# Independent Review

of the

# Low Carbon Cement Project (LCC)

## - Phase 1 -

Implemented by Ècole Polytechnique Fédérale de Lausanne (EPFL)
on behalf of
Swiss Agency for Development and Cooperation (SDC)

# Final Report

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# Executive Summary

This document comprises the review of the ongoing phase 1 of the Low Carbon Cement Project (LCC), which is supported by the Swiss Agency for Development and Cooperation (SDC) and is part of the Global Programme Climate Change (GPCC) of the SDC. The LCC Project has two pilot countries namely India and Cuba and contains a dissemination component at global level. The Project consists of an international consortium headed by the Ecole Polytechnique Fédérale de Lausanne (EPFL). Three Indian Institutes of Technology (IITs) in India (Delhi, Mumbai and Madras), Indian based Society for Technology and Action for Rural Advancement (TARA) and the Universidad Central de Las Villas (UCLV) in Cuba are the implementation partners in the corresponding countries. Phase 1 of the project has a duration of three years and ends in May 2017.

The goal of the review is to evaluate if the LCC Project has achieved or is on track for achieving its overall objective and to value the success of its implementation based on the official OECD-DAC criteria namely impact, effectiveness, efficiency, and sustainability. The project review has been carried out during the months of October until December 2016 and comprised of desk studies, interviews with international experts and one-week field visits to Cuba (October 2016) and India (December 2016).

The overall goal, being the core of the evaluation, has been defined as follows: *LCC is recognized as a cement suitable for general construction and measures for establishment in the market as a mainstream cement type initiated.*

To achieve this overall goal the LCC project needs to work on two fronts at the same time, one on policy and standard level, and the other on industry level.

- Supportive processes in terms of standards, policy framework and reference materials to be developed for LCC/LC3 (reflected in outcome 1 and defined as: *Standards accepted by standards committees*)
- The cement sector and the construction industry understands that LCC/LC3 is a financially and technically sound material and helps to reduce CO2 emissions substantially (reflected in outcome 2 and defined as: *Cement sector is investing in the development of LCC*).

These two areas of interventions are interconnected and both rely on proving the long and short term performance of LCC in concrete. The overall research and project agenda is hence dictated by producing robust scientific results to on-board industry and standardization bodies.

The project was initially called LCC but was stepwise transferred to the LC3 project. LC3 has been identified as the most suitable and relevant material to meet the project´s objectives.

The project review concludes that project implementation is well on track in both pilot countries and at a global level. There is no need for any substantial modification. The formulation of the overall goal of the project was very ambitious and the given indicators have not yet been fully achieved. However, the results so far achieved are excellent and should be recognised as important milestones to reach the goal in the course of the 2nd phase..

The evaluation based on the OECD-DAC criteria can be summarized as follows:

**Relevance:** The relevance of LCC/LC3 is very high, not only for the government and for industry sector in the two pilot countries but also at a global level. LC3 technology provides an opportunity to substantially enhance the life of existing limestone reserves and at the same time reduce the carbon footprint of the industry. The concept of LC3 has significant potential to contribute to SDC´s strategic framework on Global Cooperation on Climate Change.

**Effectiveness:** The effectiveness of the project is high, especially when looking what has been achieved in the past 2.5 years of project implementation. The project was able to put the subject of Low Carbon Cement on the agenda of Government organizations, and globally active cement companies. It also introduced LC3 at several national and international conferences, including Habitat3 and COP22.

**Efficiency:** The project used the given financial resources in a very efficient manner for positioning the subject of LCC/LC3 at national and international initiatives and to demonstrate its applicability at the level of R&D. However, more efforts are needed to materialize the final goal of establishing LC3 as mainstream cement. Mainstreaming requires a close, trustful and continuous cooperation with commercial enterprises and with relevant Government authorities.

**Impact:** The project created a very good impact by fostering the discussion of an optimized “low carbon” cement design in the two pilot countries of Cuba and India and at the international level. LC3 is very much in discussion as an option to further reduce the ecological footprint of the cement industry. Research at lab scale and pilot application in the two pilot countries confirmed the potential of LC3 as a material to reduce $CO_2$ emissions significantly. The project´s effort contributed to the global discussion that limiting $CO_2$ emissions in the cement industry is not only possible by reducing and optimizing energy input in the clinker process but at least in a similar scale by modifying cement composition.

**Sustainability:** It is too early to validate the sustainability of the project achievements after 2.5 years only. However, it can be stated that the reduction of additional $CO_2$ emissions (beside energy efficiency) will be a fact in the future and thus the project launched a sustainable road map on new cement composition. LC3 should not be seen as a competitor to fly ash or any other possible primary or secondary raw material but as an additional input material dependent on regional availability and proximity to a cement plant.

Due to the remarkable success of the project in a relatively short period, the evaluation team recommends to continue with the project in a 2$^{nd}$ phase. Recommendations for the remaining months of the present phase 1 and overall recommendations for the possible 2$^{nd}$ project phase are given in chapter 5 of this report.

The members of the review team (Dieter Mutz, Roberto Torrent and Divya Kashyap) would like to thank all partners and counterparts for their high patient and commitment during the field visits in India and Cuba and for the professional support offered by SDC in New Delhi and EPFL in Switzerland.

# Acronyms and abbreviations

| | |
|---|---|
| BIS | Bureau of Indian Standard |
| CIDC | Centro de Investigación y Desarrollo de la Construcción |
| CIDEM | Centro de Investigación y Desarrollo de Estructuras y Materiales |
| CMA INDIA | Cement Manufacturers' Association of India |
| CSI | Cement Sustainability Initiative (of the WBCSD) |
| EPFL | Ecole Polytechnique Fédérale de Lausanne |
| GECEM | Grupo Empresarial del Cemento, Cuba |
| GoI | Government of India |
| IEA | International Energy Agency |
| LC2 | Supplementary cementitious material resulting of intergrinding limestone and calcined clay, to be used as partial replacement of OPC in concrete production |
| LC3 | Limestone Calcined Clay Cement, cement resulting from the intergrinding of clinker, calcined clay, limestone and gypsum |
| LCC | Low Carbon Cement (project) |
| MCTM | Ministerio de Ciencia Tecnología y Medioambiente |
| MES | Ministerio de Educación Superior, Cuba |
| NCCBM | National Council for Cement and Building Material, India |
| ONN | Oficina Nacional de Normalización, Cuba |
| OPC | Ordinary Portland Cement |
| PBFSC | Portland Blast Furnace Slag Cement |
| PFA | Pulverized Fly Ash |
| PLC | Portland Limestone Cement |
| PPC | Pozzolanic Portland Cement |
| SCM | Supplementary Cementitious Materials, material of cementitious value added as a separate concrete ingredient |
| TARA | Society for Technology and Action for Rural Advancement |
| UCLV | Universidad Central “Marta Abreu” de Las Villas, Cuba |
| WBCSD | World Business Council for Sustainable Development |

# 1 Introduction

Cement is the basic and most widely used building material in civil engineering, the quantity of which has increased dramatically because of vast and rapid urbanization. The cement industry is also one of the most significant carbon emitters, making it the second largest carbon dioxide ($CO_2$) contributor in industry after coal-fired power plants. This sector accounted for about 1.8 Gt of $CO_2$ emissions in 2006, approximately 7% of the total anthropogenic $CO_2$ emissions worldwide. This creates two main challenges for the future, which are:

- How can current resources meet the projected increasing demand?
- How can the environmental impact ($CO_2$ emissions) of this production increase be mitigated?

Improvements in the sustainability of the cement production in major markets can have a global impact on resource efficiency and $CO_2$ released to the atmosphere. Today, the major part of $CO_2$ emissions from cement plants are generated from clinker production and only a smaller fraction from raw materials preparation and the finishing stage of producing cement. Therefore, the most effective strategy to further reduce $CO_2$ emissions from cement production lies in reducing its clinker content.

This has laid ground for the Swiss Agency for Development and Cooperation (SDC) through its Global Programme Climate Change (GPCC) to support the Low Carbon Cement (LCC) Project which aims at making the Limestone Calcined Clay Cement (LC3) a standard and at mainstreaming it as general-use cement in the global cement market[1]. This requires that:

- The framework environment in partner countries such as India, Cuba and other major cement markets is conducive to the commercial production and adoption of the new cement type. This requires conclusion of the standardization processes based on relevant and adequate documentation of the technology and its performance and thereby removing policy hurdles for its production; and
- The cement industry and their customers are convinced of LC3 as a cement suitable for general construction and the industry is ready to invest in its commercial production.

The LCC project wants to accelerate the uptake of this technology by acting as a neutral and scientifically credible partner in order to establish LC3 as a mainstream cement product. The main strategy of the LCC project during current phase 1 was to develop and document scientific knowledge by producing and using LC3 on trial basis to provide scientific evidence that it is feasible and technically sound. This was to animate a global network and learning platform among all the stakeholders so as to prepare the ground for new standards in India, in Cuba and other countries.

The key outputs of the current phase 1 of the project are outlined as:

- Efficiency, sustainability and market potential of LC3 production proven;
- Performance of concretes made with LC3 proved to be comparable to standard cements (key aspect is long-term behavior / durability)
- Engagement with policy influencing bodies to support standardization of LC3;
- Draft standards for LC3 produced and submitted to standardization bodies;

[1] The project was initially called LCC but was stepwise transferred to the LC3 project. LC3 has been identified as the most suitable and relevant material to meet the project´s objectives.

- Potential and results of LCC project communicated to all stakeholders including general public on a continuous basis; and
- Experts in LC3 technology become available.

The overall management of the project is centralized at the Ecole Polytechnique Fédérale de Lausanne (EPFL) level as a nucleus of the project. EPFL has entered into formal research collaborations with 3 Indian Institutes of Technology (IITs) in India (Delhi, Mumbai and Madras). The IITs are involved in many of the research activities under way, in particular conducting tests on raw materials used for producing LC3, as well as on the properties of LC3 and on the usability of LC3 in different building materials like concrete. EPFL has also entered into collaboration with the Society for Technology and Action for Rural Advancement (TARA), an organization known for its applied research with extensive knowledge of the building sector. TARA is in particular involved in mapping and sourcing materials, coordinating the production of LC3 in India, in producing LC3 at small scale and building demonstration structures and products in the field.

In Cuba, EPFL continued its collaboration with Universidad Central de Las Villas (UCLV), that has been a partner in the development of the LC3 production process. UCLV plays a key role in mainstreaming LC3 in Cuba in this phase. The UCLV has built laboratory facilities for testing raw materials, LC3 and concrete and has established experimental stations to monitor the long-term performance of precast concrete elements.

The LCC project contributes to SDC's overall goal of promoting sustainable development by reducing the global risk of climate change. It is anchored in the Strategic Framework 2014 - 2017 of the Global Programme on Climate Change (GPCC) and the respective strategy of the GPCC India program by developing a solution for mitigating $CO_2$ emissions in one of the fastest growing sectors in developing countries and emerging economies. It thus contributes both to safeguarding development achievements from negative climate impacts and to a climate-compatible development trajectory. In addition, it contributes to reducing poverty by strengthening social housing and infrastructure potential at a lower cost and reduced environmental impact.

Total SDC outlay earmarked for the Phase 1 of the LCC project is about CHF 4 million. The financial contribution was used to support the underpinning technical studies in academic institutions. The main research activities focus not only on specific thematic areas of cement research (such as hydrate assemblages, pore structure, rheology, reactivity, durability and mechanical properties) but also on production, environmental sustainability and cost effectiveness of the LC3 cement. The SDC support was complemented by collaborations with industrial partners who contributed time of staff, testing of materials, preparation of trial batches and further research support. Countries outside the core research cooperation of Switzerland, India and Cuba, were expected to finance their own studies, while the LCC project will support network meetings and dissemination.

The current phase of the project, which is now in the third year, is drawing to a close (May 2017). A review of the project was foreseen to consolidate the lessons and experiences of the project and capitalize on them in developing a potential next phase of the project.

This review was expected to provide a critical independent view on how the SDC funded LCC/LC3 Project is being implemented. The objectives and the scope of the review are presented in chapter 2; an overview of project´s objective and outcomes is given in chapter 3 and the methodology used in chapter 4. Chapter 5 refers to the "Evaluation and assessment of

LCC phase I" and Chapter 6 contains "Recommendations" on activities to be complemented in the remaining months of the present phase (until May 2017) and makes recommendations for a possible 2nd phase.

# 2 Objectives and scope of the review

The main purpose of the review is to assess the achievement of project results, and to draw lessons that can improve the sustainability of the project benefits and recommend future course of action. The assessment is based on the criteria prescribed by OECD viz. relevance, effectiveness, efficiency, impact and sustainability. The review assesses the overall performance of the project, including appraising the project activities and their contribution to the project objectives, by looking at the following key dimensions:

- **Relevance**: The extent to which the objective of the project matches the needs of the target groups, the policies of the partner country and partner institutions, the global development goals and the SDC's strategic framework for the Global Cooperation on Climate Change.
  *Main question: Are we doing the right thing?*
- **Effectiveness**: The extent to which the intended direct results (objectives) of the development are being achieved (comparison of actual situation with targets).
  *Main question: Are we achieving the agreed objectives of the project?*
- **Efficiency**: A measure of the degree to which the resources invested in the project are appropriate compared to the outputs and results achieved.
  *Main question: Is the objective being achieved cost-effectively?*
- **Impact**: The extent to which the project is contributing to achieving the intended overarching results and producing other indirect results.
  *Main question: Are we contributing to the achievement of overarching development results?*
- **Sustainability**: A measure of the probability that the positive results of the development measure will continue beyond the end of assistance.
  *Main question: Are the positive results durable?*

The review was expected to come out not only with an objective assessment of the project achievements but also offer recommendations that could help consolidate the generated impacts and provide ideas on follow up activities to support establishment of LC3 as a mainstream cement. Apart from improving learning, the perspectives gathered through the review should help in effective design, planning, implementation and review of climate change and mitigation policies and actions in future, not only in India and Cuba but at a global level.

Further details are described in the Terms of Reference of September 2016 (Annex A).

# 3 Overall goal, outcomes and indicators

The overall goal of the project was that "LCC is recognized as a cement suitable for general construction and that measure for the establishment in the market as a mainstream cement type are initiated". The indicators to measure the level of achievement are:

- Standards submitted for adoption in 3 countries

- Demonstration structures show positive preliminary performance
- Major cement companies produce LCC in a pilot scale in 3 countries

Two outcomes to be achieved during the project period were defined:
- Outcome 1: Standards accepted by standards committees
- Outcome 2: Cement sector is investing in the development of LCC

The indicators for Outcome 1 were:
- The standards accepted for consideration
- Standards committees discuss LCC – standard(s) in 3 countries

The indicators for outcome 2 were:
- Major cement companies produce LCC (at least on a pilot scale) in 3 countries
- Cement companies financing at least two Ph.D. projects with core partners.
- Cement companies supporting standards for LCC technology
- WBCSD CSI initiative incorporates technology paper related to LCC
- One cement plant in Cuba is producing LCC in a regular established process with local materials (production of 50000 tons per year)
- The company FLSmidth uses calcined clays from at least two countries for LCC project.

In order to achieve the milestones a set of outputs and activities were defined, which are further described in the log-frame but will not be considered in detail in this project review.

# 4 Methodology, Schedule and Review Team

## 4.1 Methodology applied

The review is a qualitative assessment consisting of four main parts:

- Desk study and definition of the methodology in the Inception report. The first part of the work offered insight into the project and its objectives. The relevant project documentation received from the SDC was analyzed (see list of available documentation in ANNEX B – Documents provided by SDC). An appropriate methodology for the review was defined and documented in the Inception Report.
- Interaction with the project implementing organization (EPFL): A meeting at the EPFL with the Project Director provided an overall introduction to the project. A teleconference was held to discuss and get feedback on the findings of the review team.
- Interaction with the main stakeholders and the implementation partners: One mission to Cuba and one to India were undertaken to understand the practical relevance of the project and the relations of the project partners with the private and public sector. The review team interacted with project partners, industry stakeholders, relevant government agencies, industry associations, etc. and visited selected project implementation sites (for details see Annex D and E).
- **Debriefing** at SDC India, SDC Berne and incorporation of the results into a final report.

Table 1 below shows the timeline of the evaluation.

## 4.2 Schedule

| Date | Activity |
|---|---|
| 23.09.2016 | Initial briefing through SDC-India (via video conference) |
| From 16.9.2016 onwards | Desk study. Review of project documents provided by the project |
| 26.09.2016 | Initial meeting with project management at EPFL in Lausanne |
| 30.09.2016 | Submission of Inception Report |
| 02.- 09.10.2016 | Field visit to Cuba |
| From 20.10.2016 onwards | Different meetings/talks with relevant stakeholders in Switzerland, Germany, Mexico and Peru |
| 28.11 - 5.12.2016 | Field visit to India, including debriefing at SDC Delhi |
| 15.12.2016 | Debriefing at SDC Berne |
| 16.12.2016 | Submission of the draft report |
| 19.12.2016 | Response on the draft report |
| 23.12.2016 | Submission of the Final Report |

**Table 1**: Overview of the main evaluation activities

## 4.3 Review team

The review team consisted of the following experts:

- Dr. Dieter Mutz, University of Applied Sciences and Art, Northwestern Switzerland. Teamleader, field visits to Cuba and India, issues on sustainable development
- Dr. Roberto Torrent, Quali-TI-Mat, Coldrerio, Switzerland. Technical issues and standardization; field visit to India
- Divya Kashyap, Senior Thematic Advisor, SDC New Delhi. Climate issues and cement sector in India; accompanied the field visits in India

# 5 Evaluation and assessment of LCC phase I

According to the TOR the review was based on the OECD-DAC criteria viz. relevance, effectiveness, efficiency, impact and sustainability.

The evaluation of OECD-DAC criteria has been primarily done in the context of the overall goal/objective and the two given outcomes.

**Overall Goal:**

*LCC[2] is recognized as a cement suitable for general construction and measures for establishment in the market as a mainstream cement type initiated.*

To achieve this overall goal the LCC project needs to work on two fronts at the same time, one on policy and standard level, and the other on industry level.

- Supportive processes in terms of standards, policy framework and reference materials to be developed for LCC/LC3 (reflected in outcome 1 and defined as: *Standards accepted by standards committees*)
- The cement sector and the construction industry understands that LCC/LC3 is a financially and technically sound material and helps to reduce CO2 emissions substantially (reflected in outcome 2 and defined as: *Cement sector is investing in the development of LCC*).

These two areas of interventions are interconnected and both rely on proving the long and short-term performance of LCC/LC3 in concrete. The overall research and project agenda is hence dictated by producing robust scientific results to on-board industry and standardization bodies. The following evaluation is done on the basis of the overall goal and its indicators (see chapter 3). On the level of outcome, the assessment has been done not only in the narrow sense of the formulated outcomes but in a more contextual understanding of the two areas of intervention.

The assessment is done separately for the two pilot countries. Reason for it is the very different framework conditions in India and Cuba. More background information on the cement sector in these 2 countries can be found in Annex C. The assessment is complemented by looking at activities beyond the pilot countries and always closes with an overall conclusion for the specific criteria. The guiding questions as listed in chapter 2 of this report and given in more details in the TOR (Annex A) have been used as overall orientation.

## A. Relevance

India:

The Government of India in the XII five year Plan has listed the following schemes that could potentially boost cement utilization:

- 100 per cent deduction for profits to an undertaking in housing project for low cost housing in urban areas approved during June 2016 to March 2019;
- Incremental spend on smart city development with allocation of CHF 1.09 billion towards Urban Rejuvenation Mission (AMRUT) and Mission for Development of 100 Smart Cities; and
- Adoption of cement instead of bitumen for the construction of new road projects as cement is more durable and cheaper to maintain in the long run.

As the proven reserves of the cement grade limestone are limited, the issue of resource management has been high on the government agenda. While on one hand, the Government of India (GoI) has been promoting blending of fly ash through compulsory use of fly ash based

[2] Actually turned into LC3 at a later stage of the project.

construction material by public and private sector agencies[3], GoI Working Group on Cement for XII Five Year Plan (2012 -17) also proposed to look at the alternative of Portland Limestone Cement (PLC's) and multi-component blends. Indian government is increasing its pressure on the industry to reduce its $CO_2$ emissions and steadily, the users will prefer "green" cements in the future. Consequently, the Indian cement industry with support of WBCSD and IEA published a roadmap on low-carbon technology[4]

With an annual production of 290 Million tons of cement, India is currently the second largest producer in the world. Its per-capita consumption (185 kg/annum) is, however, amongst the lowest in the emerging world. Many studies have projected that India's cement demand would reach 550-600 Million Tons per annum by 2025, because of growth in sectors like housing, infrastructure, commercial and industrial construction sectors, which are the biggest demand drivers of cement. Therefore, achieving $CO_2$ reduction in Indian cement industry's emissions will have a strong global impact.

Indian cement industry applies, in general, modern technologies and thermal efficiency in clinker production has reached levels with little room for further optimization. Hence, substantial reduction in $CO_2$ emissions can only be achieved by reducing the clinker fraction in concrete through lowering the amount of clinker in cement and/or reduction of cement content in concrete through mix design optimization.

India makes massive use of coal for power generation, which generates large amounts of pulverized fly ash (PFA) available (at different but cheap prices for cement and free for concrete products). It is therefore not surprising, that the most sold cement in India (65%) is the Pozzolan Portland Cement (PPC) containing 70-80% of clinker, 15-25% of PFA and 5% gypsum. It is believed that PFA will continue to be available in the coming years in the same percentage as today.

There are inconsistent reports on availability of high-grade limestone, required for clinker production. One version states that proved reserves cover 30 to 40 years of industry's needs only; other states that there are more reserves but not yet properly explored. In any case, limestone availability is a concern for the cement industry.

<u>Cuba:</u>

The subject of environment and resource management is on the agenda of the Government of Cuba and is very much linked to an efficient use of natural resources and to optimize energy consumption. Standardization of materials used in the construction sector is of relevance for the concerned authorities.

There are three major Government programs in Cuba for which LC3 is of relevance:

- *Program for the local production and sale of building materials*[5]: This program is oriented to tackle housing deficit for the whole population. It is a prominent program with a huge material demand and LC3 can be sold at an affordable price.

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[3] Ministry of Environment and Forests, MoEF Gazette Notification on Fly Ash Utilization, 1999, amended on 27 August 2003).

[4] Technology Roadmap - Low-Carbon Technology for the Indian Cement Industry, WBCSD & IEA, 2012

[5] Programa de producción local y venta de materiales de construcción

- *Program for construction of tourist resorts*[6]: Most tourist resorts are located close to the seashore, and thus corrosion of reinforcing steel is a serious issue. LC3 could contribute to mitigate corrosion and to foster sustainable and climate-friendly construction.
- *Program for road and bridges*[7]: This program is meant for both cars and railways and a huge investment is planned in the years. Corrosion of steel for such exposed structure will be an issue.

Cement demand for all kind of construction activities will be huge in the coming years. The expected consumption will triple in the coming 15 years. The production in the year 2015 was 1.8 Mio tons and will increase to an estimated demand of 5.5 Mio tons in 2031. This figure illustrates the huge demand for cement and the high potential of $CO_2$ reduction in the country. The government-owned cement industry has to undergo modernization and is very eager to look for resource and cost efficient solutions.

Beyond the two pilot countries:

Cement production results in a significant emission of $CO_2$ into the atmosphere. At a global level several initiatives have been launched to look into the subject of emission reduction. Substantial efforts have been achieved in energy efficiency in the clinker production and grinding, whereas a bigger potential remains untapped in the reduction of the clinker content in cement. There is a global political understanding that $CO_2$ reduction in the cement industry is strongly required and this was also pointed out at the COP21 in Paris in December 2015.

All the well-known globally positioned cement companies are aware of the increasing pressure to reduce $CO_2$. National cement associations are coming up with local road maps and the topic is high on the Cement Sustainability Initiative (CSI) of the WBCSD.

The LCC project aligns itself with SDC´s GPCC strategic framework 2014- 2017, which outlines the programmatic policy concerning climate change mitigation as ‘fighting the causes’ by reducing and avoiding greenhouse gas (GHG) emissions. The LC3 technology, if proven to be technically and financially viable, can contribute to this by directly reducing the CO2 emissions (by 10-30 percent in comparison to PPC and OPC, respectively) from the cement manufacturing process owing to reduction in the clinker content.

Conclusion on relevance

The relevance of LCC/LC3 is very high, not only for the government and industry sector in the two pilot countries but also at a global level. LC3 technology provides an opportunity to substantially enhance the life of existing limestone reserves and at the same time reduce the carbon footprint of the industry. The concept of LC3 has significant potential to contribute to SDC´s strategic framework on Global Cooperation on Climate Change.

[6] Programe de construcción de obras del turismo

[7] Programa nacional de vialidad

## B. Effectiveness

India:

Project's Phase 1 efforts were focused, reasonably, on characterizing the product, producing LC3 (at different scales) ~~and~~, as well as on investigating its performance in concrete mixes.

The opportunities and potential of LC3 is well known by most stakeholders within India which is an important achievement of the project. The required research needs have been covered professionally by EPFL and the three IITs involved. The experimental results produced so far have led to LC3 being recognized and accepted as a feasible technical solution, with few reservations (colour, higher water demand, low carbonation resistance). Important to outline, the influential NCCBM is convinced of the merits of LC3.

Although further experimental work may still be needed (long-term monitoring of exposed elements), the objective to prove the suitability of LC3 has been successfully achieved, beyond reasonable doubt to most stakeholders.

It was the right decision to develop the R&D tasks of Phase I in the highly reputed IITs and in parallel to apply LC3 in the field through TARA, an organization that has outstanding experiences in the manufacturing of appropriate building materials.

All this work has laid the technical ground for a possible standardization of LC3. In this context, the project team has recently collated draft standards for the LC3 technology and submitted it to the Cement and Concrete Sectional Committee of the Bureau of Indian Standards (BIS).

The project has initiated a partnership with JK Lakshmi Cements, which has provided its own clinker production and cement blending facilities near Delhi to manufacture 130 tons of LC3 and use that cement ~~the same~~ manufacture AAC blocks at the same facility for the construction of the SDC office in Delhi. Subsequent to this, JK Lakshmi on its own manufactured 200 tons of LC3 at their production facility for in-house testing and validation. Independent trials are also being undertaken by some other cement companies including Ambuja Cements, and results have been shared at the stakeholder meetings organized by the project.

There are no Indian Standards yet available covering either LC3 or LC2, which precludes their use in structural concrete applications and, hence, to meet the goal of a “mainstream cement”. Currently the use of LC3 is restricted to the production of non-structural concrete elements, such as roof tiles, pavement blocks and non-bearing masonry blocks as well as to masonry mortars, which may taint the product as “second class”.

Therefore, first priority policy is to achieve a rapid standardization of LC3, which requires considerable and persisting persuasive efforts among main stakeholders, chiefly cement industry. Builders and ready-mixed concrete producers that buy high quality OPC and blend them with high proportions (50%) of PFA. may constitute an obstacle to standardization if they are not taken on board at an early stage

Besides LC3, the product LC2 (Limestone Calcined clay) seems to become quite attractive to the cement industry to be used as a SCM (like metakaolin, fly ash, slag). The project team also seems to find the LC2 option attractive from the perspective of promoting accelerated adoption of the technology while avoiding the long-drawn process of standardization necessary for the LC3.

However, further investigations on LC2 on technical, financial and legal issues are required before promoting it at a larger scale. The LC2 solution is not accepted by the Indian Concrete Construction Code (IS 456:2000), the modification of which is probably an insurmountable task in the short-term, and so advancing this solution seems not advisable until LC3 has been standardized.

Cuba:

CIDEM as coordinator for all tasks to be performed in Cuba is very well organized and contributes at all levels to the overall goal and the outcomes of the project. The two major achievements are:

(1) Promotion of LC3 as an appropriate and advantageous alternative for OPC at national level, not only in the field of science but also at the level of ministries. The awarding of the Premio de la Academia de Ciencias de Cuba and the special price of the Ministry of Technological Sciences and Environment (MCTM) in 2015 for the work done on the *Development and Industrial Production of Low Carbon Cement in Cuba* underline the excellent work and recognition of CIDEM in the country.

(2) The Norm NC XX (*twenty*): 2016 (CEMENTO TERNARIO — ESPECIFICACIONES) has been approved and introduced by the Cuban National Bureau of Standards in January 2016 which allows the application of LC3-50 as cement in Cuba.

CIDEM has a highly motivated team with consolidated expertise in characterization, applied research, and technical development in issues related to LC3. The group understands well the concept of the project and is very much dedicated to achieve the set objective especially in its practical application in the cement industry. The project team is maintaining close links to the cement industry and its members are respected as knowledgeable experts. Two major achievements are:

(1) Setting up a team at CIDEM which is not only dedicated towards material sciences but covers also aspects such as economy, industrial processes and construction. This interdisciplinary approach makes cooperation attractive for the cement industry

(2) Two cement companies, namely Siguaney and Artemisa have already considered LC3 production. Siguaney has started a small commercial production (30 Tons per year) and Artemisa is in the phase of ~~modification~~ adapting its production line for LC3 production.

Beyond the two pilot countries:

The formation of the UNEP working group to evaluate technologies for lowering $CO_2$ emissions associated with the production of cement based materials is very much linked to the project. Not only is the project manager (Prof. Scrivaner) the co-chair of the working group, but it is an ideal (and cost effective) platform to position LC3 as a relevant material in clinker substitution. The UNEP working group presented its white paper on “Potential Solutions for Low CO2, Economically Viable Cement-based Material” successfully at the UN-Habitat in October 2016 and at the COP22 in Marrakech in November 2016. The project also strengthened the link to the CSI (Cement Sustainability Initiative) of the WBCS (World Business Council for Sustainable Development).

National and international conferences organized by the project (e.g. 1st International Conference on Calcined Clays for Sustainable Concrete being held at EPFL in June 2015) or participation as speaker at well-known working group meetings (e.g. presenting of LC3 at the

WBCSD CSI Workshop in Bergamo, Italy March 2016), helped to increase the number of contacts with industry and to assure an increasing recognition of the validity of the approach by policy makers.

Looking at the overall goal and outcomes one can conclude that the project is well on track and will achieve its set objectives by the end of the phase 1 with minor delay in the standardization process in India. The formulated outcomes and outputs with the respective indicators are not fully consistent which did not affect the project evaluation but might impede project steering and monitoring (especially in the pilot countries)

The overall achievements can be summarized as follows:

- LC3 is recognized by the cement industry and government authorities as a relevant technology option to lower $CO_2$ emissions and save resources;
- Capacity development and applied research are well established;
- Standardization process successfully concluded in Cuba, initiated in India;
- Cement industry started with the production of LC3 at pilot scale; and
- Successful dissemination of project achievements through brochure, video and participation at national and international events.

<u>Conclusion on effectiveness</u>

The effectiveness of the project is high, especially when looking what has been achieved in the past 2.5 years of project implementation. The project was able to put the subject of Low Carbon Cement on the agenda of Government organizations and globally active cement companies. It also introduced LC3 at several national and international conferences, including Habitat3 and COP22.

The formulation of the overall goal of the project was very ambitious and the given indicators have not yet been fully achieved. However, the results so far achieved are excellent and should be recognised as important milestones to reach the goal in the course of the 2$^{nd}$ phase.

## C. Efficiency

<u>India:</u>

The results achieved show that the material and human resources allocated have been efficiently used.

The reaction of the cement industry to the project has been mixed. For instance, JK Lakshmi has actively participated by producing some 200 tons under industrial conditions. On the other hand, some of the cement companies (especially the bigger ones) are showing a “wait and watch” attitude. While no numbers are available on the exact contribution by third parties towards the project, the fact that companies like Shree Ram Minerals and JK Lakshmi Cements offered their facilities for the production of calcined clay, LC3 as well as production of LC3 based AAC blocks for construction of the SDC office in Delhi is an indicator of the success of the project in engaging the interest of the industry in the technology.

The participation of the cement industry representatives in various Stakeholder Workshops as well as presentation of their independent research results on LC3 technology is noteworthy.

The main obstacle to the adoption of LC3 is the lack of Indian standards covering the product. This constitutes an insurmountable barrier to the use of LC3 for structural concrete at a commercial level at this stage.

One way of waiving the lack of standards identified is the use of LC3 in non-structural products (e.g. masonry and pavement blocks, roof tiles, masonry mortars, etc.). In India, 90% of cement is sold in bags, out of which some 30%-40% goes to masonry and plastering mortars. Using PPC, and even worse OPC, for such operations is a complete waste of clinker. Masonry cements (covered by IS 3466:1988) contain typically ~40% clinker (with the rest being ~~usually~~ pulverized stone, usually limestone), which is much less than the 70% contained in PPC. The Indian cement industry should seriously consider introducing masonry cements (which may or may not need calcined clay) in the market as a way of reducing $CO_2$ emissions. Measures (e.g. bags of different weight, colour) and training are required to avoid that the non-structural cement ends up being used (accidentally or deliberately) in load-bearing structures.

This is a segment that has not yet been fully explored by the LCC project. The project has been aiming at positioning LC3 as a high quality mainstream product, the image of which could be damaged if promoted for non-structural applications.

The other alternative is to use LC2 as a separate constituent of concrete, an option envisaged with optimism in the LCC project. However, Table 5 of IS 456:2000 ("Plain and Reinforced Concrete – Code of Practice"), that sets up minimum limits to the cement content and maximum limits to the w/c ratio of concrete subjected to different exposure conditions (from "Mild" to "Extreme"), only accepts explicitly fly-ash and GGBS, as partial replacement of cement under certain conditions, namely:

*"Cement content prescribed in this table is irrespective of the grades of cement and it is inclusive of additions mentioned in 5.2. The additions such as fly ash or ground granulated blast furnace slag may be taken into account in the concrete composition with respect to the cement content and water-cement ratio if the suitability is established and as long as the maximum amounts taken into account do not exceed the limit pozzolona and slag specified in IS 1489 (part 1) and IS 455 respectively."*

Therefore, it seems that the use of LC2 for structural concrete is not allowed by current Indian Concrete Construction Code.

The project team has shared the results of its research on the LC3 technology with the National Council for Cement and Building Materials (NCCBM), which operates one of the BIS accredited labs for cement and building materials testing and is an important agency in the standardization process for any new cement. NCCBM which was initially skeptical of the LC3 technology has now entered into an agreement with the project team for testing of the LC3 samples.

Prof. Bishnoi's role as leader of the Indian team is acknowledged as very positive, particularly in terms of IITs' R&D coordination and achievements. TARA has contributed with more applied work, producing precast elements and even constructed a house with LC3 concrete and mortar. Both organizations received continuous support and orientation from EPFL. Although a link to the cement industry was given through the part-time engagement of Mr. Chatterjee (former CEO of ACC), it seems that his expertise and contacts with the industry have not been fully exploited. Besides focussing on the research aspects of the technology, the project team could have benefitted from the participation of a senior industry expert who could have lead the team on industry oriented techno commercial assessment of LC3 which would be in-line with industry perspective on any new cement technology. This would have helped position LCC project not as an R&D initiative but a project promoting a potential commercially viable technology. The project also did not establish links with Indian ministries like Ministry of Commerce and Industries, Ministry of Earth Sciences and Ministry of Environment, Forests and Climate Change (MoEF&CC) or the Ministry for Housing and Poverty Alleviation (MoHPA) although they spearhead the industry perspective, research agenda and the political agenda setting on climate change issues in India.

Cuba:

Prof. Martirena as director of CIDEM and as project coordinator is very much dedicated to the subject, has an excellent understanding of LCC and specifically LC3 and moves the project (and his team) towards the committed objective. He was able to set up a close and trustful cooperation with policy makers, the cement industry and regulatory bodies, which allows a concertized development.

The project could set-up excellent relationship with the Ministry of Higher Education, the Institute of Construction and the Cement Association of Cuba (Grupo Empresarial de Cemento, GECEM). Those contacts allowed to drive the project forward in a transparent manner and to consider the interest from the different stakeholders from the very beginning. As a result, public and industrial interests have been created and LC3 standards approved.

The Cuban cement industry has embraced the concept of LC3 with committed investment. It will put the production of LC3 into the mainstream planning in 2017. Actions are focused on refurbishing an existing clinker kiln at the cement factory Siguaney. The investment costs foreseen are in the range of 5 million USD, with a scheduled annual production of 300´000 tons of LC3 per year.

The project team has disseminated the concept of LC3 in quite a number of countries in Latin America (Mexico, Peru, Colombia, Ecuador, Brazil) and received encouraging feedbacks. Cement companies asked for assistance to evaluate clay deposits and have sent clay samples to Cuba and have commissioned the team for resource studies and clay characterization with the expectation that ~~trails~~ trials will be carried out in the near future.

Implementation of a project of this nature on an island like Cuba and with a primarily government owned industry has advantages and disadvantages. The positive element is that action can happen much faster as implementation at the industrial level is directly linked to development target of the government. This influences also the pace of standard setting. The risks have to be seen in the availability of financial resources to implement an ambitious project like LC3 at full-scale industrial level.

Beyond the two pilot countries:

The project has generated a lot of leverage as private companies and research institutes offered support to disseminate the LC3 concept at national and international events and conferences and contributed substantially in capacity building, education and applied research (seminars, master and PhD students etc.). A few cement companies in countries other than Cuba and India started to invest into LC3 application with their own funds.

In Europe, the process toward new standards is in most of the cases initiated by the companies themselves. To support this process, Heidelberg is financing a PhD student at EPFL since 1st. August 2016 to prepare the way to adoption of calcined clay in the currently proposed CEM II / C class (down to 50% clinker) and eventually to support a standard down to 40% clinker, which would include LC3 technology. The current EU standard does allow LC3 blends to be produced with as low as 65% clinker content. The overall project management was done very efficiently at the global level but also within the two countries. Regular meetings at country level, stakeholder consultations and the formation of a high level steering committee at global level ensured a coordinated approach. The project was also well handled by the SDC team in New Delhi.

Conclusion on efficiency

The project used the given financial resources in a very efficient manner for positioning the subject of LCC/LC3 at national and international initiatives and to demonstrate its applicability at the level of R&D. However, more efforts are needed to materialize the final goal of establishing LC3 as mainstream cement. Mainstreaming requires a close, trustful and continuous cooperation with commercial enterprises and with relevant Government authorities.

## D. Impact

India:

Rightly, the main efforts of Phase I of the project have been placed on evaluation raw material availability, defining the production process, including required quality of raw materials and on characterizing the product and the performance of concrete (and to a lesser extent mortar) made with it.

As mentioned above, the academic work (which consisted mainly of applied research) developed during Phase I has paved the way to the acceptance of the product and opened the door for its standardization.

The project is based on a sound assessment of the forecasted evolution of the cement market in India and the available resources of raw materials for the manufacture of conventional and special, “low carbon” cements. The comprehensive mapping of clay reserves in the country must be seen as a professional tool for planning future exploitation of raw materials.

The LC3 looks the most promising alternative for massive reduction of $CO_2$ emissions by the cement industry, in terms of availability of raw materials, of adaptability to the manufacturing process, as well as of acceptance by the concrete construction market. The fact that high grade clay or limestone are not needed to produce LC3, opens the way to make use of “waste” materials, accumulated in high volumes in the respective quarries. This will impact the Government of India´s strategy to turn waste into a secondary raw material.

During the interviews held in India, in no case the technical suitability of LC3 concrete was questioned. There is a general belief on the feasibility of using LC3 concretes for general concrete construction. Only pinkish colour of LC3 may present minor problems, to be tackled through suitable marketing even into a benefit.

Given the traditional conservative attitude of the construction industry towards innovation, a full dossier of performance of LC3 concretes (preferably in parallel to the current most consumed concretes) produced at industrial scale, should be prepared. This should include, on top of the conventional properties, determination of complete σ-ε diagrams including descending branch, fatigue tests, sensitivity to plastic shrinkage cracking, long-term volume changes (drying shrinkage and creep), sensitivity to thermal cracking, etc.

Most concerns expressed referred to the long-term stability of LC3 concretes. Thermodynamic and microstructural investigations should be oriented to alleviate such doubts. In parallel, laboratory durability tests e.g. (permeability, migration, diffusion, accelerated carbonation, ASR, sulphate resistance, etc.) should be applied on representative LC3 concretes complying with the prescriptive requirements of Table 5 of IS 456:2000 ("Plain and Reinforced Concrete – Code of Practice").

A pending issue, which may have to wait until standardization arises the admixtures industry's interest, is to develop tailor-made chemicals of optimum performance with LC3. Today, LC3's dosage of admixture is 2x that for PPC and 4x that for OPC.

There is more work to be done in terms of identification of suitable and convenient deposits of clay and limestone which, despite the efforts made by TARA, should be developed by the industry itself. Same applies for understanding the effect of variability in raw materials' characteristics on the uniformity of the LC3 and how to cope with it efficiently.

Mainstreaming of LC3 and creating long term impact in the cement production depends strongly on standardization of the product. If it is realized that standardization is not possible, the use of LC3 for non-structural applications should be seriously considered, at the risk of downgrading the product and of abandoning (at least temporarily) the goal of a mainstream product.

Although the technical viability of LC3 has been demonstrated in the lab and in trials conducted by JK Lakshmi Cements, there is still work required to address some of the technical challenges including the light pink colour of the cement (where traditionally the colour grey is associated with cement strength in consumer perception), early strength, water demand and carbonation.

Cuba:

The project has a substantial impact on standardization and policy alike. This is explicitly reflected in the approval of the new norm which would never have been elaborated in such a quality and time span without the project.

The Cuban National Bureau of Standards has published in January 2016 its Norm XX: 2016 entitled "Ternary Cement – Specifications". This norm regulates the use of ternary binders, including LC3-50. This means, that production of LC3 is covered by standards. Negotiations are underway for adapting existing standards for the application of concrete produced with LC3. The National Institute of Construction (CIDC) and the National Association of Cement Producers (GECEM) are fully supporting this initiative. This means that Cuba can be seen as a frontrunner in the context of standardization and that the application of LC3 has its legal basis in the country.

The technical, environmental and economic viability of producing LC3 in Cuba has been demonstrated in the lab but also at exposure sites. LC3 is considered by the cement industry as a construction material for high performance applications. Durability tests have contributed to the prestige for LC3, and convinced several construction companies to consider building bridges and hotel resorts in coastal areas. Main advantage for them is LC3's contribution to reduce corrosion of concrete in a marine environment. Other cement companies in Latin America have called upon the Cuban experience (CIDEM) on contract basis to understand better the advantage and to explore replication in their own countries.

Considering the given geographical conditions and the exposure of many new buildings (e.g. tourism resorts) and infrastructure (e.g. bridges) to marine environment LC3 has the advantage of reducing corrosion of reinforced steel. This advantage has been scientifically proven in the lab as well as in specific exposure sites along the sea. This advantage of LC3 should be further evaluated as it gives an additional strong argument for LC3 applications in many other countries of Latin America (and beyond) especially on islands and construction activities along the coastlines.

Beyond the two pilot countries:

LC3 was presented at the COP22 in Marrakesh in November 2016 through the UNEP working group on low carbon cement. The project team at EPFL (namely Karen Scrivener) presented the concept of LC3 at various international conferences and the international cement community is well aware about the potential of LC3 for CO2 reduction. Combination of global dissemination, applied research at EPFL, India and Cuba, and practical application of LC3 in the two pilot countries have ~~been~~ proved beyond any reasonable doubt that:

- LC3 can be produced at an industrial scale without large modifications of the manufacturing facilities or prohibitive investments (e.g. Siguaney, Cuba; JK Lakshmi, India)
- LC3 is a robust product that has been produced rudimentarily at small scale (houses built in Santa Clara, Cuba; Jhansi, India). Main concern is differential grind ability between clinker (harder) and LC2 components (softer), that may lead to ultrafine LC2 with negative impact of higher water demand of concrete. Closed circuit mill with HES may be required for obtaining a performing LC3. An issue not yet fully clarified is the variability in quality of both clay and limestone and its impact on the uniformity of LC3; possibly some pre-homogenization may be required
- Concretes produced with LC3 perform very similarly to those produced with standard cements, with some advantages in terms of resistance to chloride penetration and disadvantages in terms of resistance to carbonation.

While the project had its focus on standardization and commercialization of low carbon cement, there seems to be a growing interest in promotion of limestone calcined clay (LC2) as a SCM (like metakaolin, fly ash, slag). This option is being considered attractive by project partners in India and Cuba from the perspective of promoting accelerated adoption of the technology and creating rapid impact while avoiding the long-drawn process of standardization necessary for the LC3[8]. In India, this approach collides with the National Concrete Code IS 456:2000, which excludes the use of LC2 as SCM, so it should be explored with caution.

[8] JK Lakshmi Cements seems to be quite positive about the potential of immediate application of LC2 as a SCM(instead of fly ash which is difficult to access at some locations and metakaolin, which costs INR 18'000 - 20'000 per ton) to produce PPC or even manufacturing prefabricated products like AAC blocks, tiles etc. as these products do not have mandatory performance standards in India.

In house blending of LC2 without adequate regulatory mechanism can potentially lead to inconsistent and inaccurate blending, and this could affect the strength and performance of the products developed. Promotion of any technology (whether as a binder or as SCM ~~an additive~~) in the construction sector, without required validation and standardization, could be fraught with potential liability issues for SDC as well as the project partners.

To further increase the impact, the knowledge and expertise developed during Phase I of the project should be condensed in a report, or better a Handbook of LC3 production. This will avoid pitfalls and will accelerate the adoption of LC3 by the industry.

<u>Conclusion on impact</u>

The project created a very good impact by fostering the discussion of an optimized "low carbon" cement design in the two pilot countries of Cuba and India and at the international level. LC3 is very much in discussion as an option to further reduce the ecological footprint of the cement industry. Research at lab scale and pilot application in the two pilot countries confirmed the potential of LC3 as a material to reduce $CO_2$ emissions significantly. The project´s effort contributed to the global discussion that limiting $CO_2$ emissions in the cement industry is not only possible by reducing and optimizing energy input in the clinker process but at least in a similar scale by modifying cement composition.

## E. Sustainability

<u>India:</u>

It is difficult at this stage to envisage the mid to long term development of LC3 as a sustainable and permanent product, because it is still at an early stage, with important challenges to overcome in the short term. However, if the standardization of the product will be achieved, the future of LC3 looks promising.

In order to appeal to major cement manufacturing companies, any alternative cement product has to be able to generate at least the same economic value as that from an OPC production plant. One of the options for cutting costs in the cement manufacturing is to focus on utilization of lower cost raw materials like in LC3, thereby boosting margins. As per the studies conducted by the project partners, LC3 has a potential to emerge as a marginally cheaper option as compared to OPC, but considering that OPC accounts for less than 25% of total cement production/consumption it does not immediately emerge as a commercially attractive proposition. The key attraction for LC3 is the use of waste limestone and clay resources, which would likely attract the industry and is therefore the aspect that should be highlighted. To convince the industry further of the commercial advantages of LC3, the project would benefit from undertaking a robust techno-economic feasibility assessment.

The proven reserves of the cement grade limestone are limited and fast depleting in many areas of India. LC3 technology provides a great opportunity to utilize the low grade limestone and clay resources for the production of cement, thereby providing an opportunity to substantially reduce the use of clinker in the cement, something the Government of India is interested in and which will be a valid reason for the sustainability of LCC.

At the same time, it is important to remember that even if the Government puts the cement industry under pressure to further reduce its $CO_2$ emissions, the industry might hesitate to adopt a technology that does not have a proven commercial value and consumer acceptance. The potential for $CO_2$ emission reductions is presently being seen more as a co-benefit by the industry in India. It is possible that future resurgence of carbon markets (e.g. Green Climate Fund at the international or $CO_2$ trading schemes at the national level) could make LC3 an attractive option for the industry in the future.

The Table below looks at the manufacturing costs of some of the cement options in India vis-a-vis LC3.

| S. No. | Item | Composition | Cost of Production for 1 ton of cement in Indian Rupees / USD |
|---|---|---|---|
| 1 | Ordinary Portland Cement (OPC) | 95% Clinker + 5% Gypsum | 1425 + 75 = 1500 / 22.05 |
| 2 | Portland Pozzolana Cement (PPC) | 72% Clinker + 23% Fly ash + 5% Gypsum | 1080 + 230 + 75 = 1385 / 20.37 |
| 3 | Portland Blast Furnace Slag Cement (PBFSC) | 45% Clinker + 50% blast furnace slag + 5% Gypsum | 675 + 1500 +75 =2250 / 33.08 |
| 4 | Portland Limestone Cement (PLC) (in India) | 85% Clinker + 10% Limestone + 5% Gypsum | 1275 + 16 + 75 = 1366 / 20.08 |
| 5 | Portland Limestone Cement (PLC) (in EU) | 70% Clinker + 25% Limestone + 5% Gypsum | 1050 + 40 + 75 = 1165 / 17.13 |
| 6 | Limestone Calcined Clay Cement (LC3) | 50% clinker + 30% calcined clay + 15% Limestone + 5% Gypsum | 750 + 600 + 24 + 75 = 1449 / 21.31 |

***Assumptions and calculation basis:***
*Clinker manufacturing cost: INR 1500.00 per ton (http://cbs.teriin.org/pdf/OCL_India_Waste.pdf)*
*Landed cost of Limestone: INR 160.00 per ton*
*Landed cost of Gypsum: INR 1500.00 per ton*
*Landed Cost of Fly Ash: INR 1000.00 per ton (at JK Lakshmi the rate quoted was INR 600/ ton)*
*Cost of Ground Granulated Blast furnace Slag Powder: INR 3000 per ton*
*Cost of Calcined Clay: INR 2000 per ton*
*1 USD = INR 68*

From the rather crude assessment in the table above, it would seem that LC3 has a potential to emerge as a marginally cheaper option as compared to OPC (because of lower cost of clay and low quality limestone, compared to the cost of clinker manufacturing), also validated by the studies conducted by the project partners. Additional benefit might be incurred from the reduction in fuel required for clinkerisation, but again this might not be very significant.

The depleting cement grade limestone deposits could prove to be the key driver for the industry to be potentially interested in LC3 technology, especially considering that average retail sale price of OPC is about the same as PPC per bag.[9]

[9] Globally wholesale prices for cement are closely guarded by suppliers. They are often supplied only on a case-by-case basis to individual customers. Prices are affected by a large number of factors such as the type of cement, supply and demand in the region and the quantity required. As a result of such variations the price of OPC varies between around US$35/t (close to the marginal cost of production in an efficient plant) up to US$180/t.

While it is expected that use of OPC would increase in future on account of it being a preferred option of the large institutional buyers or for prefabricated construction[10], it is not clear if that would also incentivize the industry to lobby with standard agencies and start manufacturing the new cement.

Cuba:

Looking at a possible primary and secondary raw material availability it can be seen that natural pozzolan, blast furnace slag and fly ash are limited in Cuba and thus the substitution rate for clinker is limited on the island. However, there are ample deposits available of kaolinitic clay and limestone for the coming years. Application of LC3 and LC2 will not only reduce the $CO_2$ emissions but will also contribute to a well-balanced resource raw material consumption of clay and limestone. However, the exploitation of clay and limestone deposits have to be validated against the protection of biodiversity sensitive areas. Clay is available close to the surface and its excavation means huge transformation of surface soil.

Considering the present economic situation in Cuba and projected development targets by the Government one can conclude that modernization and extension of all kind of infrastructure will be high on the agenda in the coming years. However, this can only be materialized if construction materials are available and if the cement industry is in a position to deliver cement in sufficient quantities and at affordable prices. The required modernization of the cement industry offers an excellent opportunity to anchor LC3 in this transformation process.

Beyond the two pilot countries:

The LC3 technology provides a possibility to explore the use of low grade clay and limestone resources (with 35% CaO as compared to 42% CaO in cement grade limestone) which is today found lying discarded in heaps around the mines. For decades industry has been struggling with the proper disposal of these discards as there are no known potential uses for the same (other than blending some of it with higher grade limestone). The potential use of such unwanted resources for cement manufacture, through LC3 technology, could potentially contribute to the “greening of economic growth”, a strategy to achieve sustainable development in the resource-constrained sectors and economies.

The LC3 technology also offers the cement industry an alternative to existing resources used for cement manufacturing (low grade china clay instead of fly ash/ metakaolin used in PPC). This could be especially valuable in areas where access to fly ash is not cost effective (because of distance from thermal power plants) or not available in bigger quantities (like in Cuba). This aspect of the LC3 technology, which is very relevant for both cement and clay industry, fits in very well with the broader strategic objective of GPCC which is now being renamed to include environment.

It is equally important to consider the potential socio-economic benefits of shifting the building sector to a low carbon emission trajectory, while meeting the need for the development of essential infrastructure in developing nations. LC3, when manufactured using low grade raw materials, could potentially offer a more sustainable (and maybe potentially cheaper) building construction material option for meeting the need for housing and infrastructure development. This would also directly and indirectly provide economic and social benefits through creation of jobs, enhanced access to housing and other social services.

To date, the project is not fully consolidated and its success requires continued efforts, particularly to win the support of the cement industry in its standardization and adoption, as well as

[10] The Government of India is increasingly promoting use of prefabricated materials for low cost housing.

in completing the information required to fully characterize the short and long-term performance of LC3 concretes. SDC's support in Phase 2 of the project seems important for the completion of these tasks. Afterwards, it is believed that the project will take its own dynamics and will run on its own merits, although dissemination to other countries should be considered, if resources allow, during Phase 2 and even beyond. For a rapid dissemination of the technology, a mapping of countries with standards like ASTM C 1157 ("Standard Performance Specification for Composite Cements") or similar, placing emphasis on the performance of the cement rather than on its composition should be made. Countries on the sphere of the European Standards (e.g. South Africa) should give priority to those on the sphere of ASTM Standards.

Sustainability of the project depends to a large extent on expertise and, hence, on people and their long-term commitment to achieve its goals globally. The nature of the project has led, naturally, to a concentration of know-how on a handful of persons of high degree of expertise. This is not negative in itself, but is risky in that the focus of interest of these few experts may change in the future, abandoning the LC3 project for that or other reasons. Hence, dissemination of that know-how is essential to guarantee the sustainability of the LCC approach. If the spread of the know-how is to be assured, teams of more than one individual should be established in each country of concern, accompanied with as comprehensive as possible documentation as possible.

One last aspect that may seriously affect the sustainability of the project is a patent, held today by Aalborg Cement. Although reassuring comments have been made by the project leaders that that company will not claim intellectual property rights, at least to small producers, the issue needs absolute legal clarification. One may trust the goodwill of the company. However, a Machiavellian thinking may set a strategy of others doing the expensive development work for that company reaping the benefits at a later stage. If the objective of the project is fulfilled and LC3 becomes a mainstream cement worldwide, the temptation to exert the legal rights of the patent-holding company will increase exponentially. Moreover, this being a long-term initiative, today's managers of Aalborg (that seem to have a generous attitude) will certainly be replaced by others who may have different viewpoints. Also, holding that patent may become an important asset of the company, which may attract investors to acquire it with the intention of making commercial use of the patent. It is very important that this legal issue is solved during Phase 2 of the project; perhaps SDC counts with a legal body of lawyers that look at this issue seriously and thoroughly.

<u>Conclusion on sustainability</u>

It is too early to validate the sustainability of the project achievements after 2.5 years only. However, it can be stated that the reduction of additional $CO_2$ emissions (beside energy efficiency) will be a fact in the future and thus the project launched a sustainable road map on new cement composition. LC3 should not be seen as a competitor to fly ash or any other possible primary or secondary raw material but as an additional input material dependent on regional availability and proximity to a cement plant.

There are some threats to the sustainability of the project that should be addressed during Phase 2:

1: Thorough selection of extension countries

2: Avoidance that the know-how remains in few hands by proper dissemination

| 3: Looking carefully at the legal implications of having a technology patent-holder |
|---|

# 6 Recommendations

## 6.1 Recommendations for the remaining period of Phase 1

Project implementation is well on track in both pilot countries and at a global level. There is no need for any substantial modification. However, if time and budget allows, the following activities are recommended to be realized in the remaining months of phase 1:

- Carry out a profound Stakeholder Analysis in India as input for the selection of partners for a 2nd phase. Special emphasis should be given to potential partners from the public and industry sector (e.g. Ministries, cement associations, etc). The analysis should describe the role identified partners could play to promote LC3 and LC2 further.
- There are comprehensive mappings of clay deposits in Cuba and India. In both countries, the mapping should be complemented by locations of protected natural areas and earmarked zones within regional spatial planning. This visualization will help to get a comprehensive understanding where excavation will be possible in the future and where clay resources cannot be exploited.
- There is an urgent need for a robust Technical-Financial Feasibility Study on LC3 application. This study should be done by a business consultant with good understanding of the commercial functioning of the cement market.
- It is recommended to develop a detailed Process Manual so as to make it easier for the industry to understand how their existing facilities have to be redesigned / retrofitted for the production of LC3. The suitability of raw materials for LC3 production should also be dealt with and the findings from the technical-financial feasibility study to be incorporated into the Process Manual.

## 6.2 Recommendations for a 2nd phase

**Due to the remarkable success of the project in a relatively short period of time, the evaluation team recommends to continue with the project in a 2nd phase.** The ffollowing recommendations are based on the review of project reports and short but comprehensive one-week field visits in both the pilot countries. Recommendations should not be understood as binding but as an additional input in the already started discussion for designing the 2nd phase of the project.

**General recommendations:**

- Together with the industries' huge investments in energy efficient equipment, as well as the efforts to substitute coal with alternative fuels, the blending of low grade limestone and calcined clays could be an important initiative within an overall strategy of the Cement Industry towards improved sustainability of its activities (UNEP 2016). This validates the continued relevance of the LC3 technology. While the first phase of the project was rightly focused on research on LC3 technology and assessing its characteristics and performance, it is important that the second phase of the project has a stronger focus on the establishment of relevant standards as well as creation of market acceptance for LC3. For both cases an even stronger cooperation with industry and government is essential.

- The evaluation team recommends to continue with the two pilot countries namely India and Cuba and to further assist in standardization and commercialization of LC3 and LC2. In both countries, LC3 is not yet fully "accepted" by industry (cement and construction) and additional hand holding is required. However, the positive political momentum and the interest of the industry in both countries are favourable for anchoring LC3 and later LC2. A more intensive dissemination at regional level especially in Asia and globally should be considered as a focal task in a possible 3rd phase. Attempts for regional dissemination (e.g. Thailand, Peru, Columbia) should depend on the readiness of the respective Government and local cement companies to invest in LC3 and/or LC2
- International networking and dissemination is important and should be done through participation at international conferences and being member of recognized working groups. It is understood that international cement companies will promote the use of LC3 beyond a pilot country like India if the top management is convinced. Therefore, "lobbying" for LC3/LC2 by EPFL at global level and through respective platforms (e.g. Supra-national Cement Associations, UNEP, Nanocem, etc.) is important.
- Going for the LC2 solution in India needs to be pondered very carefully, as the current Concrete Construction Code, difficult to modify, seems to exclude its use.
- Set-up a mechanism for coordinating activities and results of the various stakeholders (cement industries, research institutes, government bodies) so that experiences are shared and synergies used. The project in its 2nd phase could play the role as facilitator (to keep the strings together) in the two pilot countries but also at a global level. A possible partner could be the CSI of the WBCSD.
- Beside cement companies it is also important to give attention to construction companies, builders and consumer associations as they influence the market development as end-users.
- Standardization in a given period of time (1-3 years) will only happen if the cement industry is convinced and "pushes" national standardization offices to work on LC3 standardization. In parallel, Governments should be aware that LC3 has the potential to reduce $CO_2$ emissions and to contribute to reach their NDCs (nationally determined contributions) as outlined in their respective climate action plans. The role of the project should be to develop a communication and cooperation strategy and to set-up working groups on standardization consisting of representatives from industry, government and academia. This should be done in the pilot countries but also at an international level to allow dissemination of experiences and best practices.
- Low cost housing (e.g. government program on Housing for All in India) will be a prominent topic in the future and an area where huge amount of cement will be required. Urbanisation and poverty alleviation are the drivers in almost all developing countries and emerging economies. LC3 application in those programmes in combination with precast construction elements will be a unique opportunity to demonstrate resource efficiency and climate change mitigation. A link to other projects of SDC in the housing sector should be considered for creating possible synergies
- Introduction of a low carbon cement such as LC3 and LC2 is very much linked to the global debate on climate change and management of natural resources. The Swiss Government should make use of this project to be stronger positioned through its respective SDC country or regional offices.
- The presently given institutional set-up of project management and steering should continue in the 2nd phase. A stronger emphasize should be given in guiding the national

team leader through project staff from EPFL. The participation of project members at international conferences and bi- and multilateral working groups should continue. The prestige of EPFL and Prof. Scrivener should be put to good use in convincing the local cement industry of the convenience of standardizing and producing LC3.

- Full dissemination of the know-how, possibly towards the end of Phase 2 (or even in a possible Phase 3), in the most widespread and transparent manner, is essential for the sustainability of the project
- Lawyers with expertise in the field should address the controversial legal situation regarding the patent covering LC3 very seriously.

**Specific recommendations for India**

- A well formulated, comprehensive program of short-term “durability” tests coupled with field testing of real scale reinforced concrete elements (eventually real buildings), exposed to environments that are typical of the main concrete constructions in India is highly recommended. The performance of these elements should be monitored regularly, including the extraction of drilled cores for assessing the rate of penetration of aggressive species. The sample should include concretes subject to standard and substandard curing conditions, to study the sensitivity of the LC3 concretes to lack of proper curing. The onset of corrosion should be established by means of electrochemical ND tests and the threshold levels (e.g. critical $Cl^-$ concentration) triggering corrosion should be determined, as well as the ensuing rate of corrosion. NCCBM is the right place in India to conduct, at least, the laboratory tests.
- It is very important to move actively to issue a cement standard covering LC3. Samples of raw materials, cement as well as LC3 based products shall be tested and validated by BIS authorized laboratories and the National Council for Cement and Building Materials (NCCBM) and results then fed back into the relevant committees of the BIS. Steps in this direction have already been initiated by the project team and need to be strengthened considerably in the next phase.
- There is a need and time to move in India from research to application. For this, it might be an advantage to engage a team leader with a good technical understanding of industrial processes and insights of the cement market for the next phase. To assure regular and coordinated meetings for information exchange between researchers (IIT), Government bodies, the cement industry and construction companies are an essential part of the duties of the team leader.
- Engagement with the relevant Ministries and public sector institutions is required for raising awareness about the benefits of manufacturing and application of LC3 cement among the public and also incentivize the industry to take up its manufacturing and sale. Stronger engagement with industry associations (cement manufacturers association, Ready mix Concrete Manufacturer’s Association and construction industry) to promote the technology on the basis of a thorough techno-commercial assessment would be extremely important.
- There are also still some technical issues, carbonation, water demand, curing requirements and variation in cement colour with the LC3 cement, which requires some further work. The durability studies are still in the preliminary stages and require further work with exposure sites across various parts of India, especially coastal zones to validate the chloride resistance of LC3.

- As the use of fly ash to produce PPC is well established in India, more emphasis should be given to position LC3 as an alternative product in regions of India where fly ash is not available and the cement industry has no option but to produce and market OPC.
- It is believed that a decisive action should be undertaken to bring the Indian cement industry even more on board of the Project, if LC3 is to be launched as a commercial product at a global scale. Perhaps the Cement Manufacturers' Association of India (CMA INDIA) or the Indian branch office of WBCSD could support the project by in motivating the reluctant bigger cement companies like LafargeHolcim or UltraTech aiming at a more proactive attitude in India and elsewhere.
- Although there have been many studies predicting a rapid growth in the cement consumption in India , there is still unutilized manufacturing capacity (about 30%) in the existing cement plants in India. If it can be established, through multiple industrial scale trials, that LC3 can be manufactured in existing cement plants, with limited retrofitting, it would be an important consideration for the industry to adopt LC3 technology at a much faster pace.
- In addition, LC3, vide its property of chloride resistance, has a potential to emerge as a niche product for construction in and around coastal areas of India, after thorough testing and validation. The niche positioning of LC3 could support it to emerge as a product with a distinct identity (in a situation where there are already more than 25-30 variants of cements being sold) and provide an opportunity to the industry to cater to a particular market segment.

**Specific recommendations for Cuba:**

- The political and administrative set-up in Cuba, the urgent need for a low-cost cement for their housing program and the given interlinkages between Government and industry allow a relatively fast implementation of innovative approaches such as LC3 and LC2. Cuba could serve as a pilot for other countries to use LC3 in the field on commercial conditions. The proposed 2nd phase should consist of a well-balanced combination of applied research, capacity development, ongoing standardization and production of LC3 at an industrial level.
- The Hurricane Matthew, which hit the eastern part of Cuba in October 2016, underlined the need for an appropriate construction technique that is more resilient towards extreme weather conditions (e.g. concrete roofing) and for the use of a cement that has a high chloride penetration resistance that makes buildings more resistant in a marine environment. This urgent requirement could be an attractive option for the promotion of LC3 and LC2 as Cuba needs cheap and fast applications. Special emphasize should be given to this unique opportunity in the 2nd phase.
- The Cuban Technical Committee #37 “Concrete & mortar” has not yet endorsed full use of LC3 as general purpose cement to make concrete in an aggressive environments in coastal regions.
- There is no full building yet entirely made with LC3 as a “living proof” of its benefits in Cuba. But an agreement could be achieved to build a bridge in Santa Clara in 2017. There is a need to monitor and evaluate the performance of this bridge.
- The potential of LC3 to develop ultra-low clinker binders for masonry applications has not properly been addressed yet but strong interest by the Government of Cuba to

promote low cost housing with appropriate (and innovative) construction material that have economic advantages compared to OPC

- Evaluate the purchase of a semi-industrial plant with a calciner and grinder to increase level of performance beyond lab scale (check if there is a joint venture possible with LH or CEMEX). This plant could be set-up with financial resources of the Government of Cuba, the international cement companies and a symbolic financial contribution by the project to assure access to the plant and results of trial runs.
- Support for the extension of the PhD-program with a strong link to international scientific community. Universities of Cuba offer solid education and research but this could be further strengthened through international cooperation and exchange.
- Positioning of CIDEM and its senior staff within international associations and networks (e.g. RILEM or ACI). This, however, is only possible if CIDEM has the chance to increase further its reputation.
- Extend the task of CIDEM as service provider to the commercial sector through a spin-off. Support could be offered through backing of the spin-off in its initial stage.
- Durability studies are still at a very early stage and positive results cannot yet be considered conclusive. Corrosion and concrete exposer studies were launched and follow-up is required to get results which are of interest not only for Cuba but also for the international scientific community.
- Support in the improvement and upscaling of the existing laboratory at the CIDEM so that material does not have to be sent to EPFL and to act as Reference Centre and service provider for other countries in the region (e.g. Columbia, Ecuador, Peru).
- The project is focusing its research, application and training on issues related to LC3 on Cuba. There is not yet a mechanism established that allows a coordinated regional collaboration and dissemination of experiences. The set-up of a regional forum to foster supranational cooperation on the subject where prestigious partners from public and private sector can participate is required.
- Other countries in Latin America expressed their interest to get more information on LC3 application in Cuba and looking at the opportunity to promote Cuba as LC3 hub in the region it is recommended to set-up a regional LCC centre in Cuba to provide support and training for LA, Central America and the Caribbean States. However, additional human resource must be made available for this activity and responsibilities divided among senior staff at CIDEM.

# 7 Acknowledgments

The Authors are indebted to the following people, the participation of which has been invaluable to understand the situation of the project in Switzerland, Cuba and India and for the preparation of this report:

- Prof. Karen Scrivener and her staff at EPFL, particularly Rob Fielding
- All persons interviewed, see list in Annex E, who invariably shared with us their honest knowledge, opinions and recommendations
- Staff from SDC and TARA in India for an intensive, well prepared program of visits and useful discussions

- Prof. Fernando Martirena from CIDEM and his team for getting the visit to Cuba organized despite the hurricane Matthew
- Last, but not least, to Anders Nättorp, University of Applied Sciences and Arts Northwestern Switzerland (FHNW), Muttenz, Switzerland, for support in preparation of this report

# ANNEX A – Terms of reference

## Review of the Low Carbon Cement Project (LCC)

## Terms of Reference (ToR)

### 1. INTRODUCTION AND CONTEXT

Cement is the basic and most widely used building material in civil engineering, the quantity of which has increased dramatically because of vast and rapid urbanization. The cement industry is also one of the most significant carbon emitters, making it the second largest carbon dioxide ($CO_2$) contributor in industry after power plants. This sector accounted for about 1.8 Gt of $CO_2$ emissions in 2006, approximately 7% of the total anthropogenic $CO_2$ emissions worldwide. This creates two main challenges for the future, which are:

- How can current resources meet the projected increasing demand?
- How can the environmental impact ($CO_2$ emissions) of this production increase be mitigated?

Improvements in the sustainability of the cement production in major markets can have a global impact on resource efficiency and CO2 released to the atmosphere. Today, the major part of CO2 emissions from cement plants are generated from clinker production and only a smaller fraction from raw materials preparation and the finishing stage of producing cement. Therefore, the most effective strategy to further reduce CO2 emissions from cement production lie in reducing its clinker content.

This has laid ground for the Swiss Agency for Development and Cooperation (SDC) through its Global Programme Climate Change (GPCC) to support the Low Carbon Cement (LCC) Project which aims at making the Limestone Calcined Clay Cement (LC3) a standard and at mainstreaming it as general-use cement in the global cement market.  This requires that:

- The framework environment in partner countries such as India, Cuba and other major cement markets is conducive to the commercial production and adoption of the new cement type. This requires conclusion of the standardization processes based on relevant and adequate documentation of the technology and its performance and thereby removing policy hurdles for its production; and
- The cement industry and their customers are convinced of LC3 as a cement suitable for general construction and the industry is investing in its commercial production.

The LCC project wants to accelerate the uptake of this technology by acting as a neutral and scientifically credible partner in order to establish LC3 as a mainstream cement product. The main strategy of the LCC project during current phase was to develop and document scientific knowledge by producing and using LC3 on trial basis to provide scientific evidence that it is feasible and technically sound. This was to animate a global network and learning platform among all the stakeholders so as to prepare the ground for new standards in India, in Cuba and other countries.

The key outputs of the current phase of the project are outlined as:

- Draft standards for LC3 produced and submitted to standardization bodies;
- Engagement with policy influencing bodies to support standardization of LC3;
- Efficiency, sustainability and market potential of LC3 production proven;
- Potential and results of LCC project communicated to all stakeholders including general public on a continuous basis; and
- Experts in LC3 technology become available.

The overall management of the project is centralized at Ecole Polytechnique Fédérale de Lausanne (EPFL) level as a nucleus of the project. EPFL has entered into formal research collaborations with 3 Indian Institutes for Technology (IITs) in India (Delhi, Mumbai and Chennai), building on the existing partnerships. The IITs are involved in many of the research activities under project, in particular by conducting scientific tests on raw materials used for producing LC3, as well as on the properties of LC3 and on the usability of LC3 in different building materials like concrete. EPFL has also entered into collaboration with the Society for Technology and Action for Rural Advancement (TARA), an organization known for its applied research with extensive knowledge of the building sector. TARA is in particular involved in mapping and sourcing materials, coordinating the production of LC3 in India and in building demonstration structures and applications in the field. In Cuba, EPFL continued its collaboration with Universidad central de Las Villas (UCLV), that has been a partner in the development of the LC3 production process. UCLV plays a key role in mainstreaming LC3 in Cuba in this phase.

The LCC project contributes to SDC's overall goal of promoting sustainable development by reducing the global risk of climate change. It is anchored in the Strategic Framework 2014 - 2017 of the Global Programme on Climate Change (GPCC) and the respective strategy of the GPCC India program by developing a solution for mitigating $CO_2$ emissions in one of the fastest growing sectors in developing countries and emerging economies. It thus contributes both to safeguarding development achievements from negative climate impacts and to a climate-compatible development trajectory. In addition, it contributes to reducing poverty by strengthening social housing potential at a lower cost and reduced environmental impact.

Total SDC outlay earmarked for the project is about CHF 4 million. The financial contribution was used to support the underpinning technical studies in academic institutions. The main research activities focus not only on specific thematic areas of cement research (such as hydrate assemblages, pore structure, rheology, reactivity, durability and mechanical properties) but also on production, environmental sustainability and cost effectiveness of the LC3 cement. The SDC support was complemented by collaborations with industrial partners who contributed time of staff, testing of materials, preparation of trial batches and further research support. Countries outside the core research cooperation of Switzerland, India and Cuba were expected to finance their own studies, while the LCC project will support network meetings and dissemination.

The current phase of the project, which is now in the third year, is drawing to a close. A review of the project is foreseen to consolidate the lessons and experiences of the project and capitalize on them in developing a potential next phase of the project.

## 2. OBJECTIVES AND SCOPE OF THE REVIEW

The main purpose of the review is to assess the achievement of project results, and to draw lessons that can improve the sustainability of the project benefits and recommend future course of action. The assessment should be based on the set of criteria prescribed by OECD viz. relevance, effectiveness, efficiency, impact and sustainability. The review will assess the overall performance of the project, including appraising the project activities and their contribution to the project objectives, by looking at the following key dimensions:

**a) Relevance**

- How does the LCC project relate to the objectives set in SDC's strategic framework of the Global Cooperation on Climate Change?
- How does the LCC project fit in with national level development priorities of key partner countries and with global developmental and environmental concerns?
- Is the LCC project well suited to address the documented needs of the sector?
- Is LC3 a realistic alternative/complement to commonly used cements?
- Is the LC3 of interest to the industry, and government / public sector entities?

**b) Effectiveness**

- Are the project goals and approach aligned with the sectoral needs?
- Are the project activities and outputs consistent with the overall goal, project objectives and intended impacts?
- To what extent has the LCC project achieved or likely to achieve its stated objectives?
- What are the advantages and limitations of LC3 over other green cements?
- Is the research carried out and data collected adequate to help establish the new standard in cement manufacturing?
- Is LC3 ready to be launched as a commercial/ mainstream product?
- Has the industry partnership approach of the LCC project been effective in achieving the project outputs and outcomes?
- Have lessons learnt during the course project implementation been considered and effectively applied?

**c) Efficiency**

- Have the project resources been used in an efficient manner to achieve the project objectives? Have the project activities been implemented in a timely manner and within the proposed budget?
- Is the industry partnership approach used for LCC an efficient approach to achieve the outputs and outcomes?
- Has the project been able to leverage proposed resources for implementing the project activities?
- How have the project implementing agencies coordinated their efforts with relevant stakeholders including the industry, standard setting agencies, builders to promote production and use of LC3?

**d) Impact**

- To what extent has the project been able to convince the industry to invest its resources for the production and testing of LC3?
- At what stage is the project in terms of preparing ground for setting of product standards for the LC3?

- Has the project been affected by certain external factors which have affected its implementation?
- How far has the project been able to reach out to the target beneficiaries?
- Does the project reflect good practices in the context of technology development and transfer for climate change mitigation?
- Has the project had any unintended impact?

**e) Sustainability**

- To what extent does the LC3 production help reduce carbon emissions when compared to the commonly used cements in the respective countries?
- Does the project technologically contribute to longer term sustainability of the cement sector in the respective countries and globally?
- To what extent can the low carbon cement be sustainably produced and used in the long run? What are the likely environmental impacts of the project (e.g. impact of clay extraction on agriculture / food security, need of water for curing on availability of water)?
- Is the LC3 production economically sustainable? Does LC3 face any economic/ financial barriers to becoming mainstream commercial cement?
- Has the LC3 overcome 'end-use' barriers (like availability of clay, competing uses of clay, industry and customer acceptance, and establishment of standards) to become a realistic alternative to commonly used cements? What are the achievements and existing gaps and how best can the project address them?
- Can the LCC project sustain the impact and results of the project benefits beyond completion of the project?

The review is expected to come out with an objective assessment of the project achievements and to offer recommendations that could help consolidate the project achievements and provide ideas on follow up activities to support establishment of LC3 as a mainstream cement, if the technology stands out to be promising. Apart from improving learning, the perspectives gathered through the review should help in effective design, planning, implementation and review of climate change and mitigation policies and actions in future, not only in India but elsewhere.

## 3. METHODOLOGY AND APPROACH

The detailed methodology and approaches related to the review will be developed by the team and outlined in the inception report. Therefore, the approaches suggested below should be taken as indicative and provisional.

To begin with, the team will engage in a detailed Desk Review by carefully studying all the available documents including the project document, log frame of the project, six monthly and annual operational and financial reports, minutes/ proceedings of the steering committees and advisory board, agenda and proceedings of workshops held at various levels, documentation related to the project including back to office notes, minutes of meetings held in connection with the project etc. The review team will also go through the various knowledge products generated out of the project initiative.

On the basis of first interactions with SDC and project partners, the reviewers will come up with a brief inception report outlining their detailed methodology and work plan for organizing the review as well as initial findings from the desk review, after due consideration of the available time, resources and data/information. The team members will also agree on the indicators, questions and hypotheses related to the review and their respective roles and responsibilities in discharging various tasks associated with the review including writing of the reports.

Next, the review team will have interactions with project partners, industry stakeholders, relevant government agencies, industry associations, etc. If required, the review team will visit selected project implementation sites (in India and in Cuba) and have detailed discussions/ interactions / interviews / workshops with stakeholders at different levels (State, national), including with the project implementation agency and private sector partners. After these interactions, a short debriefing session shall be organized at the SDC Programme Office in New Delhi (or alternatively per Skype) in order to present and discuss interim findings.

## 4. EXPECTED OUTCOME AND DELIVERABLES

The main outcome of the review is a review report that provides an objective assessment of SDC's Low Carbon Cement Project as well as strategic inputs with regard to the future direction of SDC's engagement in the topic. The report will be made available to the project implementation team as well as project partners such as government agencies and other stakeholders.

The main products from the review are:

a. A brief inception report outlining the detailed methodology and work plan for organizing the review, after due consideration of the available time, resources and data/ information, the structure of the report and some preliminary findings from the desk review as well as some key questions for the field visits.
b. Presentation of findings (verbal presentation will be made to SDC on the approach of the review and its preliminary findings)
c. An interim draft report
d. A final review report will be an independent and comprehensive document with annexes as necessary. However, the main report should not exceed 30 pages. 3 copies of the final, bound report to SDC for distribution shall be submitted and an electronic copy (MS Word) of the report included.

## 5. DOCUMENTATION

The following documents/ material will be made available by SDC-GPCC India to the members of the review team prior to/ during the review.

- Project Document and log frame
- Fact sheets
- Annual Operational and financial reports
- All annual work plans of the project
- Minutes of the Steering Committee meetings
- Minutes of the Advisory Board meetings
- Proceedings of other important meetings/ interactions
- Research publications resulting from the project
- Key knowledge products / documents / reports / briefs coming out of the project

- Any other key documents/ reports related to the project

List of key persons to be interviewed during the review:
- SDC Programme Office
- Project Implementation Team at EPFL and sub-contractors
- Partners from cement companies
- Sector relevant industry associations
- Relevant Government Ministries and agencies

## 6. COMPOSITION AND PROFILE OF THE REVIEW TEAM

The team proposed for the review should not only be able to address the various dimensions of the review but should also be in a position to adequately and efficiently cover the geographical scope of the project. The composition of the review team would include international and national experts, including a representative of SDC. It is envisaged that the review team would combine the necessary expertise on:

- Methodological competence and experience in project evaluation and understanding of best practices in technology transfer.
- Technical and scientific know how about cement and concrete.
- Knowledge of country specific standard setting processes and product commercialisation.
- Understanding of the international development cooperation policies in general and GPCC perspective.

## 7. DURATION OF REVIEW

It is estimated that the review would require 80 person-days (40 days for the team leader, and 40 days for the other experts). This will include preparation, briefings, consultation, travel, field visits, workshops, debriefing, report writing etc.

## 8. TIME PERIOD

The review is proposed to be carried out starting from 1 September 2016 in accordance with the convenience of all concerned. All the steps in the review process should be completed latest by mid November, 2016.

## 9. FUNDING

The cost of the review will be borne by SDC.

## 10. PROGRAMME

To be worked out eventually in consultation with all concerned.

## 11. TIMELINES (as per the period indicated above)

The review is expected to adhere to the following timeline as far as possible:

| S. No. | Review Steps | Proposed Time Line |
|---|---|---|
| 1 | Initial meeting/briefing with SDC (through videoconference) | 1st September 2016 |
| 2 | Desk Review | 2 – 14th September 2016 |
| 3 | Submission of the Inception Report | 15th September 2016 |
| 4 | Meetings with relevant stakeholders in India, Switzerland and Cuba | 16th – 30th September 2016 |
| 5 | Debriefing | 4th October 2016 |
| 6 | Submission of the draft report | 17th October 2016 |
| 7 | Response / feedback on the draft report | 31st October 2016 |
| 8 | Submission of the Final Report | 15th November 2016 |

## 12. SUPPORT AND FACILITATION

SDC will extend logistic support such as air/surface travel, hotel bookings etc. during the field visits. The project team will ensure that all the requisite documentations are made available to the review team. The team will also identify facilitators (from amongst themselves) who will constitute an interface with the team. The project team will organise various interactions with relevant stakeholders and provide support and facilitation, as required.

# ANNEX B – List of documents provided and reviewed

**The following documents were provided by the project (Mr Anand Shukla):**

**01 Project Documents**

| Name | Änderungsdatum | Größe |
|---|---|---|
| LCC review presentation Lausanne 260916.pdf | 12.10.2016 14:14 | 3'650 KB |
| LCC - Phase 1 - ProDoc_final.docx | 18.09.2016 19:09 | 2'361 KB |
| 2015 16 - Second Year Report SDC - draft - 160704.pdf | 18.09.2016 19:06 | 1'183 KB |
| 2014 15 - First Year Report SDC.pdf | 18.09.2016 19:06 | 264 KB |
| 151202 - LCC - Mid Year Report - Summary Introduction - Draft A.pdf | 18.09.2016 19:05 | 229 KB |
| Final ProDoc Phase 1.pdf | 10.09.2016 13:33 | 4'347 KB |

**02 Minutes of Meetings**

- **Advisory Board (2nd Advisory Board Information will be added when feedback from everyone has been received)**

| Name | Änderungsdatum | Größe |
|---|---|---|
| 150626 - Annex A - LC3 Presentation.pdf | 18.09.2016 23:43 | 2'589 KB |
| 150626 - Annex B - LC3 Key Meetings - Year 2.pdf | 18.09.2016 23:44 | 264 KB |
| 150626_MoM_LC3_EPFL_Advisory Board.pdf | 18.09.2016 23:44 | 456 KB |
| 160818 - LCC - Advisory Board Presentation.pdf | 12.10.2016 14:14 | 1'567 KB |
| 160818_MoM_SDC_LC3_EPFL_Advisory Board.pdf | 12.10.2016 14:14 | 155 KB |

- **Steering Committee Meetings**

| Name | Änderungsdatum | Größe |
|---|---|---|
| 150622 - LC3 Steering Committee - Annex A - Agenda Slides.pdf | 18.09.2016 23:46 | 433 KB |
| 150622_MoM_SDC_LC3_EPFL_Steering Committee.pdf | 18.09.2016 23:46 | 492 KB |
| 160114 - LC3 Steering Committee - Annex A - Agenda Slides.pdf | 18.09.2016 23:47 | 318 KB |
| 160114_MoM_SDC_LC3_EPFL_Steering Committee.pdf | 18.09.2016 23:47 | 162 KB |
| 160714_MoM_SDC_LC3_EPFL_Steering Committee.pdf | 18.09.2016 23:48 | 162 KB |
| 160714 - Steering Committee Presentation - V2 (5).pptx | 18.09.2016 23:49 | 837 KB |
| 20140929_MoM_SDC_EPFL_SC_Meeting_FINAL.docx | 18.09.2016 23:50 | 317 KB |
| 20150119_MoM_SDC_EPFL_SC_Meeting_FINAL.docx | 18.09.2016 23:51 | 307 KB |

## 03 Academic and Technical Papers (Includes the lists of papers for each organisation and the current status)

- **EPFL**

| Name | Änderungsdatum | Größe |
|---|---|---|
| Avet - Development of a new Rapid Rele... | 18.09.2016 23:55 | 2'767 KB |
| EPFL Publications.xlsx | 18.09.2016 23:56 | 110 KB |
| Full paper ACCTA - Avet Francois.pdf | 18.09.2016 23:56 | 1'778 KB |
| LC3 Conference - Avet François.pdf | 18.09.2016 23:57 | 2'480 KB |
| SIQ Form François Avet.pdf | 18.09.2016 23:58 | 209 KB |

- **Cuba**

| Name | Änderungsdatum | Größe |
|---|---|---|
| 2 S Sanchez LCA assessment LC3 Cuba.pptx | 18.09.2016 23:53 | 8'714 KB |
| 3 FMartirena Sess 8 Low Clinker Low Carbon Cement Cuba.pptx | 18.09.2016 23:54 | 11'428 KB |
| Cuba Publications.xlsx | 18.09.2016 23:54 | 218 KB |

- **India**

| Name |
|---|
| 10_SBE_Process mapping and preliminary assessment of life cycle impact in Indian cement plants.pdf |
| 11_ICC_Test methods for binary and ternary cements (poster).pdf |
| 12_ICC_Identification of critical parameters for effective substitution using SCMs in low clinker factor cementsSreejith.pdf |
| 13_BMTPC_Application of Limestone Calcined Clay Cement for Production of Building Materials.pdf |
| 14-The importance of blended cements for better sustainability and efficient consumption of natural resources.pdf |
| 15-Characterization of reactivity of Supplementary Cementitious Materials.pdf |
| 16-The technical and commercial feasibility of Limestone Calcined Clay.pdf |
| 17-Utilization of Limestone Calcined Clay Cement and its evaluation in building material.pdf |
| 18-Resource efficiencies of a low carbon cement based building utilizing waste materials.pdf |
| 19-Ternary cements with fly ash – dolomite substitution.pdf |
| 1_Pilot scale manufacture of LCC-Indian Experience.pdf |
| 20-37_1st International Conference of Calcined Clay for Sustainable Conrete-Proceedings.pdf |
| 2_Second pilot production of limestone calcined clay cement in India-the experience.pdf |
| 3_An economic analysis of the production of limestone calcined clay cement in India.pdf |
| 4_NCB_Limestone Calcined Clay Cement-Properties and Prospects.pdf |
| 5_NCB_Feasibility of ternary cements as potential green cements in India.pdf |
| 6_NCB_Phases assemblage in trial blend of limestone and calcined clay cement.pdf |
| 7_SEC_High Level Clinker Replacement in Ternary Limestone -Calcined Clay-Clinker Cement.pdf |
| 8_SCMT_Sustainability assessment of cements and concretes in the Indian context Influence of supplementary cementitious m... |
| 9_UKIERI_A study on low clinker cements using calcined clay limestone substitution.pdf |
| India Publications.xlsx |
| LC3 Technical Report - India.pdf |

**04 Conference Presentations. (Standard presentations that are used at conferences and workshops by the key project researchers. These presentations have evolved during the course of the project.)**

| Name | Änderungsdatum | Größe |
|---|---|---|
| Bishnoi - LC3 - Stakeholder meeting - India update.pdf | 19.09.2016 00:08 | 12'356 KB |
| Gettu - LC3 - LCA presentation - Lausanne - stakeholders meeting.pptx | 19.09.2016 00:09 | 2'138 KB |
| LC3 Conference - Avet François.pdf | 19.09.2016 00:09 | 2'480 KB |
| LC3 Portland Cememt_Ashok Khosla_DA.pdf | 19.09.2016 00:10 | 21'183 KB |
| LC3 Technical Report - India.pdf | 19.09.2016 00:11 | 9'361 KB |
| Maity - LC3 - Project_Resource Mapping_EPFL Lausanne.pptx | 19.09.2016 00:12 | 9'017 KB |
| Martirena - LC3 - Stakeholder meeting - Cuba update.pptx | 19.09.2016 00:12 | 8'781 KB |
| Scrivener - LC3 - Introduction and basic science.pptx | 19.09.2016 00:14 | 25'756 KB |

**05 Brochures and posters (Sample of publicity material)**

| Name | Änderungsdatum | Größe |
|---|---|---|
| LC3 Brochure-July 2016 compressed.pdf | 10.09.2016 13:33 | 4'744 KB |
| LC3 Brochure-Final File.pdf | 19.09.2016 00:15 | 15'919 KB |
| LC3 Poster for Tech4Dev.pdf | 19.09.2016 00:15 | 4'293 KB |

# ANNEX C – Overview of the Cement Sector in Cuba and India

## C1: Overview of the cement sector in Cuba

### 1. Background

Cuban cement production output in 2015 was around 1.8 Mio tonnes of which a significant portion was exported (around 30%[11]). The domestic demand has a large accumulated backlog in demand due to some structural and case-specific reasons. The cement group's forecast shows a demand increase of 10-18% per year, reaching 3.5 Mio tonnes in the year 2019 and 5.5 Mio tonnes in 2031. This forecast scenario is based on the demand for housing programs, improvement of local infrastructure and the expanding tourism industry.

Prices for cement are fixed by the government and the cement companies are serving designated provinces. There is no free market or competition between the cement manufacturers.

### 2. Types of cement manufactured in Cuba

In terms of composition, ordinary Portland Cement (OPC) predominates with a 63% market share and Pozzolanic Portland Cement (PPC) with zeolite addition makes up the remaining 37%. In terms of clinker technology, 62% of the total clinker production is done with a dry process in two major cement plants (Cienfuegos and Mariel/Curazao). The remaining 38% of clinker is produced with wet processes in the plants of Siguaney, Artemisa, Nuevitas and Santiago (Figure 1).

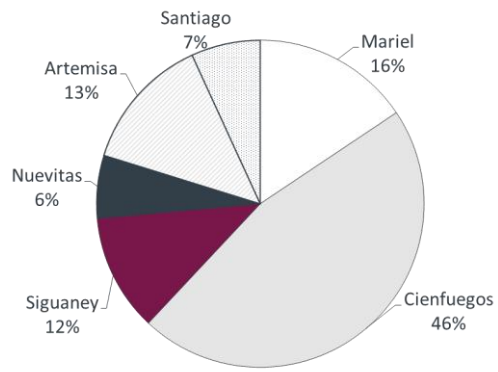


Figure 1: Cuban cement production. Sofía Sanchez et al, Calcined Clays for Sustainable Concrete, Springer 2015

In order to increase production capacity to meet the present and future growing demand with a cement at an affordable price, clinker substitution by using Supplementary Cementitious Materials (SCM) is presently discussed. Main sources of SCM considered are natural pozzolans and limestone. In addition to this, LC3 is becoming more prominent and seen as the most favourable option by the cement industry and the standardization bodies.

[11] Foresight Cuba 2016

## 3. Cement plants in operation

The Cuban cement industry counts six plants which all began operation in the 1980's. Their current nominal cement production capacity of 4.4 mio tons per annum is lower than before, as the economic crisis during the 90's affected the cement sector considerably as all capital investments were stopped and productive capacities decreased over the past 20 years. Out of the only 64% was used in 2015. This is in part due to outdated technology in the 4 smaller plants that makes necessary several annual periods of maintenance and repair of equipment and facilities.

The four smaller plants are 100% state-run enterprises, while Cienfuegos is a 50% joint venture with LafargeHolcim and the Mariel/Curazao plant a 50% joint venture with CEMEX. The ongoing market liberalisation process and economic reforms in Cuba could possibly foster new joint ventures. To meet the predicted increasing demand the cement industry in Cuba needs to be modernized. Different scenarios are under discussion but it is difficult to predict which of them will be selected by the Government of Cuba.

## 4. Availability of resources

The Cuban energy supply is highly dependent on imports and thus vulnerable to disruptions in trade relations. Venezuela decreased oil exports to Cuba by 40% in the first half of 2016[12]. The cement industry relies on 100% fossil fuels, typically crude oil. However, since the share of Venezuelan oil is important in the Cuban energy mix (40% of primary energy in 2003 and supplied at a preferential price[13]) the decreased supply is likely to lead to energy shortages and/or higher energy prices. Older data[14] indicate a consumption of one barrel (150 kg) of oil per tonne of cement resulting in a process in which oil consumption accounted for 60 percent of the cost of production. The specific energy consumption has stayed fairly constant since then (0.19 t oil/ t cement in 2001[15]), which is e.g. 40% above Canadian standards[16]. Thus specific energy consumption is high and energy cost continues to be a major share of cement production costs, higher than in many other countries.

The Cuban cement industry benefits from domestic abundance of all the minerals used in the current cement types: limestone, clays, gypsum and silicates[17].

## 5. Challenges faced by the cement industry in Cuba

The future development of the Cuban cement industry and of the Cuban society as a whole will depend on the development of the political situation and the trade relations with the United States, other neighbouring countries and the rest of the world.

- Energy cost and consumption are certainly a main cost factor in Cuban cement production and energy prices will thus influence production cost.

12 Reuters, July 2016

13 IAEA, 2008, Cuba : a country profile on sustainable energy development

14 Teo A. Babún, Jr., CUBA'S CEMENT INDUSTRY

15 IAEA, 2008, Cuba : a country profile on sustainable energy development

16 Energy Innovators Initiative in Canada, Natural Resources Canada, 2001, Energy Consumption Benchmark Guide: Cement Clinker Production. Canadian standards for 60% dry/ 40% wet process is 5 GJ/t. Cuban consumption of 0.19 t of crude oil /t is about 7.3 GJ/t. Thus Cuban specific energy consumption per ton of cement is about 40% above Canadian standards.

17 Teo A. Babún, Jr., CUBA'S CEMENT INDUSTRY

- To cover the projected increase in demand of 10-18% per year, the export can be decreased. However, present export is linked to existing joint ventures which choose to export clinker to produce cement outside the country. Another option is to increase production capacity but this will require considerable investment capital which is not easily available. The production cost of the new production capacity will depend on whether the investment can financed without incurring massive cost from private investment capital.

The substitution of clinker as investigated in the LC3 project can contribute to facing these two challenges. On the one hand, the specific energy demand can be lowered, thus decreasing supply vulnerability and also indirectly lowering cost. On the other hand the clinker fraction can be lowered and the cement production capacity increased as a consequence.

## C2: Overview of the cement sector in India

### 1. Background

Since the deregulation of the cement industry in 1991, India's cement industry has grown faster than the overall economy, making India the second largest producer of cement in the world. The current installed capacity for cement production in India is more than 380 million tons per annum (MTPA) while the current cement production about 272 MTPA, which is about 71.5 percent of the total installed capacity.

Per capita consumption of cement in India – at 185 kg per person per year – is amongst the lowest in the emerging world[18]. India's low consumption levels are due to three key reasons –

a). Low infrastructure intensity, as India is largely a services-oriented economy,

b). High level of housing deficit; and

c). Low pace of urbanization as compared to other countries.

Per capita consumption is however expected to rise due to rising consumption from urban areas, rising nuclear family households, and upgrades from non-pucca to more permanent pucca houses. Many studies have projected that India's cement demand would reach 550-600 MTPA by 2025, on account of growth in the sectors like housing, infrastructure, commercial and industrial construction sectors, which are the biggest demand drivers of cement [19].

### 2. Types of cement manufactured in India

There are various varieties (more than 20) of cement manufactured and sold in India. The basic difference lies in the percentage of clinker used. Here are the most common types –

- **Ordinary Portland Cement (OPC)**: This is commonly known as "grey" cement, and is used in ordinary concrete construction. It has 95% clinker and 5% gypsum and other materials and is manufactured in three grades: OPC Grade 33, OPC Grade 43 (most popular with almost 80% of the OPC marked share) and OPC Grade 53.

OPC which accounted for around 70% of total cement consumption in India in 1995, now accounts for less than 30% of the total market share. But the share of OPC could increase in future on account of it being a preferred option of the large institutional buyers and convertors which at present account for up to 32% and 8% of cement purchase in India (unlike developed countries where this number is more than 70%).

- **Portland Pozzolona Cement (PPC)**: PPC has 70% -80% clinker, 15-25% Pozzolona, and 5% gypsum. This cement accounts for 65% of the total cement consumption in India

18 Indonesia and Brazil, for instance, have per capita consumption of 225 kg and 345 kg respectively (Source: CII, 2012, Cement Vision 2025 – Scaling New Heights, Confederation of Indian Industries).

19 While the housing sector accounts for about 67 per cent of the total cement consumption in India. The other major consumers of cement include infrastructure at 13 per cent, commercial construction at 11 per cent and industrial construction at nine per cent (Source: CII, 2012, Cement Vision 2025 – Scaling New Heights, Confederation of Indian Industries).

today.[20] The cement industry also invested in improving the quality and performance levels of the cement. As it prevents cracks, it is useful in the casting work of huge volumes of concrete. It can be availed at low cost in comparison to OPC.

- **Portland Blast Furnace Slag Cement (PBFSC)**: This consists of 45% clinker, 50% blast furnace slag, and 5% gypsum. PBFSC accounts for around 7% - 8% of the total cement consumed in India. It is generally used in construction of dams and similar massive constructions.
- **White Cement:** It is a kind of OPC. The ingredients of this cement are inclusive of clinker, fuel oil and iron oxide. The content of iron oxide is maintained below 0.4% to secure whiteness. White cement is largely used to increase the aesthetic value of a construction. It is preferred for tiles and flooring works. This cement costs more than grey cement.

Earlier this year Kiran Global Chems Ltd, a leading manufacturer of a key ingredient for a number of industries, has introduced its indigenously-developed Geocement, which, the company claims, will be stronger than normal Portland cement and not require water for mixing or curing[21]. Geocement, which is made out of industrial wastes, comes in two-part packing - 35 kg Geocement powder and 15 kg Geobinder liquid. Geopowder is a mineral compound – blended with bye-product materials like fly ash, rice husk ash, slag, activated clay, alumina in the geopolymer formation. Geobinder is a specially formulated alkaline activator that acts as binder to the powder. Both can be mixed at construction sites like normal cement with aggregates like sand. It doesn't require water. Price of Geocement will be slightly higher than normal cement, but it promises lower finished building cost and less construction time and labor.

## 3. India’s leading cement companies

Over the years, the cement industry in India has become more organized and with technological upgrading evolved to become one of the most effective industries in the world in terms of process efficiencies. Currently almost 93% of the total production capacity is based entirely on the modern dry process.

The average size of industry players has increased to 1.2 MTPA.

Large producers contribute about 97% to the installed capacity while mini plants account for the rest. India’s top six cement companies control almost 50% of the domestic capacity, production, and market. Ultratech Cement, the country’s largest firm in terms of cement capacity (55+ MTPA capacity in 2014), holds over 18% of the domestic market, with ACC (50%-owned by Holcim) and Ambuja (50%-owned by Holcim) having 10% and 9% shares respectively (as per FY13 capacity numbers). The other top players are India Cements, Shree Cements,

20 One of the reasons for this change has been wide spread availability of fly ash and the Government promoting blending of fly ash through exemptions on excise duty as well as compulsory use of fly ash based construction material by public and private sector agencies in a radius of 100 kms. of a coal or lignite thermal power plant. (Ministry of Environment and Forests, MoEF Gazette Notification on Flyash Utilisation , 1999, amended on 27 August 2003). Source: http://ospcboard.org/ckeditor/CKFiles/02-Jan-2015Utilisation%20of%20flyash%20from%20coal%20or%20lignite%20Based%20Thermal%20Power%20Plant.pdf

21 Prof. J. Davidovits, invented this technology in which Silicon (Si) and aluminum (Al)ions in the by-product materials is made to react and the chemical reaction that takes place in this case is a polymerization process and hence product is called Geocement. Kiran Global has entered into an exclusive agreement with Geopolymer institute, France for developing a range of new-age Geocement for advance applications.

Ramco Cements, Lafarge, Birla Cement and Binani Cement. Around 100 other smaller companies produce and grind cement on a wide range of scales but are often confined to small areas.

There is a growing interest among Indian and foreign cement majors in acquiring cement capacities in India because of a). Excess capacity of the existing players which can be used to fulfil the global demand at lower cost of production; b) Rising cost of greenfield/new projects which also tend to have longer gestation period.

Growing scale, coupled with improvement in manufacturing technology, has led to significant cost efficiencies as well. Energy use per kg of clinker production has dropped from 880 kcal per kg in 1991 to 690 kcal per kg now. Apart from this, power consumption has declined from 120 units per tonne to 65 units during the same period.

## 4. Challenges faced by the cement industry in India

- **Supply side bottlenecks have intensified.** For instance, the share of coal linkage in the overall energy mix of the industry has declined from 65% in FY06 to around 35% now. Companies are thus more dependent on alternative sources.
- **Setting up additional capacity has also gotten difficult** due to declining levels of linkage coal, inadequate logistics infrastructure (railways), shortage of skilled labour, and delays in getting land and environmental approvals.
- **Linkages of raw materials like limestone also serve as an entry barrier**. Most cement companies have backward integration to limestone by way of owning captive mines. Most limestone deposits in India are located in Madhya Pradesh, Rajasthan, Andhra Pradesh, Maharashtra, and Gujarat, thus leading to concentration of cement units in these states. As far as gypsum is concerned, its domestic reserves are limited, which has led some cement companies to explore the option of acquiring overseas gypsum mines. In addition to gypsum, the domestic coal supply has also become a major bottleneck (around 160 kg of coal is consumed per tonne of cement production). As a result, cement companies are looking to secure access to coal, either through joint ventures with overseas players or through the acquisition of overseas coal mines.
- **Cost of manufacturing cement has risen over the years**, because of higher costs of fuel and financing, and high taxes. While the companies have been able to pass on a part of cost hike to consumers, costs are still rising faster than cement prices.
- **Fixed costs in the cement industry are particularly high and significant relative to variable costs.** Fixed costs generally account for more than 50% of the overall production costs. The fixed costs are usually sunk costs. Once built, a cement plant can serve no other purpose. As fixed costs are high with respect to the variable costs, the break-even point is high. With automation, labor costs have decreased, but energy consumption is a more significant variable cost. Thus, profits in the industry are sensitive to the level of utilization of the production capacity. Significant cash flows are generated only when product increases beyond the break-even point, which depends on the efficiency of the plant.
- Cement is largely a regional product – manufactured and sold in a region – as transporting it over long distances is not possible (due to the nature of the product). **Transportation is a major cost element for cement companies (around 20-25% of sales), often a bigger line item than net profits.**
- While the widening gaps in operating costs and sales realization have been reducing the average operating profit per tonne for the industry, **capital costs have been steadily rising (from an average of Rs 4,200 per tonne in 2009 to Rs 7,200 per tonne in**

**2013).** As a result, the internal rate of return or IRR on a new green-field cement plant in India has seen a steady decline from 17% in 2008 to 9% in 2013.

- Cement prices have not increased as much as production and capital costs in the past four to five years,[22] which has taken a toll on industry profitability. Cement capacity in India has kept ahead of demand which, during times of slowdown, really hurts companies in the form of lower capacity utilization and declining margins (as fixed costs remain high). As a result, the rate of technological improvements in the industry has been slowing down, with a large share of the industry already employing the best available technology in terms of material and energy efficiency.

## 5. Government of India policies affecting cement sector

Since the deregulation of the cement industry in 1982 (partial decontrol) and 1991, India's cement industry has grown faster than the overall economy, making India the second largest producer of cement in the world. The current installed capacity for cement production in India is more than 380 MTPA while the current cement production is about 272 MTPA, which is about 71.5 percent of the total installed capacity.

## 6. Growth in cement consumption

The Government in the XII five year Plan has listed the following schemes that could affect cement utilization:

- 100 per cent deduction for profits to an undertaking in housing project for flats up to 30 square meters in four metro cities and 60 square meters in other cities approved during June 2016 to March 2019;
- Incremental spend on smart city development, the government has allocated Rs 7,296 crore (US$ 1.09 billion) towards Urban Rejuvenation Mission (AMRUT) and Mission for Development of 100 Smart Cities; and
- The Government of India has decided to adopt cement instead of bitumen for the construction of all new road projects on the grounds that cement is more durable and cheaper to maintain than bitumen in the long run.

As per Government of India assessment, if this infrastructure demand comes in, the cement production capacity utilization level rise could rise to about 80% (up from the present 71%).

## 7. Growth in production capacity

Although there have been many studies predicting a rapid growth in the cement consumption in India[23], there is still unutilized manufacturing capacity (about 30%) in the existing cement plants in India. Also, given the rising cost of land and its unavailability, rising costs of equipment

22 As per data published by the Economic Advisor of India, all India cement production grew 10.8 per cent YoY at 51.4 million for the January-February, 2016, while prices fell by 4.8 per cent QoQ (down 7.2% YoY) on weakness in prices across regions. Source: ECONOMICTIMES.COM | Apr 25, 2016, 10.45 AM IST.

23 GoI (2012) Report of the Working Group on Cement Industry for the XII Five Year Plan (2012 -2017), Planning Commission

and engineering services, the capital cost to set up cement capacity in India is expected to rise[24], making it unattractive for the industry to install new capacity.

## 8. Resource linkages

Most cement companies have backward integration to limestone by way of owning captive mines. Most limestone deposits in India are located in Madhya Pradesh, Rajasthan, Andhra Pradesh, Maharashtra, and Gujarat, thus leading to concentration of cement units in these states. The Parliament of India has cleared amendments to the Mines and Minerals Development and Regulation (MMDR) Act, which will enable companies to transfer captive mines leases similar to mines won through an auction, and which is expected to lead to increased Mergers and Acquisitions (M&A) of steel and cement companies.

As far as gypsum is concerned, its domestic reserves are limited, which has led some cement companies to explore the option of acquiring overseas gypsum mines.

The domestic coal supply has also become a major bottleneck (around 160 kg of coal is consumed per ton of cement production). The share of coal linkage in the overall energy mix of the industry has declined from 65% in 2006 to around 35% in 2016. Companies are thus more dependent on alternative sources, including securing access to coal, either through joint ventures with overseas players or through the acquisition of overseas mines.

## 9. Energy efficiency measures

Although the cement industry contributed to around 7% of India's total energy and process CO2 Emissions in 2010, it has evolved to become one of the most energy efficient globally with its specific carbon emissions amongst the lowest (second only to Japan)[25]. The average gross CO2 emissions from production of cement have declined from approximately 800 kg per ton in 1990 to around 600 kg per ton in 2011.[26]

The Indian cement industry has emerged as a frontrunner in terms of implementing low carbon measures. It has voluntarily agreed for energy saving targets of 0.815 million ton of oil equivalent energy under the first cycle (2012 – 2015) of the Perform and Trade (PAT)[27] scheme of the Bureau of Energy Efficiency, Ministry of Power as a sector's contribution to the Government's National Mission for Enhanced Energy Efficiency (NMEEE)[28].

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24 It takes around US$ 120-140 per tonne to set up a cement plant in India. This has risen from around US$ 100 per tonne 3-4 years back. Break-even EBIDTA (earnings before interest, tax, depreciation and amortization), for instance, for a 1 MTPA (million tonne per annum) capacity, operating at 80% utilization (assuming a 70:30 debt to equity ratio) works out to around US$ 21 per tonne. In other words, this is the minimum a new cement capacity must earn in order to provide for depreciation and interest costs.

25 The best thermal and electrical energy consumption presently achieved in India is 663 kcal/kg clinker and 59 kWh/t cement which are comparable to the best figures of 650 kcal/kg clinker and 65kWh/t cement in a developed country like Japan.

26 CII, 2012, Cement Vision 2025 – Scaling New Heights, Confederation of Indian Industries.

27 Perform Achieve and Trade (PAT): A regulatory instrument to reduce specific energy consumption in energy intensive industries, with an associated market based mechanism to enhance the cost effectiveness through certification of excess energy saving which can be traded. The scheme has remained largely voluntary and has been marred by incomplete substantiation of energy savings reported.

28 The basic objective of the NMEEE mission is to ensure a sustainable growth by an approximate mix of 4 E's, namely-Energy, Efficiency, Equity and Environment

## 10. Use of fly ash

The PPC cement accounts for 65% of the total cement consumption in India today. One of the reasons for this change has been wide spread availability of fly ash and the Government promoting blending of fly ash through exemptions on excise duty as well as compulsory use of fly ash based construction material by public and private sector agencies in a radius of 100 kms of a coal or lignite thermal power plant. 29

According to the Ministry of Environment Forests and Climate Change, utilization of fly-ash and blast furnace slag reduces dust emission by 9800 tonnes per annum and CO2 emission by 33.6 MTPA. It also contributes to conservation of limestone by 67 MTPA.

However, power plants which had been earlier supplying fly ash to the cement industry free of cost have started charging for fly ash from November 2009. The MOEF order of 2009 has also made it mandatory for the cement plants having captive power plants to supply 20 per cent of the fly ash generated as free of cost to the small scale brick manufacturers, etc. within the vicinity of 100 kms. of their plants. Both these factors have severely impacted the production cost of cement and also affected the fly ash recycling potential in the country.

## 11. Alternate resources

There has been a growing emphasis on research in multi-blend/ composite cements. The Government of India Working Group on Cement for XII Five Year Plan (2012 -17) also proposed to look at the alternative of Portland Limestone Cement (PLC) and multi-component blends that are being produced at various plants across the American and European Countries. PLC's have strong positive environmental credentials. Up to 35% limestone addition (including low quality limestone) is allowed in PLC's in Europe. This cement type accounted for more than 40% of the European cement market. These cements have not been produced in Indian cement industries because there is no standard specification for Portland limestone cement in India as yet.

29 Ministry of Environment and Forests, MoEF Gazette Notification on Flyash Utilisation , 1999, amended on 27 August 2003).

# ANNEX D – Schedule of Missions to Cuba and India

## D1: Schedule Cuba:

| Date | Activity | Responsible | Comments |
|---|---|---|---|
| 02.10.2016<br>Sunday | Landing in Habana<br>Pm: Pick up Habana | F. Martirena | proceed straight to Santa Clara |
| 03.10.2016<br>Monday | 9:00: Meeting at International Affairs Office UCLV<br>10:00-12:00: Work at CIDEM (visit labs, general presentation, interviews with key players, etc.) | F. Martirena | |
| 04.10.2016<br>Tuesday | 8:00: depart to Siguaney (120 km)<br>10:00: meeting at Siguaney (visit facilities, interviews with key players, etc.)<br>4:00 pm: Meeting with Dr. André Castro, Rector de la UCLV | F. Martirena | |
| 05.10.2016<br>Wednesday | 8:00: depart to Cayo Santa María<br>10:30: visit to exposure site and lab ECOT (interview with key players)<br>Afternoon: depart to Habana | F. Martirena | This visit had to be cancelled due to the Hurricane Matthew. |
| 6.10.2016<br>Thursday | 10:00: meeting with the cement industry Habana<br>12:00: meeting with officials of the Ministry of Higher Education at Habana<br>14:00 meeting with officials of the Institute of Construction | F. Martirena | |
| 7.10.2016<br>Friday | 10:00 meeting with Peter Sulzer, Director SDC | F. Martirena | |
| 9.10.2016<br>Sunday | Departure | | |

## D2: Schedule India:

| Date | Time | Person name and/or Activity | Venue | Purpose of Meeting |
|---|---|---|---|---|
| 28.11.2016 | 9.00 am - 9.45 am | Meeting with Daniel, Anand and Divya at SDC | SDC, Chanakyapuri | |
| | 10.30 am - 1.00 pm | Meeting with Dr Shashank Bishnoi - LCC Project - IITD India team | IIT Delhi | Briefing on LC3 India research activities and results achieved |

| Date | Time | Person name and/or Activity | Venue | Purpose of Meeting |
|---|---|---|---|---|
| | 1.00 pm - 2.00 pm | Lunch | IIT Delhi | |
| | 3.30 pm - 5.00 pm | National Council for Cement and Building Materials, S.K. Chaturvedi | Ballabhgarh, Haryana | Research and scientific work connected with cement and building materials |
| 29.11.2016 | 07.00 am - 2.00 pm | Travel to JK Lakshmi Cements, Jhajjar. Meeting with Mr S.K Saxena, Plant Head and Dr. Mukesh, R&D Head at Jhajjar plant | Jhajjar, Haryana | Practical application of grinding and production of cement |
| | 2.00 - 2.30 pm | Lunch | J K Lakshmi Cement Ltd. Jhajjar | |
| | 7.30 pm - 9.00 pm | Dinner with TARA and JK Lakshmi | India International Centre, Lodhi Road | Sustainability and Resource Efficiency perspective |
| | 12002 Bhopal Shatabdi Dep. New Delhi at 6.00 am | Visit to Jhansi - LC2/LC3 pilot production facilities, production of building materials and application in House | Jhansi | Applied research, small scale production and practical application of LC3/LC2 |
| 30.11.2016 | 10.00 am - 1.00 pm | Meeting with Daniel, Anand and Divya at SDC | | |
| 01.12.2016 | 1.00 pm - 3.00 pm | Lunch Meeting | Development Alternatives | Sustainability and Resource Efficiency perspective |
| | 3.00 pm - 4.30 pm | Meeting with Daniel, Anand and Divya at SDC | | |
| | 9W 334 (Jet Airways) (Dep. 18.15 - Arr. 20.20) | Travel to Mumbai | Hotel in Mumbai | |
| 02.12.2016 | 9.30- 11.00 am | Ambuja Cement Ltd. Dr. B.N: Mohapatra, Er. S.T. Varpe, S.K. Gupta | Ambuja Cements, Mumbai | Research of LC3 and Industry view |
| 02.12.2016 | 11.30am – 13.30pm | Dr. A.K. Chatterjee | | Industrial perspective on LC3 initiative and project development |
| | | Lunch | | |

| Date | Time | Person name and/or Activity | Venue | Purpose of Meeting |
|---|---|---|---|---|
| | 4.30 pm - 6.00 pm | Dr. Prakash Nanthagopalan | IIT Mumbai | Scientific studies by project partner |
| | | Stay at Mumbai (Dr Mutz and Divya). | Mumbai | |
| | 9W 2535 Jet Airways (Dep. 6.10 - Arr. 7.25) | Visit to a calcination unit & Clay Mines | Bhuj | China clay perspective with respect to waste utilization |
| 03.12.2016 | 8.00 - 10.00 am | Check-in at Hotel Prince Residency<br>Station Road, College Road Mirzapar Highway, Bhuj, Kutch, Gujarat 370001<br>Phone: 02832 220 370 | | |
| | 10.00 am - 2.00 pm | Visit to China clay mines and large scale calcination unit | Madhapar, Bhuj | China clay mines, various types of china clay waste and large scale calcination |
| | 2.00 pm - 3.00 pm | Lunch | Shreeram Minerals | |
| | 3.00 - 3.30 pm | Shreeram Minerals | Bhuj | Different types of clays and china clay calcination perspectives |
| | 9W 309 (Dep. 17.20 - Arr. 21.30) | Return to Delhi | | |
| | | Preparation or for any specific meeting | From Hotel | |
| 04.12.2016 | 3.00 pm - 5.00 pm | De-briefing at SDC | SDC office | De-briefing |
| 05.15.2016 | | | | |

# ANNEX E – People met in Cuba and India

## E1: Persons met in Cuba

| Name | Institution | Position |
|---|---|---|
| Universidad Central de las Villas (UCLV) | | |
| Prof. Dr. Fernando Martirena | CIDEM | Director |
| Adrián Alujas Díaz | Faculty of Chemistry | Senior scientist |
| Sofia Sánchez | Faculty of Economics | PhD student |
| Grisel Barrios | Faculty of Economics | Professor |
| Yudiesky Cancio | Faculty of Economics | PhD student |
| Raul Gonzalez | Faculty of Constructions | Professor |
| Dayran Rocha | CIDEM | PhD student |
| Sergio Betancourt | Faculty of Constructions | Professor |
| Eilys Valdes | Faculty of Constructions | PhD candidate |
| Elisabeth Cabrera | Faculty of Chemistry | PhD candidate |
| Dr. Andrés Castro | UCLV | Rector |
| | | |
| Cement plant Siguaney | | |
| Florencio Arcial | Geominera | Senior Geologist |
| Adrian Alujas | Faculty of Chemistry | Senior scientist |
| Gonzalo Reina | Siguaney | Director |
| Salvador Damas | Siguaney | Technical advisor |
| Belkis Delgado | Siguaney | Technical chief |
| Roberto Hernandez | Siguaney | Technical advisor |
| Carlos Rodriguez | Siguaney | Member Board |
| | | |
| Cement Industry (GECEM), Havana | | |
| Néstor Ramos Ledesma | Grupo Empresarial del Cemento | Director Técnico y Mantenimiento |
| | | |
| Ministry of Higher Education, Habana | | |

| Name | Institution | Position |
|---|---|---|
| Dr. José Luis Garcia | Ministerio de Educación Superior | Asesor del Ministro |
| | | |
| Institute of Construction (CIDC), Habana | | |
| Dr. Miguel Angel Otero | Pilar Cientifico, Technológico y de Innovación de las Construcccio-nes in Cuba | Director General |
| José M. López Santana | CIDC | Grupo Consultores |
| Juan M. Lavennia | CIDC | Investigador |
| Elena Téllez Girón | CIDC | Investigador Titular |
| | | |
| DEZA, Habana | | |
| Peter Sulzer | DEZA | Director Residente |

## E2: Persons met in India

| Date, Location | Name | Institution | Position |
|---|---|---|---|
| 28 Nov 2016, New Delhi | Mr. Daniel Ziegerer | Swiss Agency for Development and Cooperation | Director of Cooperation |
| | Dr. Anand Shukla | Swiss Agency for Development and Cooperation | Senior Thematic Advisor |
| | Dr. Shashank Bishnoi | Indian Institute of Technology, Delhi | Associate Professor |
| Ballabhgarh, Haryana | Dr. S. K. Chaturvedi | National Council for Cement and Building Materials, Ballabhgarh, Haryana | Joint Director and Head, Centre for Cement Research and Independent Testing |
| | Dr. Ashwani Pahuja | National Council for Cement and Building Materials, Ballabhgarh, Harayana | Director General |
| 29 Nov 2016, Jhajjar Haryana | Mr. S. K. Saxena | J K Lakshmi Cement Ltd. | Vice President Jhajjar Unit and Quality Assurance, |
| | Dr. Mukesh Kumar | J K Lakshmi Cement Ltd. | Deputy General Manager (R&D), |
| | Mr. Bhaskar Dutta | TARA | Specialist Energy, TARA |
| | Dr. Arun Kumar | TARA | President |
| 30 Nov 2016, Jhansi, Uttar Pradesh | Dr. Soumen Maity | TARA, Jhansi | Chief General Manager |
| | Dr. Palas Kumar Haldar | TARA, Jhansi | Project Manager |
| 1 Dec 2016, New Delhi | Dr. Ashok Khosla | Development Alternatives, New Delhi | Chairman |
| | Dr. K. Vijaylakshmi | Development Alternatives, New Delhi | Vice President |
| 2 Dec 2016, Mumbai | Dr. B.N. Mohapatra | Ambuja Cements Limited | Vice President, New Product Development and Product Quality Management |
| | Mr. Shrikant Tukaram Varpe | Ambuja Cements Limited | Deputy Manager, Corporate Product Quality |

| Date, Location | Name | Institution | Position |
|---|---|---|---|
| | | | Management and New Product Development |
| | Mr. Sanjay Kumar Gupta | Ambuja Cements Limited | Chief Marketing Officer |
| | Dr. Anjan K Chatterjee | Dr. Fixit Institute of Structural Protection and Rehabilitation, Mumbai | Material and Process Consultant, Cement and Concrete Industry, Director, Dr. Fixit Institute of Structural Protection and Rehabilitation |
| | Dr. Prakash Nanthagopalan | Indian Institute of Technology, Bombay | Assistant Professor |
| 3 Dec 2016, Bhuj | Mr. Jaydeep M. Solanki | Shree Ram Minerals, Bhuj, Kutch. | |

## ANNEX F – Results of SWOT Analyses

SWOT Analysis CIDEM, Cuba 03.10.2016 Participants: Academic staff of the Universidad Central de las Villas

| STRENGTHS | | WEAKNESS |
|---|---|---|
| • Interdisciplinary approach<br>• Applied sciences, not only academic and lab approach<br>• Strong link to the cement industry<br>• Standard for LC3 already approved<br>• Favourable conditions: $CO_2$ reduction, reduced costs, availability of all raw materials in good quality<br>• Fundamental mechanisms of hydration are understood<br>• CIDEM is a recognized member in an international network promoting LCC | | • Many scientific papers have already been published but wider communication is still behind requirements<br>• Standardization well advanced but restricted to Cuba and USA<br>• Limited human resources to cope with the existing and increasing workload. Limited number of professionals with leadership capacity available<br>• Limited equipment to carry out lab tests (dependency on EPFL which is time consuming) and for industrial trials (dependency on CIDC in Havana)<br>• Cement industry not yet fully aware about potential of LC3 to reduce $CO_2$ emission |
| | | |
| OPPORTUNITIES | | THREATS |
| • Change/transition in Cuba with high investment in construction<br>• Transfer and dissemination of knowhow and experiences to other countries in the region<br>• Possibility to expand rapidly as most of the characterization tools are available and procedures are well known<br>• Increase of recognition and reputation of Cuba as pioneer in the cement and building sector in the region and beyond<br>• Further development of mineral admixture against corrosion (from LC3 to LC2) | | • Red colour of the cement/concrete<br>• Increase of water demand which might hamper the acceptance of LC3 by the construction companies<br>• Higher degree of carbonation<br>• Not enough scientific staff in the future to respond to expectations<br>• Industry and decision makers do not yet have sufficient awareness of the huge impact and potential in $CO_2$ mitigation of LC3 |

| STRENGTHS | | WEAKNESS |
|---|---|---|
| • Economic development is given priority in Cuba which has positive impact on the building sector<br>• Trustful cooperation between CIDEM and Siguaney promotes innovation<br>• Young professionals at Siguaney very much motivated towards innovation and sensitive for environment and climate issues<br>• Application of LC3 concept at bigger scale possible within a short period of time | | • Laboratory not yet sufficiently equipped to respond to the requirements<br>• Special requirements for raw material (kaolinite clay) |
| | | |
| OPPORTUNITIES | | THREATS |
| • Access to raw material<br>• Positioning of Siguaney in an international network and thus access to international knowledge exchange<br>• Cement industries becomes more attractive for young professionals due to its innovative approach and attention to climate change<br>• Easier and faster access to financial resources due to the innovative character of the project<br>• Government of Cuba has access to international credits<br>• Demand of a new cementitious product in the market to combat or reduce corrosion | | • Characterization of the minerals<br>• No sufficient capacity building of staff<br>• Limited experiences with the production of LC3 cement might result in reduced cement output |

SWOT Analysis at Cement plant Siguaney, Cuba 04.10.2016 Participants: Director, advisor and senior staff of the cement plant

SWOT Analysis TARA in Jhansi, India 30.11.2016 Participants: Staff member of TARA

| STRENGTHS | WEAKNESS |
|---|---|
| • Strong support by NCB and IITs<br>• Lab tests confirm that LC3 is a robust and financially suitable product<br>• Strong interest by the cement industry. Aware about resource scarcity<br>• LC3 is a further option and not a competition to fly ash and slag<br>• With JK Lakshmi there is already a cement company on board | • Not all experiences and research results by the cement industry are made available<br>• Delay of standardization process<br>• No uniform colour of calcined clay<br>• Carbonization resistance<br>• Higher water demand<br>• Cement industry to be considered as conservative (fly ash application took 20 years)<br>• Lack of information on mortar quality<br>• Lack of long term experiences and standardized monitoring |
| | |
| **OPPORTUNITIES** | **THREATS** |
| • Extension of limestone quarries; better use of limited limestone deposits<br>• Government promotes renewable energy which will limit the available quantity of fly ash in the future<br>• From LC3 to LC2<br>• Big market for blocks, tiles and mortar which is not yet fully explored for the application of LC3. Faster standardization expected | • Lack of commercial interest by some cement companies<br>• Acceptance by the user (e.g. builders)<br>• Increase of clay price<br>• Possible bad practice will have negative impact on reputation of LC3 |