Climate Technology & Development: Energy efficiency and GHG reduction in the cement industry

Case study of Sub-Saharan Africa

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Contents

Executive Summary

1 Introduction
1.1 Rationale for low-carbon innovation in Sub-Saharan Africa

2 Technical options for GHG emission reductions in the cement sector
2.1 The cement production process
2.2 GHG emissions from the cement manufacturing process
2.3 Potential for GHG emission reductions

3 The cement industry in Sub-Saharan Africa
3.1 World market
3.2 Cement production in Sub-Saharan Africa
3.3 Market structure and suppliers
3.4 State of the technology
3.5 Emissions reduction potential for Sub-Saharan African cement plants

4 Enablers of low-carbon innovation
4.1 The effects of market liberalization
4.2 Government support for industry development
4.3 The role of equipment manufacturers
4.4 Impact of information and technical capacity
4.5 The role of OECD-based multinationals
4.6 The impact of resource availability
4.7 Access to international climate finance

5 Messages for policymakers

References
Executive Summary

In a developing country context, cement production is closely linked to economic development. The availability of cement is vital for infrastructure expansion, modern housing and urbanization. Sub-Saharan Africa has a low per-capita cement consumption compared to other world regions, but demand is growing and is expected to continue to grow in the coming decades. Cement production is an energy intensive process and a major source of CO₂ emissions. Facilitating access to technologies and knowledge to promote cost effective low-carbon technology adoption in the cement industries of Sub-Saharan Africa is important for regional economic growth and competitiveness, as well as for the global reduction of greenhouse gas emissions.

This report explores a number of factors that influence low-carbon innovation, through both energy efficiency and other CO₂ abatement measures, in the cement sector in Sub-Saharan Africa. These influencing factors have been identified through a literature review and via several interviews with experts and operations managers in African cement facilities.

Market liberalisation, government support for industrial development, the activities of equipment suppliers, financiers and OECD-based multinationals are key factors that influence the rate of deployment of low-carbon technology. Poor resource availability (of alternative fuels and clinker substitutes for example), a lack of information and technical capacity, and access to international finance mechanisms are regarded as salient barriers.

There are a wide-range of energy efficiency improvements and CO₂ emission reduction options for the Sub-Saharan African cement industry that have considerable potential for reducing GHG emissions. Based on the analysis of potential enablers for low-carbon innovation, the following recommendations for policy makers are drawn:

Recommendations for national policy makers

Understand the effects of market liberalization and align industry politics and low-carbon development considerations

The analysis undertaken suggests that market liberalization incentivizes investments into more energy efficient, and thus less carbon intensive production processes and potentially the closure of the least efficient plants. On the other hand, the increased cost pressure related to market liberalization has been observed to also incentivize a switch to higher carbon fuels such as coal. When planning to take action to incentive low-carbon innovation, it is key to understand the links between general industry developments, particularly market liberalization, and low-carbon innovation. Policies and programmes that could complement market liberalization with a low-carbon aspect include regulation mandating best-available technology for new and renovated plants, as well as offering access to capital at attractive rates for investments in high-efficiency plants.
**Improve access to alternative fuels**

Reliable availability of alternative fuels is the main barrier to an increased use of alternative fuels in cement kilns in Sub-Saharan Africa. Little cooperation between different sectors and industries hinders the development of supply chains for alternative fuels. Governments, potentially with the help of international donors, can support the development of such alternative fuel supply chains through programmes which analyse the concrete potential for using alternative fuels, facilitate the process of establishing relationships between the cement industry and other existing industries, e.g. food processing, or support the development of new businesses, e.g. in the collection of used tyres. In parallel, policy makers should make sure that there is enforceable waste legislation which ensures that the collection systems guarantee that asbestos and heavy metal containing waste, electronic scrap, mineral acids, batteries, and infectious medical wastes do not enter waste streams destined for incineration in cement kilns. The use of biomass to fuel cement kilns should be considered carefully to ensure that it is not in competition with the production of food and does not have negative impacts on land cover and biodiversity.

**Data collection, energy audits and establishing baselines**

A key priority, if not already available, would be the collection of efficiency and emissions data and site specific details of industrial installations within a country. Auditing the energy use of an industrial sector such as cement, is a fundamental step upon which to develop national policies, as a basis for mediation with industrial stakeholders, and in communicating the status quo and potential interventions to overseas donors, such as multinational investment banks. Knowledge of the current level of plant technology is necessary to identify possible options to improve energy efficiency.

**Recommendations on an international level**

**Incentivise collaborative R&D and information sharing**

Equipment manufacturers play an important role in low-carbon innovation in the sector. In addition, it has been observed that especially in the case of smaller companies and plants in Sub-Saharan Africa, employees often don’t have all necessary information and expertise for improving the manufacturing process or making investments into low-carbon technologies. It is therefore recommended to support initiatives which improve communication and information sharing between equipment manufacturers and Sub-Saharan cement companies, potentially also including elements of collaborative R&D.

Under the UNFCCC, the Technology Mechanism, in particular the Climate Technology Centre and Network (CTCN), could facilitate RD&D cooperation between smaller countries in Sub-Saharan Africa, in order to gain expertise and share practices on long and short term CO\textsubscript{2} reduction strategies in the cement sector.

**Leverage international finance**

Multilateral Development Banks already play a constructive role in enabling environmental technologies in the cement sector by favouring or requiring the use of BAT. These practices, of tying certain types of support to low-carbon technology adoption, could be promoted and expanded.
Under the UNFCCC, NAMAs could provide a source of support to policies and installations that encourage sustainable sources of energy – such as waste and biomass feedstocks – and efficiency measures. This idea is already being tested in Vietnam (Thue, 2012). Other forms of climate finance - where support is tied to the use of low-emission technology - from sources including bilateral channels and the Green Climate Fund may also be viable options, although the mechanisms for delivering support from the latter are still being defined. Lastly, there is the possibility, if carbon prices rise, that the CDM again becomes more promising as an option (for least-developed countries, which remain eligible for registering new projects).
Introduction

The aim of this report is to illustrate potential enablers and barriers to low-carbon innovation, through both energy efficiency and other CO₂ abatement measures, in the cement sector in Sub-Saharan Africa. The analysis leads to recommendations for policy actions that could facilitate low-carbon innovation in the sector given the specific local context.

Research on different enablers and barriers for low-carbon innovation in developing countries has predominantly focused on innovation in industrial sectors in large, middle-income emerging economies, especially in China and India or on innovation related to small-scale technologies such as improved cook-stoves. Little work has been done researching innovation and technology transfer in industry in Sub-Saharan Africa, although the accelerated economic development which many countries in the continent have witnessed over the past decade has caused industrial sectors to expand to meet demand for construction materials. So far, Sub-Saharan Africa has proven to be relatively resilient to the global economic slow-down from 2008 and in many cases growth has been maintained up to now. There is potential for sustained growth, including industrial growth (McKinsey Institute, 2009). In this context, a better understanding of how to facilitate low-carbon innovation in large industries in the continent is important not only from a climate change mitigation point of view, but also because the use of modern and efficient technologies and manufacturing processes are a key prerequisite for economic competitiveness and resource conservation.

In that respect, the cement industry is an interesting case study. In a developing country context, cement production is closely linked to economic development as cement is a key material for infrastructure development, modern housing and urbanization. Global cement consumption was approximately 3.6 billion tons in 2011, up by 10% compared to 2010. Further projections estimate total consumption to reach almost 5 billion tons by 2025, with the majority of demand (92%) in developing countries (Lafarge, 2010, Cembureau, 2012a). China produces more than 57% of the world’s cement (Cembureau, 2012a). Africa still has the lowest per capita cement consumption, but demand is expected to continue to grow rapidly (Schmidt et al., 2012, Cembureau, 2012a). Innovation in cement manufacturing is relevant for the majority of African countries as most countries have at least one plant within their boundaries. As a
consequence of increased demand, over the past decade in many markets, investments were made to increase production and more African countries opened their borders to cement imports.

Cement manufacturing is also highly relevant from a climate change mitigation point of view: Today, cement production accounts for about 7% of global CO₂ emissions (Ali et al., 2011). With the projected increase in production in Sub-Saharan Africa, the sub-continents contribution to global CO₂ emissions can be expected to increase.

Very little literature is available on the topic of innovation in the cement sector in Sub-Saharan Africa, or on innovation in other industrial sectors in the region. Therefore, the case study takes an exploratory approach, examining potential enablers for innovation based on the limited amount of literature available in academic journals and online, complemented by a review of news articles and a number of interviews with stakeholders in the sector.¹

The report starts with a description of the cement manufacturing process and potential GHG emission reductions (Chapter 2), and continues with an overview of the cement market in Sub-Saharan Africa (Chapter 3). Chapter 4 represents the results of the case study and discusses different enablers for low-carbon innovation in the sector. Chapter 5 and 6 conclude with a discussion and recommendations for policy makers.

1.1 Rationale for low-carbon innovation in Sub-Saharan Africa

Prior to this analysis, it’s important to justify the rationale for Sub-Saharan African countries considering taking action on improving energy efficiency and stimulating low-carbon innovation. Although energy efficiency is often considered inherently good for productivity in a country, literature provides no clear consensus on evidence and theory linking aggregated growth and energy efficiency in developing countries (Compton, 2011). Evidence from the manufacturing sector of Nigeria between 1970-1990 actually indicates that heavily subsidized energy prices, generally considered detrimental for energy efficiency, caused a positive relationship between energy consumption and productivity growth. However, subsidized prices led to a reliance on old and energy inefficient technologies, which could leave the Nigerian manufacturing industry vulnerable to energy price increases (Adenikinju and Alaba, 1999). Therefore it’s important to understand the link between energy efficiency and the foreseen benefits to a nation, and acknowledge these when developing policy recommendations.

Compton, (2011), collected from literature a number of foreseen direct and indirect benefits to industrial energy efficiency:

- **More economic output requiring less energy supply** – This is particularly important where electricity and energy supply is constrained. Efficiency

¹ The interviews and the majority of the literature review were completed in the frame of a Master thesis undertaken at the Institute of Environmental Studies at the Vrije Universiteit Amsterdam.
investments at plant level could also mean that less investment is needed in national energy infrastructure.

- **Lower production costs at firm level** – Investment in energy efficiency measures can lower production costs and increase competiveness.

- **Improve livelihoods and reduce poverty** – Increased competiveness could increase employment in skilled and unskilled labour.

- **Environmental sustainability** – Improvements in energy efficiency reduces the associated negative environmental impacts of burning fossil fuels, including CO₂ emission reductions.

- **Reduce import bill** – Energy imports can be reduced, and greater industrial output can increase exports.

In the cement industry, electrical and thermal energy efficiency has the co-benefit of reducing CO₂ emissions, however it is not the only route to achieve this. Whereas taking national actions to improve energy efficiency can be justified to a certain extent based on the direct and indirect benefits outlined above, the rationale for Sub-Saharan African countries incentivising other forms of low-carbon innovation such as clinker substitution and the use of alternative fuels is less clear.

As classified by the United Nations, 34 of a total of 49 least developed countries (LDCs), characterised by the lowest levels of socioeconomic development, are located in Sub-Saharan Africa. In terms of global CO₂ reduction commitments made by some developed and developing nations within the United National Convention on Climate Change (UNFCCC), LDCs are not expected to adopt such commitments due to other development priorities. In light of this, emphasis in this report will be placed on Sub-Saharan nations accessing support and finance mechanisms made available by multinational development banks and bi/multilateral climate funds.
2 Technical options for GHG emission reductions in the cement sector

2.1 The cement production process

Cement is manufactured in a complex multistage process, whereby raw materials are converted into clinker, which forms the primary component for the cement production process. To produce clinker, limestone, which is extracted from a quarry, is crushed and further ground together with clay or similar materials, sometimes also adding smaller quantities of sand, waste bauxite or iron ore. In state-of-the-art plants, this mixture is pre-heated before entering a kiln for further heating at temperatures reaching 1450°C to produce clinker.

Figure 1: Visual depiction of cement manufacturing (Source: Ohorongo Cement, 2013)
The clinker is cooled rapidly when exiting the kiln. In the next step, the clinker is finely ground with the addition of calcium sulphates and potentially other additives such as blast furnace slag, natural pozzolanas or fly ash, to produce cement ready to be stored or transported (IEA ETSAP, 2010). The entire process is depicted in Figure 1 above.

2.2 GHG emissions from the cement manufacturing process

Cement production is relatively carbon intensive: Worldwide, it currently accounts for 7% of total man-made CO\textsubscript{2} emissions (Ali et al., 2011). This is a result of both the sheer volume of cement produced and of the carbon intensity of the production process. CO\textsubscript{2} emissions stemming from cement manufacturing come mainly from the process of calcination, which involves the decomposition of calcium carbonate (limestone) to calcium oxide (lime; CaO) and CO\textsubscript{2}. This process occurs at high temperatures inside the kiln and accounts for approximately 60% of the CO\textsubscript{2} emissions from cement production (Habert et al., 2010). The burning of thermal fuels to heat the kiln accounts for approximately 40% of CO\textsubscript{2} emissions. See Figure 2 for a simplified depiction of the cement manufacturing process which highlights the various sources of CO\textsubscript{2} emissions.

In this respect, cement production is different from many other industrial processes, as a substantial part of the GHG emissions do not originate from fuel or electricity use, but are related to the production process (calcination) itself. Achieving emissions reductions from cement manufacture is therefore technically challenging as there is no alternative production process for conventional cement (often referred to as Ordinary Portland Cement or OPC) as of yet, nor is there a viable and sustainable replacement material for the building sector.

![Figure 2: Simplified depiction of the cement manufacturing process, demonstrating sources of CO\textsubscript{2} emissions (Source: Habert et al., 2010)](image)

2.3 Potential for GHG emission reductions
There is broad recognition of four different levers for reducing GHG emissions from the cement manufacturing process (WBCSD & IEA, 2009; IEA, 2008 & 2009; CSI, 2009; ECRA, 2009; CCAP, 2008; McKinsey, 2008). These are:

1. Improvement of the thermal and electric efficiency through deployment of best-available technologies in new cement plants, retrofitting existing plants with more energy efficient equipment and optimization of the production process.
2. Changing the fuel mix for heating of the kiln by using less carbon-intensive fossil fuels, waste fuels or biomass.
3. Substituting the carbon-intensive clinker by alternative lower-carbon materials such as pozzolana, or industrial by-products such as fly ash and slag.
4. Deploying CO₂ capture and storage (CCS) technology.

1. Improvement of the thermal and electric efficiency

Many different options for improving the thermal and electric efficiency of the cement manufacturing process exist. The three main types of manufacturing processes, i.e. the wet, semi-wet and dry processes, for example differ widely in terms of thermal and electrical energy efficiency. The wet process, where long kilns of up to 200m length are fed with a wet slurry that is heated up and dried in the kiln, is the least efficient, followed by the semi-wet process, which is usually preferred in small cement plants. The dry process employs shorter kilns of up to 50m and uses only dry input materials, resulting in less energy consumption for removing the water. The dry process consumes 13% less electricity and about 28% less fuel than the wet process per ton of cement produced (Ali et al., 2011). Further improvements to the dry process include the addition of multi-stage preheaters and pre-calciners, both contributing to an increase in the overall energy efficiency of the process (IEA-ETSAP, 2010). Figure 3 demonstrates how CO₂ emissions per tonne of clinker differ between the various technologies employed.

![Figure 3: Cement production technologies and associated CO₂ emissions (Source: CSI, 2009)](image)

The wet process was the main technology in the industry from its early years onwards and was widely disseminated world-wide until the mid-1970s. Spurred by the 1970’s energy crisis, companies started switching to the more energy-efficient dry process,
which is more efficient both in terms of GHG emissions associated with the clinker production process and fuel usage, although the dry process requires input material of limited moisture content, which is not always available (IEA-ETSAP, 2010). Currently, dry manufacturing processes with a preheater and pre-calciner have become the state-of-the-art technology which is applied for most new plants (IEA & WBCSD, 2009). The commissioning of such efficient new plants also often leads to the closure of old, inefficient facilities (IEA & WBCSD, 2009).

In addition, although the thermal efficiency of a plant depends to a large extent on the original design and technologies employed, it is still important to operate and maintain the machinery in an efficient manner to achieve the maximum potential operational efficiencies. However, this operational efficiency is difficult to quantify and may differ by technology (IEA & WBCSD, 2009)

2. Use of alternative fuels
Instead of heating the kiln by using fossil fuels such as coal, coke and to a lesser extent oil and natural gas (IEA-ETSAP, 2010), alternative fuels such as pre-treated industrial and municipal solid waste, discarded tyres, waste oil and solvents, plastics, textiles and paper residues and biomass (e.g. meat and bone meal, woody material, agricultural residues and biomass crops) can be used. According to the IEA, a mix of fossil and alternative fuels can be 20-25% less carbon intensive than using only coal (IEA & WBCSD, 2009). Moreover, the use of alternative fuels in cement manufacturing has the additional advantage that the remaining ashes can be integrated into the clinker, whereas the burning of many waste fuels in a waste incineration process requires additional fossil fuel inputs (IEA & WBCSD, 2009).

To be suitable for use in a cement plant, waste fuels should possess high net calorific value, low moisture content and low concentrations of trace substances such as heavy metals or chlorine (IEA & WBCSD, 2009). If these requirements are not met, pre-treatment would be required which is energy intensive and may not be economically viable. For the use of biomass, similar considerations to using biomass for transportation or electricity fuels emerge, including competition with those applications.

Globally, the rate of alternative fuel use varies widely: In Europe, average alternative fuel use has increased to 17% by 2007, with some European countries using more than 50% of alternative fuels (ETSAP, 2010). In the developing world, the usage rate was estimated at only 5% in 2007 (IEA & WBCSD, 2009). Switching to alternative fuels is generally considered to be the cheapest option for lowering GHG emissions from cement production (WBCSD and IEA, 2009). The potential of this option is primarily related to proximity to sources of suitable alternative fuels, and the consequential trade-off between transport costs of alternative fuel and coal.

3. Clinker substitution
Due to the high share of CO₂ emissions from cement manufacturing which are related to the chemical processes of producing clinker and due to the large fuel requirements for clinker production, substituting clinker in the final cement mix with alternative materials generally leads to significant GHG emission reductions. Alternative materials, which can partially replace clinker, are blast furnace slag, which is a by-product from the
iron or steel industry, fly ashes from coal-fired power stations, pozzolanas e.g. natural volcanic ashes, and limestone. However, most of these alternative materials alter cement properties, frequently leading to lower early-stage strength of the material which limits the applicability of the cement. Other barriers to an increased use of clinker substitutes are the regional availability of the alternative materials, but also common practices, regulation and how accepted composite cements are with construction companies and other customers (IEA & WBCSD, 2009). Today, the use of clinker substitutes varies widely between countries.

4. CO₂ capture and storage

CCS is the only technology that can achieve very deep reductions in GHG emissions from conventional cement manufacturing. During cement manufacturing, carbon capture could be applied to the exhaust gases of the kiln, capturing both process and combustion CO₂ emissions, with a CO₂ reduction potential of approximately 80% per tonne of cement produced. The cement industry is already pursuing R&D activities, and pilot tests have been completed (ECRA, 2012). A disadvantage of CCS is the additional energy required for operating the capture processing unit, where steam is required to regenerate the amine compounds used to capture CO₂. A key barrier to CCS is that it will increase both the capital and operating costs of a cement plant, and it may be some time before it becomes commercial. These extra costs cannot be recuperated without strong climate change mitigation policies in place.

CCS is unlikely to be broadly deployed in the cement manufacturing industry within the next 5 – 10 years. The present case study therefore only focuses on low-carbon innovation which applies thermal and electric efficiency measures, alternative fuels and clinker substitutes.

There are a number of low carbon cements in research phases, which are based on new production processes. These production processes are numerous and diverse, and it's not clear whether such products can replace conventional cements. For example, Project Aether is an EU/industry collaboration which has developed a new form of clinker which is made at lower temperatures, reducing CO₂ emissions by approximately 30% (Aether-Cement, 2013).
The cement industry in Sub-Saharan Africa

3.1 World market

Figure 4 below shows the shares of cement production by different countries and regions. While the recent financial crisis has slowed the growth of the cement market in most developed countries, rapid expansion of the sector in developing countries continues to offset the downturn in developed markets (Global Industry Analysts, Inc, 2009). Cement production is expected to further increase to 4.9 billion tons by 2025, with the majority of demand (92%) coming from emerging economies.

Figure 4: World cement production in 2011 (Source: Cembureau, 2012a)

3.6 billion tonnes

* Including EU27 countries not members of CEMBUREAU
A small number of companies dominate the global cement production market, with Lafarge (France), Heidelberg (Germany), Holcim (Switzerland), Cemex (Mexico) and Italcement (Italy) being the top five global players. Apart from these and several other major producers, there are also thousands of small locally-owned cement plants worldwide. Cement manufacturing is a dynamic sector where frequent mergers and acquisitions take place (Global Cement, 2011).

3.2 Cement production in Sub-Saharan Africa

Due to the high cost associated with transporting cement and the fear of overly relying on imports from politically-unstable neighbouring countries, the majority of African countries have at least one cement plant within their borders (Schmidt et al., 2012). Per-capita cement consumption in Sub-Saharan Africa is relatively low compared to other world regions, with less than 100kg per capita consumption in the majority of Sub-Saharan countries compared to almost 400 kg in Western Europe (Schmidt et al., 2012; Waerp and Arnoldsen, 2011).

Cement is also relatively expensive in Sub-Saharan Africa. A bag (25kg) of in-country produced cement can cost up to three times more in Kenya or Mozambique, for example, than a similar product in Pakistan (pers.com Kjaergaard, 2012). Reasons for the high prices include high transportation costs due to the long average distances to the next cement plant, the absence of an extensive railway network and poor road conditions, high fuel costs for production, a large number of middle-men in the distribution chain, and the fact that demand exceeds supply in most countries (PanAfrican Capital Research, 2011).
With increasing urbanization, infrastructure development and economic growth, demand for cement has been growing rapidly over the last decade. As a consequence, production capacity has also seen fast growth in many Sub-Saharan African countries, with the majority of new plants being situated in the Western and Eastern parts of the continent. Capacity increases have been achieved by expanding capacity of existing factories as well as by building new plants. In Nigeria, production capacity tripled for example from 10 Megatons per year (Mtpa) in 2002 to 30 Mtpa in 2012. In Kenya, 4 out of the country’s 5 cement plants were newly installed or upgraded after 2010. Amongst other countries, Senegal, Ethiopia and Mozambique have seen large increases in production capacity over the past few years with more new plants being planned. In addition, over the last decade, some countries with formerly closed borders for cement imports, started importing cement to meet the growing demand.

3.3 Market structure and suppliers

Historically, cement plants in Sub-Saharan Africa had been government-owned enterprises. Following the trend towards market liberalization in the 1980’s and 90’s, many governments sold their plants partly or completely to private companies, mostly foreign multi-nationals (UN/DESA, 2011). OECD-based multinationals Lafarge, Heidelberg, and Holcim were prevalent in the Sub-Saharan market for decades, sharing ownership with local governments. Until 2007, Italcementi-operating only in the North of the continent, together with Lafarge, Heidelberg Cement, and Holcim held 45% of the total market share in Africa, owning 13, 13, 9 and 6 plants respectively (PanAfrican Capital Research, 2011).

This picture has started to change recently, although, with African companies gaining market share. In 2007, Holcim sold most of its shares in factories in South Africa and Tanzania to the South African company AfriSam. Similarly, Heidelberg Cement sold all its Nigerian plants to the Nigerian company Dangote Cement, which in turn bought by the Nigerian BUA Group in 2010. In addition Heidelberg Cement sold its Nigerian cement terminal to Nigerian company Dangote (World Bank, 2009). The latter had joined the market in 1992. Dangote recently announced its plan to become one of the top-eight world-wide cement producers (Dangote, 2012a). Currently, the company has 3 cement plants (combined capacity of 20 Mtpa) and 5 terminals in Nigeria (combined capacity of 9 Mtpa), and 10 cement plants and 9 terminals all over Sub-Saharan Africa (Dangote, 2012b). Most of these are existing factories that Dangote bought from their previous owners. As of June 2012, Dangote had become Sub-Saharan Africa’s second

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Table 1: Breakdown of cement plants and production capacity in SSA (World Bank, 2009)

<table>
<thead>
<tr>
<th>Region</th>
<th>Number of Plants</th>
<th>Production Capacity (tonnes of cement)</th>
<th>Actual Production (tonnes of cement)</th>
</tr>
</thead>
<tbody>
<tr>
<td>West Africa</td>
<td>29</td>
<td>19,241,000</td>
<td>8,779,130</td>
</tr>
<tr>
<td>Central Africa</td>
<td>11</td>
<td>3,613,000</td>
<td>1,720,000</td>
</tr>
<tr>
<td>East Africa</td>
<td>29</td>
<td>8,954,000</td>
<td>6,768,110</td>
</tr>
<tr>
<td>Southern Africa</td>
<td>6</td>
<td>13,145,000</td>
<td>12,348,000</td>
</tr>
<tr>
<td>Total</td>
<td>75</td>
<td>44,953,000</td>
<td>29,615,240</td>
</tr>
</tbody>
</table>
largest player (in terms of number of plants) owning 10 plants, with Lafarge owning 12, Holcim 5 and Heidelberg Cement 4 plants.

In addition, there are also many locally-owned private factories that operate within the borders of the parent country or have recently expanded their operations to two or three other countries. ArmAfrica, Kenya, has for example subsidiaries in Tanzania, Rwanda and South Africa. The South African Pretoria Portland Cement (PPC) is looking for new markets in Mozambique, Zambia, Angola, the Democratic Republic of Congo, Tanzania, Kenya and Uganda (IOL News, 2010). The majority of these privately-owned factories share ownership with OECD-based multinationals and/or national governments (Cemnet, 2008).

3.4 State of the technology

Age and state of technology varies greatly between different plants, with average output capacity ranging from 0.36 Mtpa per production line in Central Africa to 6 Mtpa in West Africa (PanAfrican Capital Research, 2011). In terms of technology, in 2002, 66% of the African cement plants already had dry process production lines, while wet and semi-wet processes covered 24%, and 9% of the total respectively (WBCSD, 2002). The situation is likely to have further improved since then, as a large majority of new production lines use the dry process.

However, a 2009 World Bank study of the Sub-Saharan African cement market still found that the thermal energy consumption of clinker produced in East and Central African plants is significantly higher (between 800 and 1000 kcal/kg of clinker) than the average of plants in India (760 kcal/kg of clinker). The increased thermal and electrical efficiency seen in India appears to coincide with considerable price reductions for the end product.

Table 2: Comparison of key operational and energy use data between India and SSA (World Bank, 2009)

<table>
<thead>
<tr>
<th>Comparison Elements</th>
<th>India</th>
<th>SSA (excluding South Africa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity Utilization</td>
<td>94% (2008)</td>
<td>54% (2008)</td>
</tr>
<tr>
<td>Annual Growth Rate</td>
<td>10% (2007)</td>
<td>9.4% (2007)</td>
</tr>
<tr>
<td>Price of Cement</td>
<td>USD 5.50 (per bag of 50 kg)</td>
<td>USD 8.4 – 15.6 (per bag of 50 kg)</td>
</tr>
<tr>
<td>Process types</td>
<td>98% dry process (2008)</td>
<td>66% dry process (WBCSD, 2002)</td>
</tr>
<tr>
<td>Thermal energy use</td>
<td>780 kcal/kg of clinker</td>
<td>800–1000 kcal/kg of clinker</td>
</tr>
<tr>
<td>Electrical energy use</td>
<td>85 kWh/t of cement</td>
<td>105 – 140 kWh/t of cement</td>
</tr>
</tbody>
</table>

Figure 6 shows the development of thermal energy consumption for cement production in different regions over time and demonstrates that in 2006 energy demand per tonne of clinker was still relatively high in Africa and the Middle East when compared with other world regions, apart from CIS countries and North America which were less efficient.

2 Commonwealth of Independent States.
Levels of alternative fuel use are relatively low in Sub-Saharan Africa: in Europe, in some plants up to 80% of the fuel used in the production process comes from alternative sources (waste, tyres and biomass) and only 20% from fossil fuels (CSI and ECRA, 2009). Whereas in Sub-Saharan African, at most 20% of alternative fuels (including peat) are used with the remaining 80% being mostly coal, charcoal and heavy furnace oil (pers.com., Schmidt, 2012).

Figure 6: Development of thermal energy consumption for cement production in different regions over time (Source: WBCSD, 2012c)

3.5 Emissions reduction potential for Sub-Saharan African cement plants

The World Bank (2009) has assessed the technical potential of emissions reductions for Sub-Saharan cement plants for a number of mitigation options, excluding CCS. In an assessment of the potential to develop Clean Development Mechanism\(^3\) (CDM) projects in Sub-Saharan countries, a maximum technical potential of approximately 9 MtCO\(_2\)/yr was identified, with the greatest potential being in cement blending and the use of biomass as an alternative fuel. As a cautionary note, this assessment has been completed with highly aggregated data, and no country or site-specific factors have been accounted for. For the full breakdown of the type of potential CDM projects, and the estimated cumulative CO\(_2\) savings, please see Table 3: Breakdown of the type of potential CDM projects and the estimated cumulative CO\(_2\) savings.

\(^3\) The CDM is a flexible mechanism which is part of the Kyoto Protocol under the United Nations Framework Convention on Climate Change. It allows countries signatory to the Kyoto Protocol, which have legally binding emission reduction targets (Annex 1 countries), to meet part of their targets by procuring CO\(_2\) offsets that have been generated through the implementation of CO\(_2\) abatement projects in countries without legally binding emission targets (non-Annex 1 countries).
Table 3: Breakdown of the type of potential CDM projects and the estimated cumulative CO\textsubscript{2} savings

<table>
<thead>
<tr>
<th>Type of Projects</th>
<th>Number of Projects</th>
<th>Emissions Reduction Potential (tCO\textsubscript{2}/year)</th>
<th>Initial Investment (USD million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal energy efficiency</td>
<td>35</td>
<td>1,073,419</td>
<td>Abatement cost of USD 24/tCO\textsubscript{2} for preheater upgrade</td>
</tr>
<tr>
<td>Electric energy efficiency</td>
<td>49</td>
<td>319,028</td>
<td>N/A</td>
</tr>
<tr>
<td>Waste heat recovery</td>
<td>35</td>
<td>2,123,349</td>
<td>323.4</td>
</tr>
<tr>
<td>Alternative fuels (biomass)</td>
<td>35</td>
<td>2,393,226</td>
<td>536.1</td>
</tr>
<tr>
<td>Blended cement</td>
<td>44</td>
<td>2,910,149</td>
<td>127.32</td>
</tr>
</tbody>
</table>

Observing the current state of the cement production technology and processes in Sub-Saharan Africa, and the significant technical potential for CO\textsubscript{2} emission reductions, there is considerable scope for encouraging low-carbon investment in the sector across Sub-Saharan Africa. Chapter 4 explores a number of pathways for accelerating such investment.
4

Enablers of low-carbon innovation

Based on a literature review and interviews with relevant stakeholders, a number of factors have been identified that are considered potential enablers for accelerating low-carbon innovation in the cement sector in Sub-Saharan Africa.

4.1 The effects of market liberalization

The structure and progressive growth of developing economies suggests that market liberalization could encourage low-carbon innovation in the cement sector, as pressure on prices would lead to investments in energy efficiency.

The cement market in African countries is oligopolistic in nature, as in each country, only a few players operate. In addition, in many cases, imports of cement are regulated or not allowed. This situation contributes to high prices and can act to discourage investments into efficiency improvements which would also lower GHG emissions per tonne of cement produced.

In the case of Kenya, Uganda and Tanzania, local cement manufacturers were, for example, protected from cheaper imports through a 30% suspended duty and a common external tariff pegged at 25%, which were both withdrawn in 2008. Since then, Kenyan companies have been investing in measures to reduce the cost of production through investments in new and efficient production lines, technologies which lower the clinker factor and through a fuel switch. East African Portland Cement Company (EAPCC) and Bamburi Cement, both subsidiaries of Lafarge, have for example installed technologies that allow them to increase the share of pozollanic additives.

Similar to Kenya, there is pressure in Ghana to liberalize the market and facilitate cement imports to meet increasing demand and thus put pressure on cement prices (Daily Graphic, cited by Cityfm, 2012). Experience from South-East Asia (Indonesia,
Malaysia, Thailand, Philippines) points at the same direction that in closed, oligopolistic markets, there is little incentive to reduce energy consumption in the manufacturing process or to support other types of low-carbon innovation (pers.com, Rock, 2012).

Generally speaking, cement market liberalization is likely to encourage existing companies to innovate in order to reduce their costs of production and to secure their market position. Investments into a reduction of the production costs may be undertaken in any of the three areas of increasing thermal and electric efficiency of production, blending cement with non-clinker materials, or switching to a cheaper fuel source. While the first two measures lead to lower GHG emissions, switching to cheaper fuels often implies opting for coal, which tends to increase GHG emissions per tonne of cement produced.

4.2 Government support for industry development

In some emerging markets, most notably in China, a major driver for low-carbon innovation has been a clear commitment by the national government to growth and modernization in the sector. China’s cement market went through a period of very fast development in the 1970’s and 1980’s, when demand for cement started to grow exponentially. At that point, the Chinese government realized that vertical shaft kilns were not efficient enough to cater for the required demand, but that there was a need to shift to rotary dry kilns and to increase the scale of production at single plants. As a consequence, the government initiated a process of closing small cement plants to replace them with new and more efficient production lines (Rock et al., 2011; Hasanbeigi et al., 2010). Whilst this was met with some resistance from local governments, which preferred to continue to have regional cement production facilities, the process led to a significant modernization and related efficiency improvements in the sector. In parallel, incentives were given to support the development of Chinese equipment suppliers, after an initial focus on importing more modern and efficient technologies. The Chinese cement equipment manufacturer, Sinoma, which is now one of the largest global players in the sector, was founded in this period.

Whilst the Chinese experience is not directly comparable to the situation in Sub-Saharan Africa, it still demonstrates the fact that innovation towards increasing efficiency of production is likely to occur faster when there is a need for large increases in production and additional government support for a modernization of the industry. Similarly, Jacobsson and Johnson (2000) advocate that targeted support for the creation of a market, spurs innovation in a sector.

In this context, the example of Ethiopia is interesting. Ethiopia has significant infrastructure development plans for the coming decade and at the same time, has indicated a commitment to a low-carbon economy through its recent “Ethiopia’s Climate-Resilient Green Economy” strategy. In the latter document, the government states, among other targets, its goals to increase cement production capacity ten-fold in
the next 5 years (from 2.7 Mtpa in 2010 to 27 Mtpa in 2015 and further up to 65 Mtpa in 2030) (Government of Ethiopia, 2011). To avoid a potential lock-in to obsolete technologies if trying to meet the target with minimal up-front cost (which might include the option of buying second-hand cement plants), the government only allows the commissioning of new production lines deploying best-available technology. In 2011, the Saudi-born Ethiopian investor Sheikh Mohammed al-Amoudi opened the 2.5 Mtpa Derba Midroc Cement plant supported by a 45 million USD loan from the African Development Bank (AfDB). In addition, two state-owned cement companies have expanded their production lines by a total of 1 Mtpa. All of these are large-scale production lines deploying best-available technology (All Africa, 2010).

4.3 The role of equipment manufacturers

Pavitt (1984) categorizes large industrial firms according to sources of technological change and innovation, a taxonomy that later became widely established in the area of innovations research (Kristensen, 1999). Cement manufacturing, together with other industries such as food production, metal manufacturing, shipbuilding and glass manufacturing, falls into the category of scale-intensive industries, which are dominated mostly by large companies. According to Pavitt’s taxonomy, in these sectors sources of innovation can come from within the firm or from specialized suppliers outside of the firm. This is in contrast to science-based companies relying almost exclusively on their own sources of innovation and to supplier-dominated sectors such as textile production and printing where innovation comes mostly from outside of the company. In scale-intensive sectors, innovative firms are generally relatively large, produce both product and process innovation, but have relatively low shares of R&D costs as a percentage of total revenues (Pavitt, 1984; Kristensen, 1999).

In line with this general taxonomy, the Cement Technology Roadmap developed by the IEA and the World Business Council for Sustainable Development (WBCSD) (2009) recommends a significant increase in R&D programmes and networks which include both cement companies and equipment suppliers, potentially also in the form of public-private partnerships in collaboration with research institutes and governments (IEA & WBCSD, 2009)

Cement plants in Africa have been supplied by a rather small number of equipment manufacturing companies (see Figure 7). Among them, FLSmidth (Denmark) and Polysius (Germany) have the longest history on the continent. More recently, several Chinese companies, led by Sinoma, joined the market and managed to secure contracts for a third of the kilns installed between 2004 and 2008 in Africa.
Figure 7: New kiln capacity contracted by equipment manufacturers between 2004 and 2008 in Africa (Source: FLSmidth, 2008b)

According to FLSmidth (pers.com., Kjaergaard, 2012), which is one of the largest global equipment manufacturers, suppliers and service providers to the cement sector, innovation is mostly customer-driven. This means that clients usually look for cheaper equipment, for technologies that lower fuel and raw material consumption and for increased reliability of the products or have special requests, such as the use of particular alternative fuels. In addition, the environmental impact of manufacturing is considered to be one of the most important drivers for innovation in the sector today.

Although for most new production lines, cement companies request larger sized plants using BAT, there is still some demand for small plants with low production capacity (1000 tpd or less) in Sub-Saharan Africa where the complexity of the technology involved is limited, i.e. these plants are easy to maintain and operate. In the past, even some very experienced factories have requested additional low-capacity production lines (pers.com., Kjaergaard, 2012), which might often be due to a scarcity of skilled labour.

With respect to larger production lines using BAT, although there is no internationally-agreed definition for BAT in the cement industry, the differences between various competitor products are relatively small. The current common understanding of BAT is a dry-process kiln, with pre-heaters and pre-calciniers and a “closed” milling system (pers.com., Kjaergaard, 2012). In most cases, it is the customer that provides the technical requirements of a new plant to the supplier, as the equipment needs to fit as much as possible to the specific context and needs of the customer, e.g. to the type and quality of available raw materials. This can pose a challenge in Sub-Saharan Africa as access to information about current BAT is not always available.

International Property Rights (IPR) are rarely an issue in cement manufacturing in Sub-Saharan Africa. Although there have been reports of attempts to replicate smaller parts of equipment, these were isolated cases. Thus, breaches of IPR in Sub-Saharan Africa are not a real concern for suppliers due to the lack of local technical capabilities to construct full replicas of the equipment (Kjaergaard, 2012).
4.4 Impact of information and technical capacity

Literature on national innovation systems (Jacobsson and Johnson, 2000; Liu and White, 2001; Feinson, 2003; Negro and Hekkert, 2007) generally highlights the importance of investing in building human capacities to support a country’s absorptive capacity for new technologies. Dalhman and Nelson note that “a key input is a technical human capital base able to assess and decide on technology matters, [which] requires a well-developed educational system that lays the necessary foundations at all levels” (Dalhman and Nelson, 1995, p.97, cited by Feinson, 2003). The operation of cement plants requires trained specialists, partly with a university degree. These employees play an important role in the diffusion and adoption of new technologies at the plant level. In addition, the commissioning of new production lines requires in-depth studies of the available raw materials in the region of the plant. Understanding moisture levels, silica content and the microstructure of the raw materials well in advance can improve the efficiency and performance of the plant and the quality of the final product by adjusting the design (including the number of crushers, grind facilities, etc.) (Riser and Dover, 2007).

Another prerequisite for innovation is access to information about the latest technologies available on the international market. According to Maritim (pers.com., 2012), technical staff of cement plants are generally aware of the different parts of the production process that could be improved. However, they might not be aware of the existence of recent technologies that could meet their needs, nor of the respective costs of such technologies. To fill this information gap, equipment manufacturers regularly hold presentations and information sessions at their customer’s sites. As this type of promotional activity is quite expensive, equipment manufacturers limit their coverage to the plants from which they expect further investment. Additionally, large cement plants have more resources available for their staff to regularly attend fairs, training and seminars on cement-related technologies (pers.com., Maritim, 2012). Employees at smaller plants have more limited access to information and training, which lowers their opportunities for innovation.

In a study on behalf of the World Bank about supporting the realization of opportunities for low-carbon innovation in the African cement sector through CDM projects, Econoler International (2009) recommend a strong focus on improving technical capacities and availability of information at the plant level. Specifically, they recommend undertaking study tours in China and India to learn about their successful approaches, conducting energy audits and improving the process of regularly gathering and analysing performance data of plants, encouraging stronger information sharing across the industry by developing performance benchmarks and promoting national and regional research initiatives, specifically on blended cement (Econoler International, 2009).

4.5 The role of OECD-based multinationals
The large OECD-based multinational cement companies, which have a leading role in the Sub-Saharan cement market as large shareholders of multiple plants in the region (Lafarge, Heidelberg Cement and Holcim) have more access to knowledge, finance and technologies for low-carbon innovation compared to their African counterparts. These multinational companies also form part of the Cement Sustainability Initiative, which committed in 2002 to reduce global CO₂ emissions in the cement sector by 20% by 2012 (WBCSD, 2012a). Therefore, it could be assumed that they play a leading role in facilitating low-carbon innovation in cement manufacturing in the region.

However, when contacted for interviews, companies were reluctant to disclose information on specific cement plants in Africa. Local Corporate Social Responsibility campaigns are usually focused on meeting urgent social needs (e.g. building and operating health-care centres for employees and people living in the area of the plant) or tangible projects with strong visual impact (e.g. the rehabilitation of old quarries) (Lafarge, 2007). Given the rather small scale of the cement industry in a specific country, the established position of the different market players and the frequently oligopolistic nature of the business, as well as the fact that there is no regulation of GHG emissions in the region, there seems to be no pressure to invest in low-carbon innovation in Africa compared to other world regions (pers.com., Kjaergaard, 2012). In addition, the context in African countries frequently makes low-carbon innovation more difficult to realize than elsewhere, e.g. due to limited supply chains for alternative fuels. Overall, this case study has found no clear evidence for a significantly positive impact of OECD multinationals on low-carbon innovation in cement manufacturing in the region.

4.6 The impact of resource availability

Availability of fuel may hinder or facilitate low-carbon innovation in cement manufacturing in Sub-Saharan Africa. Globally, there is a trend towards using higher shares of alternative and waste fuels in cement production to reduce production costs and CO₂ emissions. Switching to alternative fuels is generally considered to be the cheapest option for lowering GHG emissions from cement production (WBCSD and IEA, 2009).

In Sub-Saharan Africa, the majority of kilns use heavy furnace oil (e.g. Tanga Cement, Tanzania) or a combination of coal and fuel oil (e.g. Bamburi Cement Plant and EAPCC, Kenya). Fuel accounts for 30% to 40% of the operational costs of the plant (Murray and Price, 2008). Price increases and occasional scarcity of fuel on the local market often force plants to interrupt production for a period of time, until enough fuel is in stock again (pers.com. Schmidt, 2012). As a reaction to the unreliability of fuel supply, at its latest Nigerian cement plant in Ibese, Dangote has even invested into four redundant fuel supply lines, which can use low pour fuel oil, diesel, natural gas and coal. When the plant runs out of one of the fuels it immediately switches to another one, thus ensuring continuity of production (Dangote, 2012c).

Efforts to switch to alternative fuels are mostly at an early stage. Notable pilots are taking place in Uganda, where since 2007, Lafarge owned Hima Cement uses coffee husks from local farms as fuel, which are fed into the kiln through a specially-developed
device. This covers approximately 35% of the total fuel demand, with heavy-fuel oil used to cover the remaining demand. In Cameroon, Cimenteries du Cameroon uses 15% of waste oil as fuel, collected from car service stations in partnership with oil company Total. This programme initiated by Total also covers cement plants in Gabon and Morocco (Total, 2011).

The switch to alternative fuels requires an initial investment into replacing the fuel supply line of the kiln. However, the most salient barrier for the adoption of alternative fuels on a large scale in Sub-Saharan Africa are the generally poor local waste collection systems. Plants have to negotiate with other large industries in the country (including large agricultural production facilities) to use their by-products. In addition, in many countries there is only relatively little (waste-producing) industrial activity, which implies that the available industrial waste can only cover a certain, rather small, percentage of fuel demand of cement plants as is the case in Uganda and Cameroon. In addition, if cement manufacturing does not take place in close proximity to waste-producing industrial or agricultural activities, high costs of transportation of industrial waste products might not justify the initial investments into specialized alternative fuel supply lines. A trend towards investing into the switch from fuel oil to coal as fuel for the kiln has been observed in Senegal and Kenya (Cemnet, 2008), a change which actually increases CO₂ emissions.

4.7 Access to international climate finance

Leveraging multi-lateral and bilateral investment within the international climate agreements of the UNFCCC, is a key route for developing countries in accessing capital in order to implement national energy efficiency and climate change policies. Access to climate finance and low-carbon technologies can be supported by the clear designation of climate experts and decision makers within national governments, and the development of project proposals or a low carbon roadmap for the cement sector.

There have been approximately 60 CDM projects registered involving abatement projects in the cement industry. Although India, China and Indonesia account for the majority of most projects, CDM projects in the cement industry have been developed in Senegal, Nigeria and Kenya. Over 50% of the approved CDM projects in the cement sector involve increasing the amount of blending during cement production⁴.

⁴ CDM Methodology ACM0005.
The lack of ambitious global GHG reduction commitments globally, has led to a
decline in the value of CO$_2$ offsets generated by CDM projects. Offsets generated by
CDM projects have currently very little value, and therefore the scope for new CDM
projects in the Sub-Saharan cement industry is limited. New emerging UNFCCC climate
mechanisms such as the Nationally Appropriate Mitigation Actions (NAMAs), may offer
some potential access to international climate finance.

Although the development of the NAMA concept is currently at an early stage, there
has been an announcement for international support for the development of a NAMA
in the Vietnamese cement sector (Thue, 2012). The Nordic Environmental Finance
Corporation, is funding a €1.5 million project to prepare the Vietnamese authorities for
the development of NAMAs in the cement sector. Work includes:

- Collection of data on emissions reduction potential
- The development of a baseline emission scenario
- Capacity to identify possible emission reductions
- Capacity to develop a measurement, reporting and verification system of
  international standard

Other emerging financial and technology transfer mechanisms under the UNFCCC,
include the Climate Technology Centre and Network (CTCN), which aims to accelerate
the transfer of environmentally sound technologies to developing countries. The CTCN
is financially supported by the governments of Canada, Denmark, Japan, United States
and the European Commission. It is currently unclear to what extent the CTCN can
support the Sub-Saharan African cement sector as the centre is not yet operational.
Messages for policymakers

There are a wide-range of energy efficiency improvements and CO₂ emission reduction options for the Sub-Saharan African cement industry, which have considerable potential for reducing GHG emissions. Based on the analysis of potential enablers for low-carbon innovation, the following recommendations for policy makers can be drawn:

**Recommendations for national policy makers**

*Understand the effects of market liberalization and align industry politics and low-carbon development considerations*

The analysis undertaken suggests that market liberalization incentivizes investments into more energy efficient, and thus less carbon intensive production processes and potentially the closure of the least efficient plants. On the other hand, the increased cost pressure related to market liberalization has been observed to also incentivize a switch to higher carbon fuels such as coal. When planning to take action to incentive low-carbon innovation, it is key to understand the links between general industry developments, particularly market liberalization, and low-carbon innovation. Policies and programmes that could complement market liberalization with a low-carbon aspect include regulation mandating best-available technology for new and renovated plants, as well as offering access to capital at attractive rates for investments in high-efficiency plants.

*Improving reliable access to alternative fuels*

Reliable availability of alternative fuels is the main barrier to an increased use of alternative fuels in cement kilns in Sub-Saharan Africa. Little cooperation between different sectors and industries hinders the development of supply chains for alternative fuels. Governments, potentially with the help of international donors, can support the development of such alternative fuel supply chains through programmes which analyse the concrete potential for using alternative fuels, facilitate the process of establishing relationships between the cement industry and other existing industries, e.g. food processing, or support the development of new businesses, e.g. in the collection of used tyres. In parallel, policy makers should ensure that there is enforceable waste legislation which ensures that the collection systems guarantee that asbestos and heavy metal containing waste, electronic scrap, mineral acids, batteries,
and infectious medical wastes do not enter waste streams destined for incineration in cement kilns. The use of biomass to fuel cement kilns should be considered carefully to ensure that it is not in competition with the production of food and does not have negative impacts on land cover and biodiversity.

**Data collection, energy audits and establishing baselines**
A key priority, if not already available, would be the collection of efficiency and emissions data and site specific details of industrial installations within a country. Auditing the energy use of an industrial sector such as cement, is a fundamental step upon which to develop national policies, as a basis for mediation with industrial stakeholders, and in communicating the status quo and potential interventions to overseas donors, such as multinational investment banks. Knowledge of the current level of plant technology is necessary to identify possible options to improve energy efficiency.

**Recommendations on an international level**

*Incentivize collaborative R&D and information sharing*
Equipment manufacturers play an important role in low-carbon innovation in the sector. In addition, it has been observed that especially in the case of smaller companies and plants in Sub-Saharan Africa, employees often don’t have all the necessary information and expertise for improving the manufacturing process or making investments into low-carbon technologies. It is therefore recommended to support initiatives which improve communication and information sharing between equipment manufacturers and Sub-Saharan cement companies, potentially also including elements of collaborative R&D.

Under the UNFCCC, the Technology Mechanism, in particular the Climate Technology Centre and Network (CTCN), could facilitate R&D cooperation between smaller countries in Sub-Saharan Africa, in order to gain expertise and share best practices on long and short term CO₂ reduction strategies in the cement sector.

*Leverage international finance*
Multilateral Development Banks already play a constructive role in enabling environmental technologies in the cement sector by favouring or requiring the use of BAT. These practices, of tying certain types of support to low-carbon technology adoption, could be promoted and expanded.

Under the UNFCCC, NAMAs could provide a source of support to policies and installations that encourage sustainable sources of energy – such as waste and biomass feedstocks – and efficiency measures. This idea is already being tested in Vietnam (Thue, 2012). Other forms of climate finance - where support is tied to the use of low-emission technology - from sources including bilateral channels and the Green Climate Fund may also prove to be options, though the mechanisms for delivering support from the latter are still being defined. Lastly, there is the possibility, if carbon prices rise, that the CDM again becomes more promising as an option (for least-developed countries, which remain eligible for registering new projects).
References


