in their Guidance Manual on Value Transfer Methods for Ecosystem Services (Brander, 2004). Where possible, Trucost has endeavored to follow these guidelines in all of its value transfer calculations. It is important to note, however, that value transfers can only be as accurate as the initial study (Ecosystem Valuation, 2000). In some instances, studies from different ecosystems and geographies have had to be ubiquitously used throughout a valuation methodology due to data availability and data quality.

Importantly, the majority of environmental impacts of businesses are currently losses because typical business activities consume natural resources rather than regenerating or replacing these resources and the ecological services linked with them. However there are a number of ways companies can enhance and restore the environment. Figure A4 illustrates both the scope of the project's valuations and how a company's emissions and resource use result in changes to the environment and in turn this affects people through changes in their wellbeing.

FIGURE A4: SCOPE OF VALUATIONS

IMPACT AREA	EMISSIONS AND RESOURCE USE	ENVIRONMENTAL CHANGE	CHANGE IN WELLBEING
AIR POLLUTION	Emissions of pollutants ($PM_{2.5}$, $PM_{2.5-10}$, PM_{10}, NO_x, SO_x, VOCs, Mercury)	Increase in concentration of pollution	Human health impacts (e.g. respiratory disease); Biodiversity impacts
GREENHOUSE GAS EMISSIONS	Emissions of greenhouse gases (CO_2e) in kg	Climate change	Range of impacts e.g. health impacts, economic losses due to sea level rise, change in natural environment
WATER CONSUMPTION	Water consumption in m^3	Increase in water scarcity	Malnutrition; Biodiversity impacts

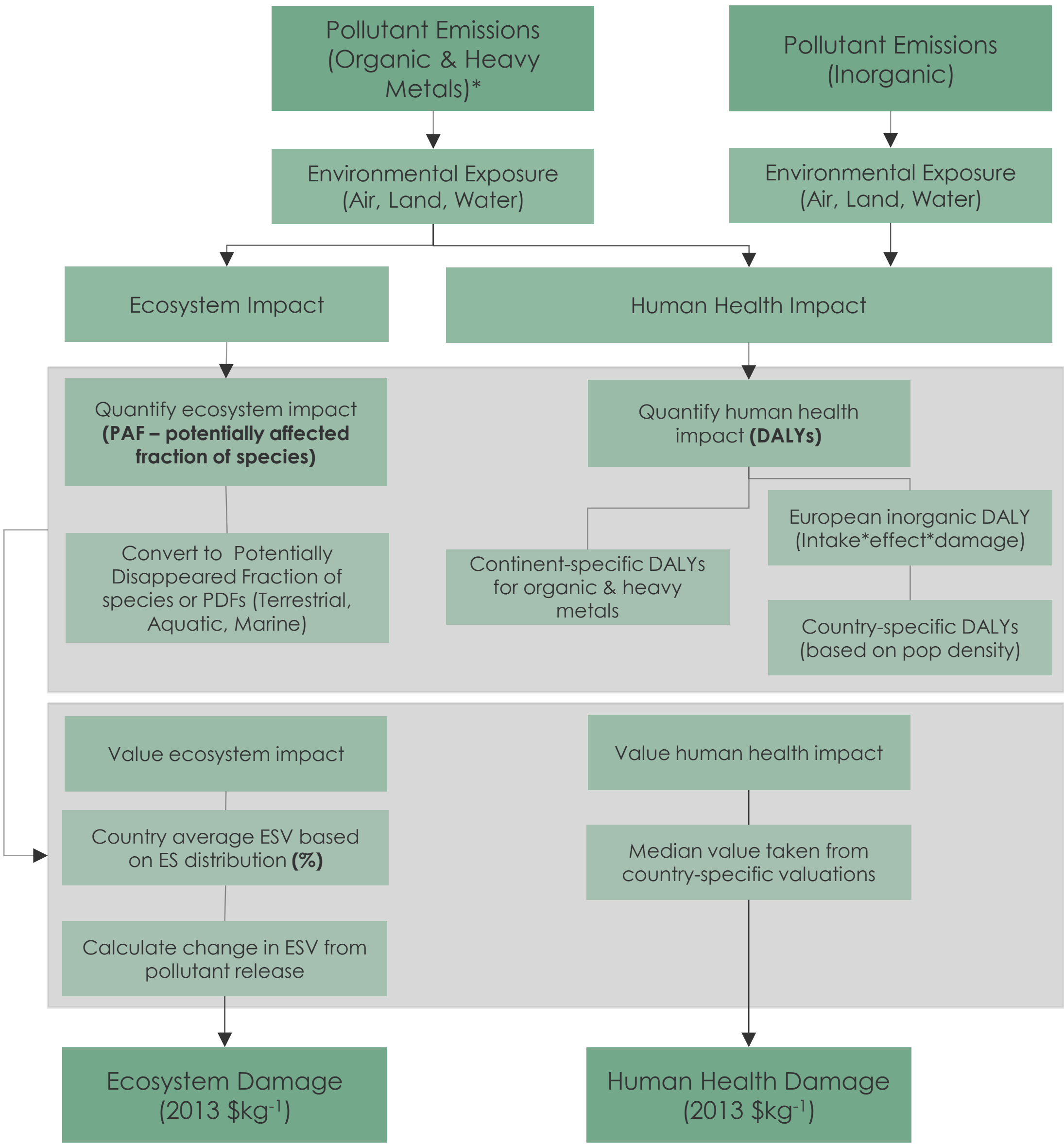
SOURCE: TRUCOST PLC 2015

A.2.2 MONETIZATION COEFFICIENTS FOR AIR POLLUTION

GENERAL PROCESS

Figure A5 summarizes the overall approach used to value the emission of air pollutants. The first shaded box indicates the steps taken to quantify the environmental impact of air pollutants, whereas the second indicates the steps taken to value these impacts.

FIGURE A5: GENERAL OVERVIEW OF TRUCOST VALUATION PROCESS FOR AIR POLLUTANTS



ESV: Ecosystem Services Value

DALY: Disability Adjusted Life Years

ES: Ecosystem Services

Inorganic pollutants include carbon monoxide (CO), sulphur dioxide (SO_2), nitrous oxides (NO_x), ammonia (NH3), particulate matter (PM), and volatile organic compounds (VOCs)

*Organic pollutants and heavy metals are grouped together due to the similarity in methodology, not chemical properties.

GENERAL PROCESS

IMPACT ON HUMAN HEALTH: BIOPHYSICAL MODELLING

Organic substances and heavy metals (mercury)

Trucost uses disability adjusted life years (DALYs) as a measure of the impact on human health from environmental impacts. In order to calculate the quantity of DALYs lost due to the emission of pollutants to air, Trucost used USES-LCA2.0 (EC, 2004; National Institute of Public Health and the Environment, 2004). This model, originally developed in the context of life cycle assessment (LCA) studies, calculates the quantity of DALYs lost due to emission of over 3,300 chemicals to; freshwater and seawater; natural, agricultural and industrial soil; and rural, urban and natural air. USES-LCA2.0 takes into account the impact of cancer and non-cancer diseases caused by the ingestion of food and water, and the inhalation of chemicals.

The output of this analysis step is the number of DALYs lost due to the emission of each pollutant, to a specific media, at the continental level. Note that organic substances and heavy metals are grouped together due to the similarity in methodology, not their chemical properties.

Sulphur dioxide, nitrogen oxide, and particulate matter

USES-LCA2.0 does estimate DALY impacts for common inorganic air pollutants such as sulphur dioxide, nitrogen oxide and PM_{10}. Adaptation of USES-LCA2.0 to model these substances would result in higher than acceptable uncertainty due to the different characteristics of organic and inorganic substances. Trucost thus conducted a literature review to find an alternative method to quantify the DALY impact of emission of these pollutants (Zelm, et al., 2008).

IMPACT ON HUMAN HEALTH: ECONOMIC MODELLING

Once the quantity of DALYs lost is calculated, several valuation methods can be used to put a monetary value on a DALY, such as the cost of illness, the value of a statistical life (VSL), and the value of a statistical life year (VOLY). Trucost decided to use the WTP technique utilized in the VOLY method to value DALYs, as it encompasses most aspects relating to illness and expresses the value of a year of life to the wider population. To value DALYs, Trucost used the results of a stated preference study conducted in the context of the New Energy Externalities Development for Sustainability (NEEDS) project (Desaigues et al., 2006; 2011). This is a proactive cost estimate, which takes into account the perceived effects of morbidity. The value of a life year used in this methodology is just in excess of $46,500.

IMPACT ON ECOSYSTEMS: BIOPHYSICAL MODELLING

Organic substances and heavy metals

USES-LCA2.0 models the impact of polluting substances emitted to air, land and water, on terrestrial, freshwater and marine ecosystems. This model was adopted by Trucost for assessing the ecosystem damage caused by organic substances and heavy metals. It follows the same modelling steps as for human toxicity, namely exposure assessment; effect assessment; and risk characterization. USES-LCA2.0 has also been adapted to generate results at a continental level.

USES-LCA2.0 estimates the potentially affected fraction of species (PAF) due to the emission of pollutants to air, land and water. It is important to note that affected species need not disappear. Trucost adjusted the PAF results to reflect the proportion of species disappeared (PDF) using assumptions from the Eco-Indicator 99 model (Goedkoop & Spriensma, 2000). This was done to match the valuation methodology which uses PDF (and not PAF) as an input, due to data availability.

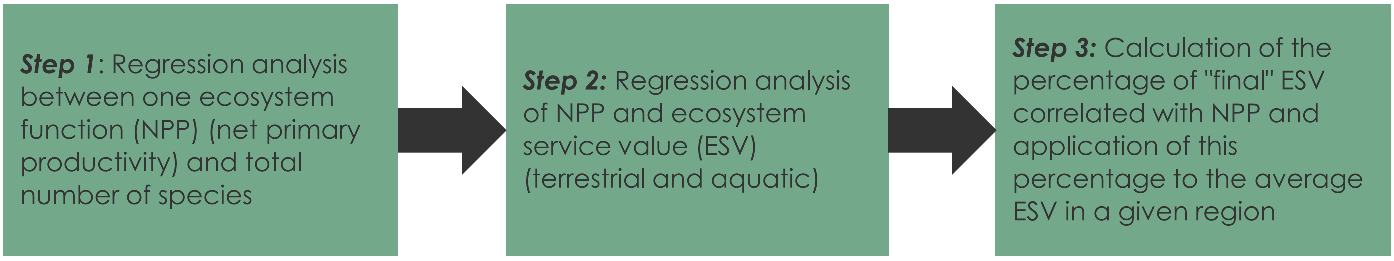
Ozone, sulphur dioxide, nitrogen oxide, and particulate matter

Impact on ecosystems has not been included for ozone, sulphur dioxide, nitrogen oxides and PM_{10}.

IMPACT ON ECOSYSTEMS: ECONOMIC MODELLING

Trucost's approach to valuing a change in the PDF of species follows a three step process, as shown in Figure A6.

FIGURE A6: STEPS FOR CALCULATING THE VALUE OF ECOSYSTEM SERVICES LINKED DIRECTLY TO BIODIVERSITY



In this methodology, Trucost decided to assess the link between biodiversity, measured species richness (IUCN, 2015), net primary productivity (NPP) (Costanza et al., 2007), and ecosystem service value (ESV). NPP was chosen over other ecosystem processes, such as nutrient cycling, due to data availability, and its direct link with key ecosystem services. A monetary value for the provisioning, regulating and cultural services by terrestrial ecosystem type was first calculated based on the analysis of De Groot et al. (2012) using the specific ecosystem split per country (Olson et al., 2004). De Groot et al. calculate the minimum, maximum, median, average and standard deviation for each service provided by key terrestrial and aquatic ecosystems. Finally, Trucost calculated the percentage difference pre- and post-change of ESV at a country and substance level, and applied this percentage to the average value of one square meter of natural ecosystem in a given region. This aligns with the results of USES-LCA2.0, which calculates change of species richness, or PDF, at a continental level.

A.2.3 MONETIZATION COEFFICIENTS FOR GREENHOUSE GASES

GENERAL PROCESS

Trucost values greenhouse gas (GHG) emissions, usually expressed in tons of carbon dioxide equivalents (CO_2e)[1], using the social cost of carbon (SCC). The SCC is typically considered best practice as it reflects the full global cost of the damage generated by GHG emissions over their lifetime. The SCC is also applicable to emissions globally, which is not the case with other common approaches such as the market price method (emissions trading schemes: ETS) and the marginal abatement cost (MAC).

ETS are generally promoted for their flexibility to reduce emissions at the lowest cost for the economy and their steadily increasing reach showing promise at a global level (World Bank Group, 2014). However, traded market prices currently face a number of limitations which prevents their use as a valuable pricing and decision-making tool. For example, they do not reflect non-traded carbon costs nor the impact of other market-based mechanisms such as subsidies for fossil fuels or support for low carbon technologies; they have been historically slow to come about and fragmented; and they can be impacted by sudden economic changes reducing the carbon price to levels that undermine the incentive for polluters to cut emissions (Krukowska, 2014).

MAC is based on the known actual costs of existing reduction efforts which renders it a valuable tool for shaping policy discussions, prioritizing investment opportunities and driving forecasts of carbon allowance prices. It too does not reflect non-traded carbon costs, severely underestimating the cost of GHG emissions; is highly time and geography specific with costs of reduction fluctuating over time, by sector and by geography; and estimates are influenced by fossil fuel prices, carbon prices and other policy measures.

The SCC is an estimate of the monetized damages associated with an incremental increase in GHG emissions in a given year. To estimate the SCC, Integrated Assessment Models (IAMs) are used to translate scenarios for economic and population growth, and resulting emissions, into changes in atmospheric composition and global mean temperature. Trucost bases its SCC valuation on the Interagency Working Group on Social Cost of Carbon values reported at the 95th percentile under a 3% discount rate, which represents higher than expected impacts from temperature change further out in the tails of SCC distribution (IWGSCC, 2013). This is to address material omissions due to current modelling and data limitations such as lack of precise information on the nature of damages and because the science incorporated into these models naturally lags behind the most recent research. Table 20 summarizes the valuation of GHG emissions in each respective year.

[1] Carbon dioxide is only one of many GHGs, such as methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. CO_2e (carbon dioxide equivalents) is a measure that takes into account the emission of other GHGs when calculating the level of GHG emissions

TABLE A20: US EPA REVISED SCC, 2010-2014 ($ PER METRIC TON OF CO_2, DOLLAR-YEAR AND EMISSIONS-YEAR SPECIFIC)

DISCOUNT RATE YEAR	3.0 % 95TH
2010	93
2011	101
2012	107
2013	113
2014	120

IMPACTS: BIOPHYSICAL AND ECONOMIC MODELLING

Over 300 studies attempt to put a price on carbon, quantifying and valuing the impact of climate change on agricultural productivity, forestry, water resources, coastal zones, energy consumption, air quality, tropical and extra-tropical storms, property damages from increased flood risk and human health. The IAMs apply 'damage functions' that approximate the global relationships between temperature changes and the economic costs of impacts such as changes in energy (via cooling and heating) demand; changes in agricultural and forestry output from changes in average temperature and precipitation levels, and CO_2 fertilization; property lost to sea level rise; coastal storms; heat-related illnesses; and some diseases (for example malaria and dengue fever). Finally, the models translate future damages, going as far out as to year 2300, into present monetary value using a discount rate.

Out of the many studies that attempt to calculate a SCC, Trucost has chosen to use the SCC estimates provided by the US Interagency Working Group's SCC (IWGSCC, 2013) for a number of reasons:

- These SCC calculations are based on three well-established Integrated Assessment Models (IAMs), which renders the estimate robust and credible.
- The SCC calculations incorporate the timing of emission release (or reduction), which is key to the estimation of the SCC. For example, the SCC for the year 2020 represents the present value of the climate change damages that occur between the years 2020 and 2300 and are associated with the release of CO_2e in year 2020. Results are also presented across multiple discount rates (2.5%, 3% and 5%) because no consensus exists on the appropriate rate to use. This allows flexibility in the choice of discount rate according to project objectives.
- They are also based on continuous improvement loops ensured through regular feedback workshops with experts in the field, transparency and integrating the latest scientific evidence. As a result, the latest 2013 update provides higher values than those reported in the 2010 technical support document, and incorporates updates of the new versions of each underlying IAM.

However, SCC valuations are highly contingent on assumptions, in particular the discount rate chosen, the emission scenarios and equity weighting discussed in the following sections.

LIMITATIONS

Despite being the most complete measure of the damage caused by GHG emissions, SCC estimates have attracted much criticism as they omit or poorly quantify some major risks associated with climate change. This includes social unrest and disruptions to economic growth; ocean acidification (notably Tol's Fund model); biodiversity, habitat and species extinction; and damages from most large-scale earth system feedback effects such as Arctic sea ice loss and changing ocean circulation patterns (Howard, 2014; Kopits, 2014).

Three well-established IAMs which form the foundation of the US Interagency Working Group's SCC estimates have received most attention in the literature: DICE -2010, FUND 3.8, and PAGE09. Some of the limitations of these models are summarized below:

- Extensive experiments with DICE by a range of researchers have shown that with small, reasonable changes to the basic data, DICE can yield very different projections.
- PAGE sets a relatively high temperature threshold for the onset of catastrophic damages.
- The FUND model was found by the Heritage Foundation's Centre for Data Analysis (CDA) to be extremely sensitive to assumptions; so sensitive that at times it even suggests net economic benefits to GHG emissions (Dayaratna and Kreutzer, 2014). According to the FUND model, change in temperature up to 3°C is contributing beneficially to the environment (IWGSCC, 2010).

SCC estimates also vary across studies from below-zero to four-figure estimates, mainly due to the four factors that have been outlined below:

- **Emissions scenarios:** In order to derive the SCC, assumptions need to be made on future emissions, the extent and pattern of warming, and other possible impacts of climate change, to translate the impacts of climate change into economic consequences.
- **Equity weighting:** A global SCC can take into account variations in the timings and locations at which the costs of climate change impacts will be internalized, which may differ from the locations where the GHGs are emitted. Some studies including Stern (2006) and Tol (2011) take account of equity weightings – corrected for differences in the valuations of impacts in poor countries.
- **Uncertainties:** The variation in valuations is influenced by uncertainties surrounding estimates of climate change damages and related costs. The mean estimate of the SCC, as well as the standard deviation, have declined since 2001, suggesting either a better understanding of the impacts of climate change, or the convergence of methodologies (Ibid).
- **Discount rate:** Higher discount rates result in lower present day values for the future damage costs of climate change. The very long time scale of climate change makes the discount rate crucial at the same time as it makes it highly controversial, with consensus is not yet fully established (IPCC, 2014). For example, Stern (2006) uses a discount rate of 1.4%. As a reference point, discount rates used by the US EPA (2013) range between 2.5% and 5%.

SENSITIVITY ANALYSIS

To illustrate the sensitivity of estimates to discount rates, using a discount rate of 1%, the discounted value of $1 m 300 years [from today] is around $50,000 today. But if the discount rate is 5%, the current value is less than 50 cents (Burtraw and Sterner, 2009). This range of discount rates, which span those commonly used in calculating the SCC, lead to differences in net present value after three hundred years that vary by a factor of one hundred thousand (Bell, 2011).

Within standard lifecycle analysis frameworks, impacts and benefits are not discounted, and the same value is attributed to an impact (benefit) happening today and in the future. Potential arguments for no temporal discounting include the ethical consideration of not considering emissions that happen in the future and impact future generations as less important as damages to the present generation, and the 'polluter pays principle' stating that agents causing damages should be accountable for the full extent of the impact caused.

An alternative approach is to use a positive temporal discounting which places less significance on future impacts (benefits) than on present ones. This stems from the concept of pure time preference, stating that individuals prefer benefits occurring in the present rather than in the future; that future generations will be richer and a dollar is worth less to them as a result; and recognizing the opportunity cost of capital. The Stern Report used a social discount rate of 1.4% in its analysis of the future cost of carbon, which was considered low at the time of publication, compared to Nordhaus, who currently uses a discount rate of 3% in the near term (Bell, 2011).

Some consensus is also building for using declining rates over time (IPCC, 2014). Literature suggests that if there is a persistent element to the uncertainty in the rate of return to capital or in the growth rate of the economy, it will result in an effective discount rate that declines over time (RFF, 2012). This approach would yield a higher present value to the long-term impacts of climate change and thus a higher value for the SCC (Arrow et al., 2014).

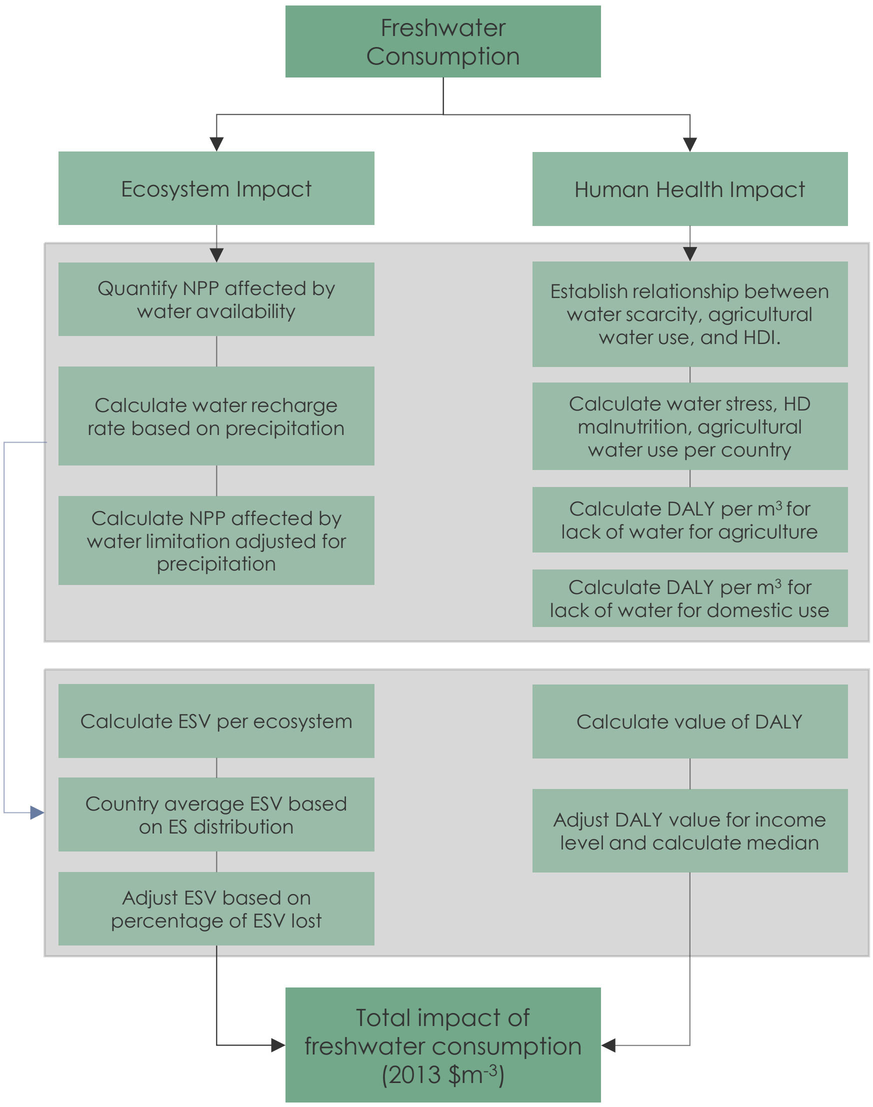
In light of existing disagreement, the US Interagency Working Group displays the average SCC for discount rates of 5%, 3% and 2.5%, with 3% being the central value (IWGSCC, 2013). It also recommends presenting the results undiscounted (using a discount rate of 0%).

A.2.4 MONETIZATION COEFFICIENTS FOR WATER CONSUMPTION

GENERAL PROCESS

Figure A7 summarises the overall approach used to value water consumption. The first shaded box indicates the steps taken to quantify the environmental impact of water consumption, the second indicates the steps taken to value these impacts.

FIGURE A7: GENERAL OVERVIEW OF TRUCOST VALUATION PROCESS FOR WATER CONSUMPTION



NPP: Net Primary Productivity
ESV: Ecosystem Services Value
HDI: Human Development Index
DALY: Disability Adjusted Life Years

IMPACT ON HUMAN HEALTH: BIOPHYSICAL MODELLING

The quantification methodology for human health impacts due to water consumption was developed using an estimate of the disability adjusted life years (DALY) lost per unit of water consumed as reported in Eco-indicator 99 (Goedkoop & Spriensma, 2000). The impacts due to lack of water for irrigation and lack of domestic water are both quantified in 'DALYs per cubic meter' of water abstracted.

Lack of water for irrigation

In order to quantify human health impacts associated with malnutrition as a result of lack of water for irrigation, the methodology developed by Pfister (2011) was applied. This parameter is country-specific and depends on several variables such as water stress, the share of total water withdrawals used for agricultural purposes, the human development factor, and the per-capita water requirement to prevent malnutrition.

Lack of domestic water

For the quantification of human health impacts due to the spread of diseases, country-specific factors were sourced from Motoshita et al. (2010). This model is based on a multiple regression analysis and covers health impacts related to the incidence of diarrhea and three intestinal nematode infections: ascariasis, trichuriasis, and hookworm disease.

IMPACT ON HUMAN HEALTH: ECONOMIC MODELLING

Once the quantity of DALYs lost is calculated, several valuation methods can be used to put a monetary value on a DALY, such as the cost of illness, the value of a statistical life (VSL), and the value of a statistical life year (VOLY).

Trucost decided to use the WTP technique utilized in the VOLY method to value DALYs, as it encompasses most aspects relating to illness and expresses the value of a year of life to the wider population. To value DALYs, Trucost used the results of a stated preference study conducted in the context of the New Energy Externalities Development for Sustainability (NEEDS) project (Desaigues et al., 2006; 2011). This is a proactive cost estimate, which takes into account the perceived effects of morbidity. The value of a life year used in this methodology is just in excess of $46,500.

IMPACT ON ECOSYSTEMS: BIOPHYSICAL MODELLING

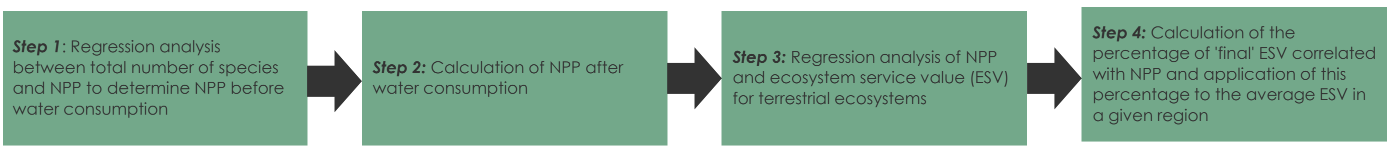
Impacts of water consumption on ecosystems were measured based on net primary productivity (NPP). NPP was considered here as a proxy to measure impacts on ecosystems, as it is closely related to the vulnerability of vascular plant species (Pfister, 2011). Furthermore, vascular plants are primary products in the food chain and are therefore essential for the healthy functioning of an ecosystem (Ibid). In addition, it is assumed that damage to vascular plants is representative of damage to all fauna and flora species in an ecosystem (Delft, 2010).

The objective of the biophysical modelling is to determine the fraction of NPP which is limited only by water availability, and thus captures the vulnerability of an ecosystem to water deficiencies. However, as the effects of water consumption on ecosystems depend on local water availability, NPP limited by water availability was adjusted for water scarcity. Thus, the parameter reflects the percentage of one square meter that will be affected by the consumption of one cubic meter of water in a year.

IMPACT ON ECOSYSTEMS: ECONOMIC MODELLING

Trucost's approach to valuing a change in NPP due to water abstraction follows a 4 step process, as displayed in Figure A8 below. The underlying approach calculates NPP before and after water consumption, and linking those to the ecosystem service value (ESV) before and after water consumption. This allowed quantifying the loss of ESV due to water abstraction.

FIGURE A8 STEPS FOR CALCULATING THE VALUE OF ECOSYSTEM SERVICES LINKED DIRECTLY TO BIODIVERSITY



Trucost first calculated the average NPP for each country in its database, based on the average NPP per ecosystem type (Costanza et al., 2007) and the ecosystem split per country (Olson et al., 2004). Species richness is based on the International Union for Conservation of Nature (IUCN) Red list, which provides at a country-level, the number of fauna and flora species, as well as their conservation status (IUCN, 2015).

Trucost then tested the strength of the relationship between NPP and species richness to assess whether a significant correlation exists. Trucost used this relationship to calculate the pre and post change in average NPP for each country in its dataset based on species richness

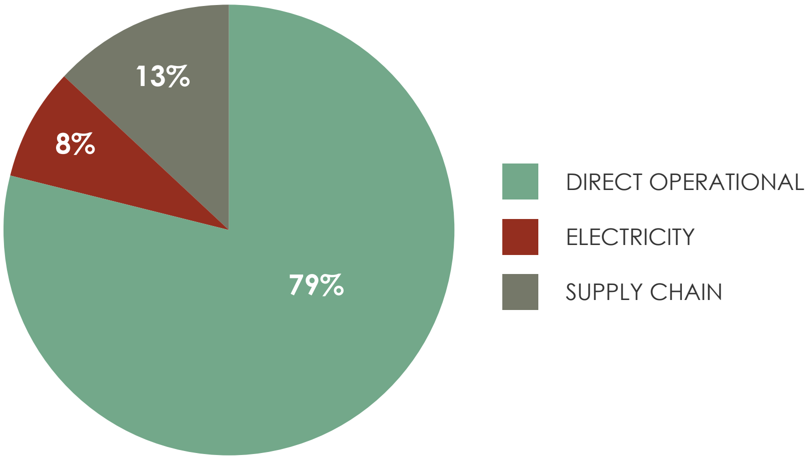
In order to calculate the post change NPP, Trucost used the NPP limited by water availability to estimate the change in NPP that is attributable to water consumption. By using the percentage of NPP affected by water availability, the NPP remaining after water consumption was determined.

A monetary value for the provisioning, regulating and cultural services by terrestrial ecosystem type was first calculated based on the analysis of De Groot et al. (2012). De Groot et al calculate the minimum, maximum, median, average and standard deviation for each service provided by key terrestrial ecosystems.

Finally, Trucost calculated the percentage difference between pre- and post-water consumption ESV at a country level. Trucost applied this percentage to the average value of one square meter of natural ecosystem in a given region to align with the results of the biophysical modelling.

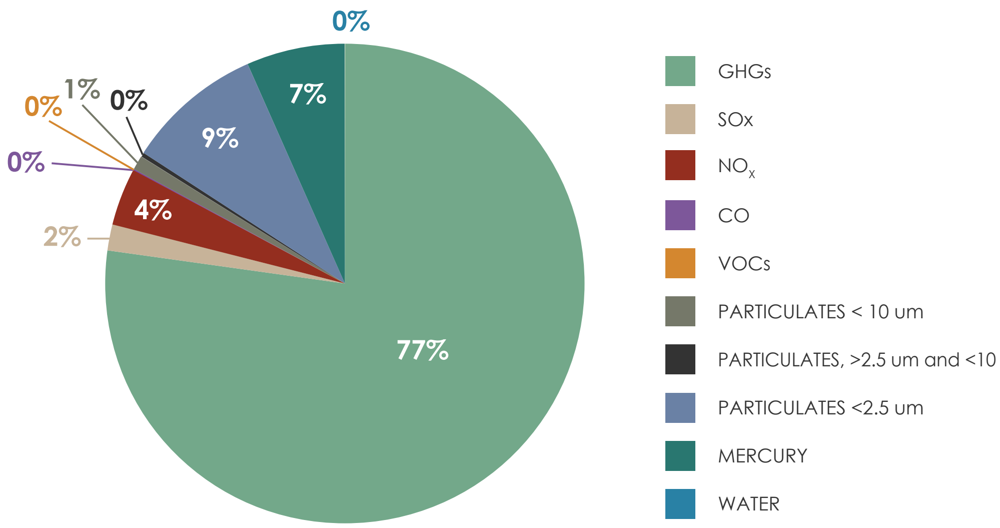
A.3 BENCHMARK RESULTS: OTHER MATERIAL IMPACTS

FIGURE A9: TOTAL EXTERNAL COST OF 32 CEMENT COMPANIES IN CHINA, BY VALUE CHAIN, 2013



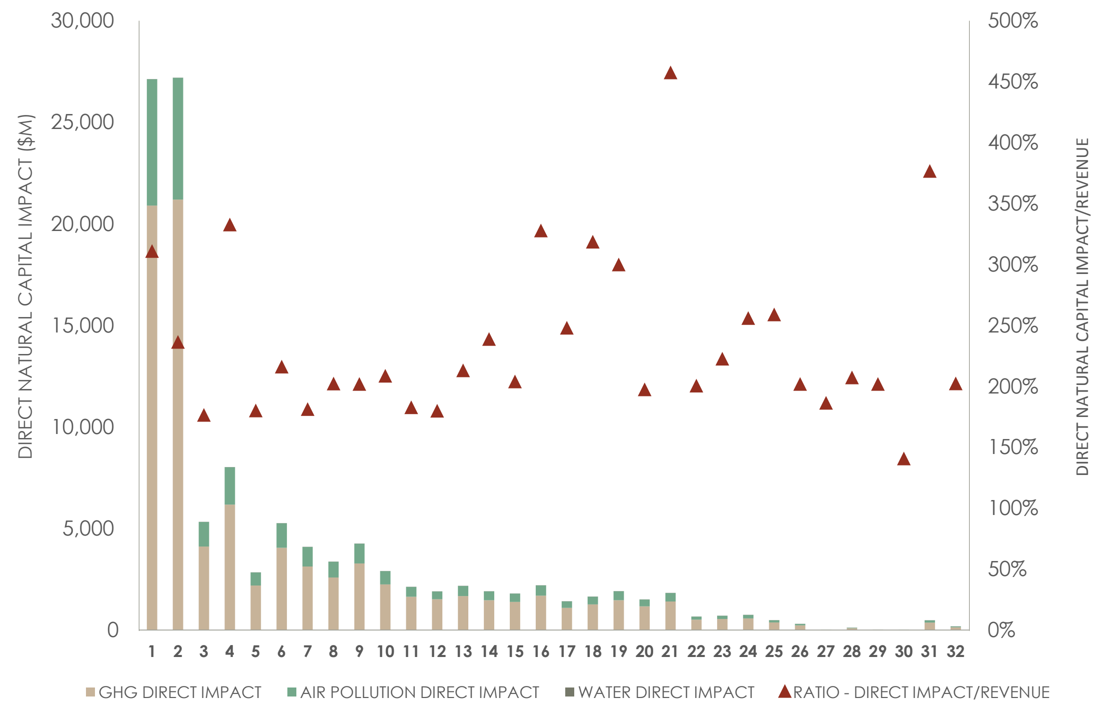
SOURCE: TRUCOST PLC 2015

FIGURE A10: AVERAGE EXTERNAL COST OF DIRECT OPERATIONS, BY KPI, 2013



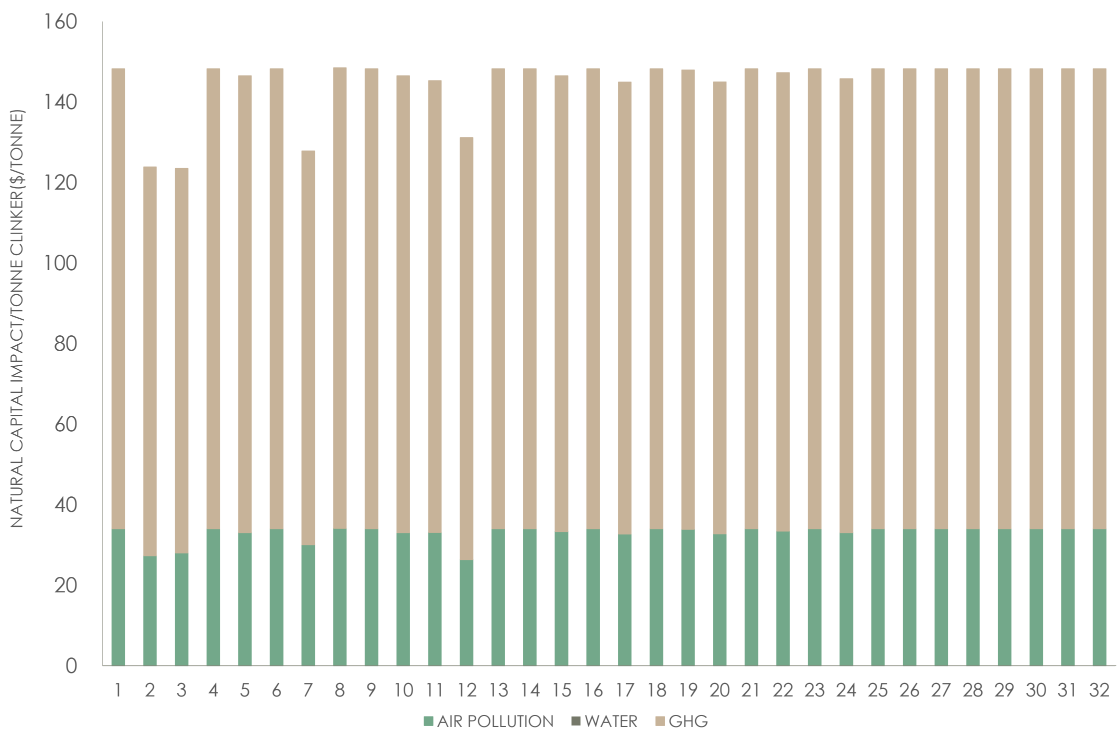
SOURCE: TRUCOST PLC 2015

FIGURE A11: TOTAL EXTERNAL COST OF DIRECT OPERATIONS, INCLUDING GHG EMISSIONS



SOURCE: TRUCOST PLC 2015

FIGURE A12: EXTERNAL COST OF DIRECT OPERATIONS PER TONNE OF CLINKER



SOURCE: TRUCOST PLC 2015

A.4 BEST PRACTICE POTENTIAL

A.4.1 TECHNOLOGICAL UPGRADES

TABLE A21: CLEAN PRODUCTION TECHNOLOGICAL UPGRADES FOR NSP KILNS IN CHINA

POTENTIAL TECHNOLOGICAL UPGRADES	DESCRIPTION[1,2,3]	FUEL SAVINGS[1,2,3] (GJ/t-clinker)	ELECTRICITY SAVING[1,2,3] (kWh/t-clinker)	TOTAL FINANCIAL COST SAVINGS[4] ($ / t-clinker)	TOTAL ENVIRONMENTAL COST SAVINGS[4] ($ / t-clinker)	FINANCIAL ROI[4]	TOTAL ROI[4]
RAW MATERIALS PREPARATION							
VFD in raw mill vent fan	Variable frequency drive (VFD) reduces power consumption by reducing the fan speed and also reduces high pressure loss across damper	--	0.33	0.03	0.01	2.44	3.35
High efficiency raw mill vent fan with inverter	Replacing energy consuming, less efficient fans with high efficiency fans with power supply through invertors to optimize speed of fans	--	0.36	0.03	0.01	1.84	2.59
FUEL PREPARATION							
Efficient roller mills for coal grinding	Vertical roller mills can be used to replace ball mills or tube mills. Roller mills can handle large size of coal and with high moisture variability. Power consumption in vertical roller mills is around 16-18 kWh/t coal as compared to 30 – 50 kWh/t coal in ball mills and 25-26 kWh/t coal in tube mills. Waste heat from kiln can also be used in vertical roller mills	--	1.47	0.13	0.04	7.10	9.24
New efficient coal separator	Separators or classifiers with higher efficiency separate larger particles more accurately thereby reducing over-grinding and decreasing mill energy consumption	--	0.26	0.02	0.01	5.15	6.78
Installation of VFD & replacement of coal mill bag dust collectors fan	Installing variable frequency drive reduces power consumption of fans. Replacing dust collector fans with more efficient fans can lead to power savings	--	0.16	0.01	0.004	0.54	0.95
CLINKER MAKING: MOTOR AND FANS							
Adjustable speed drive for kiln fan	Adjustable speed drives for kilns fans leads to reduced power use and reduced maintenance costs	--	6.10	0.56	0.15	5.53	7.26
Kiln shell heat loss reduction (Improved refractories)	Due to very high temperatures in the kiln, temperature loss can be very significant unless it is reduced using kiln coating by refractory materials. This also reduces kiln downtime, production costs and energy needs at start-ups of kiln	0.26	--	1.39	2.21	15.11	40.72
Use of high efficiency preheater fan	Less efficient, old generation and high power consuming fans can be replaced with high efficiency fans leading to power consumption	--	0.70	0.06	0.02	1.68	2.39

POTENTIAL TECHNOLOGICAL UPGRADES	DESCRIPTION[1,2,3]	FUEL SAVINGS[1,2,3] (GJ/t-clinker)	ELECTRICITY SAVING[1,2,3] (kWh/t-clinker)	TOTAL FINANCIAL COST SAVINGS[4] ($ / t-clinker)	TOTAL ENVIRONMENTAL COST SAVINGS[4] ($ / t-clinker)	FINANCIAL ROI[4]	TOTAL ROI[4]
VFD in cooler fan of grate cooler	Variable frequency drives can be installed in grate cooler to reduce amount of power consumption	--	0.11	0.01	0.003	1.37	1.99
Energy management & process control systems in clinker making	Improved process control leads to steadier kiln operations, fuel savings, increased clinker quality and optimises combustion process. Use of online analysers can be used to determine chemical composition of raw material in real time. This also reduces the NO_x emissions and improves heat recovery	0.15	2.35	1.02	1.33	2.22	6.44
Low temperature Waste Heat Recovery for power generation	In clinker production process, a significant amount of heat is typically vented to the atmosphere without utilization. A Waste Heat Recovery (WHR) system can effectively utilize the low temperature waste heat of the exit gases from Suspension Preheater (SP) and Air Quenching Chamber (AQC) in cement production	--	30.80	2.82	0.75	0.01	0.28
Optimize heat recovery/ upgrade clinker cooler	The clinker cooler drops the clinker temperature from 1200°C down to 100°C. Heat recovery can be improved through reduction of excess air volume, control of clinker bed depth and new grates such as ring grates. It results in reduced energy use in the kiln and precalciner, due to higher combustion air temperatures	0.11	-2.00	0.41	0.89	3.67	13.88
FINISH GRINDING							
High efficiency cement mill vent fan	Replacing old generation, less – efficient and high energy consuming mill vent fan with more efficient fan can result in power savings	--	0.13	0.01	0.003	2.76	3.76
Energy management & process control in grinding	Improved process control in grinding leads to electricity savings along with improved final product quality, less variability in product and improved production	--	4.00	0.37	0.10	1.22	1.88
Improved grinding media for ball mills	Improved grinding media which are more wear resistant like chromium steel reduces energy consumption in grinding mill	--	6.10	0.56	0.15	0.45	0.83
GENERAL MEASURES							
High efficiency motors	Around 500 – 700 motors are used in a typical cement plants for moving fans, rotating kilns, transporting materials and for grinding. Use of high efficiency motors can reduce power consumption	--	4.58	0.42	0.11	2.46	3.38

POTENTIAL TECHNOLOGICAL UPGRADES	DESCRIPTION[1,2,3]	FUEL SAVINGS[1,2,3] (GJ/t-clinker)	ELECTRICITY SAVING[1,2,3] (kWh/t-clinker)	TOTAL FINANCIAL COST SAVINGS[4] ($ / t-clinker)	TOTAL ENVIRONMENTAL COST SAVINGS[4] ($ / t-clinker)	FINANCIAL ROI[4]	TOTAL ROI[4]
Adjustable Speed Drives	Adjustable speed drivers are used at multiple steps in cement manufacturing plant. It can be applied in cement kilns, coolers, pre-heaters, separator and mills to control the speed of the machinery and leads to power savings.	--	9.15		0.22		
Use of alternative fuels	Alternative fuels can be replaced by different alternatives materials like tires, carpet, plastic waste, sewage slug and other wastes. These waste materials can be used to replace traditional fuels like coal.	0.60	--		5.10		

SOURCE: [1]PRICE ET AL. 2009 [2]WORRELL ET AL 2008 [3]INDUSTRIAL EFFICIENCY TECHNOLOGY DATABASE N.D [4]TRUCOST CALCULATIONS (see below)

Total financial cost savings: calculated by converting fuel and electricity savings to financial savings; assumed cost of electricity 0.545 RMB/kWh, 31.9 RMB/GJ, conversion factor 6.84 RMB/USD (all taken from Price et al., 2009), adjusted for inflation (consumer prices, annual %) to 2013 (World Bank, 2015)

Total environmental cost savings: calculated by applying the external cost of air pollution generated from 1kWh of electricity or 1GJ fuel use

Financial ROI: calculated using financial cost savings against the cost of conserved electricity (CCE) and cost of conserved fuel (CCF) (all taken from Price et al., 2009)

Total ROI: calculated using total financial and external cost savings against the cost of conserved electricity (CCE) and cost of conserved fuel (CCF) (all taken from Price et al., 2009)

A.4.2 AIR POLLUTION ABATEMENT

The best available technologies reducing the emission level of a particular KPIs at specific stage of cement manufacturing process are presented below. The applicability of these technologies is site specific and requires a careful assessment of associated costs and benefits. For existing plants it can be more costly due to the replacement of equipment. Supplementing this analysis with the monetized external cost reductions adds an extra layer of analysis allowing decision-makers to maximize the financial as well as the environmental return on investment.

TABLE A22: BEST AVAILABLE TECHNOLOGIES FOR EMISSION ABATEMENT IN CEMENT MANUFACTURING

TECHNOLOGY	DESCRIPTION	EFFICIENCY (%)
PM		
Electrostatic precipitator	Electrostatic precipitators use electrostatic forces to separate the dust from the exhaust gas. In contrast to bag filters, the design of electrostatic precipitators allows the separate collection of coarse and fine particles.	Up to 99.99
Bag filter	Bag filters make use of a fabric filter system, the “bags” which separate the dust particles from the exhaust gas. The dust particles are captured on the bag surface while the gas passes through the bag tissue.	Up to 99.99
NO_x		
Optimization of clinker burning process (OCBP)	Optimization of the clinker burning process is usually done to reduce the heat consumption, improve the clinker quality and to increase the lifetime of the equipment through the stabilization of process parameters. NO_x reduction is a side effect of the optimization.	0-20
Expert system for kiln operation (ES)	Expert systems allow emission data to be monitored and process parameters to be kept much closer to the set points, in particular also those parameters which are decisive for NO formation.	Up to 30

TECHNOLOGY	DESCRIPTION	EFFICIENCY (%)
Low NO_x burner	The reduced NO_x formation with low-NO_x burners is partly caused by a more uniform flame flow pattern without high temperature peaks and partly caused by the flame flow pattern also creating a flame internal reducing atmosphere. It is very difficult if not impossible to predict the NO reduction efficiency of low-NO_x burners for individual applications.	0-30
Add water to flame or fuel to kiln (AWFF)	Addition of water to the fuel or directly to the flame (e.g. in the form of organically polluted water) reduces the temperature and increases the concentration of hydroxyl radicals. This has a positive effect on NO_x reduction in the burning zone.	10-50
Multi-stage combustion in precalciners (MSCI)	By introducing fuel through a burner in the kiln inlet zone or the riser duct a reducing environment is set up in this second combustion stage. The resulting intermediate products from the consecutive reactions of combustion act as reducing agents for NO created in the sintering zone and at the same time prevent the formation of more NO.	10-50
Selective Non-catalytic reduction (SNCR)	Selective Non-Catalytic Reduction is the only available secondary reduction measure at the moment. NH2-X compounds are injected into the exhaust gas at a temperature of about 950 to 1000° C to reduce NO to N_2. The required temperature window must provide sufficient retention time for the injected agents to react with NO.	Up to 65
SO_2		
Optimize clinker burning process (OCBP)	Optimization of the clinker burning process is usually done to reduce the heat consumption, to improve the clinker quality and to increase the lifetime of the equipment. SO_2 reduction is a side effect of the optimization.	0 - 50
Slaked lime addition to kiln feed (SLKF)	Experience of SLKF is relatively limited but these two techniques have relatively modest costs and their maximum reduction potential is significant.	Up to 65
VOCs		
Addition of organic matter containing raw material to the hot zone of the Kiln	If a component of the raw material that is responsible for the high emission of VOC is added directly to the hot zone of the kiln (e.g. kiln inlet) the organic compounds are burned before they can escape to the atmosphere.	Up to 95
Increased Oxygen concentration at the Kiln inlet of long wet or long dry kilns	An increase of the oxygen concentration can significantly reduce the organic emission from the raw materials in long wet and long dry kilns. It is assumed that the large temperature difference between raw meal and exhaust gas at the point of release of the organic compounds is responsible for the emission reduction.	Up to 40
MERCURY		
High efficiency dedusting (HED)	High dedusting efficiencies can be achieved with electrostatic precipitators (EP) and bag filters (BF). Especially existing EPs can be optimized with various measures starting with exhaust gas conditioning and ending with enlargement or replacement of the filter.	
Reduction of Hg in raw materials and fuels (RMR)	A reduction of the semi-volatile and volatile HM in the raw materials and fuels is virtually impossible.	

SOURCE: CEMBUREAU 1997

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