Zurich, June 15-17 2016
Sustainable Built Environment (SBE) Regional Conference

Expanding Boundaries:
Systems Thinking for the Built Environment

ECONOMIC AND ECOLOGICAL ASSESSMENT OF CUBAN HOUSING SOLUTIONS USING ALTERNATIVE CEMENT

Y. Cancio[1]*, S. Sanchez[1], F. Martirena[1], I.R. Sanchez[1], K. Scrivener[2], G. Habert[3]

Universidad Central de Las Villas, Carretera a Camajuani Km. 5 ½, Santa Clara, Villa Clara, Cuba

[2] Laboratory of Construction Materials, Swiss Federal Institute of Technology Lausanne, EPFL, STI-IMX-LMC MXG 211 (Bâtiment MXG) Station 12 CH-1015 Lausanne, Switzerland

[3] Chair of Sustainable Construction, Swiss Federal Institute of Technology ETH Zürich, IBI, HIL F 27.3, Stefano-Franscini Platz 5, 8093, Switzerland

*Corresponding author; e-mail: yudieskycd@uclv.edu.cu

Abstract

Concrete is the most manmade material solution produced and used worldwide. Its cornerstone is the cement composite due to the high emissions level and resources consumption volume. Roughly 5-7% of global carbon dioxide emissions come from cement manufacture process. The far-reaching alternative of replacing a clinker portion in the cement material composition has gained consensus. It becomes relevant in emerging economies since in the short term there are no widely available ways for increasing the production capacity while diminish the environmental impact with no additional investment cost. Low carbon cement (LC^3) is leading the contemporary path towards facing environmental challenges and resource scarcity. This article aims to assess the theoretical consideration of replacing the Cuban traditional cements with LC^3 according to housing case studies in Villa Clara province. On the basis of LCA background and the supply chain rationale, a procedure for discussing a sustainable contribution of LC^3 is designed and applied. Hollow blocks and mortars have been included in the calculations as well as the manufacturing/transportation processes for the entire supply chain of one semidetached two storey row houses built in the core of a slum-like settlement at Condado Suburb-Santa Clara city. This approach demonstrates that the LC^3 incorporation in the Cuban construction sector could afford considerable economic savings with the subsequent contribution in favour of the environment.

Keywords:

Low carbon cement; LCA; sustainability; eco-efficiency

1 INTRODUCTION

One of the most acute concerns of the current century is the survival of mankind. Global carbon dioxide (CO_2) emissions from fossil fuel combustion and from industrial processes (cement and metal production) increased in 2013 to a new record of 35.3 billion tonnes (Gt) CO_2, which is 0.7 Gt higher than last year's record [1]. Cement production accounts for roughly 5-7% of this environmental damage. So far, cementitious materials are not replaceable when building up infrastructure since concrete is a composite that requires a binder reacting with water to further harden. Cement production and consumption is meant to be trending upward in developing countries in forthcoming decades. This is the case in Cuba, where the demand for cement has been forecasted to have a growth rate of 18% (short term), 10% (middle term) and 5% (long term). The clinker is the active ingredient of cement and its production process is quite energy intensive. That is why cement manufacture is not only a matter of pollution, but also a matter of the economy. Ordinary Portland Cement (OPC), with at least 88% of clinker, becomes a very pricey good. Bearing these two sustainability dimensions in mind (Economy and Ecology), the use of a potential surrogate for clinker in the cement content has been deeply studied and well-documented. Funded by the Swiss Agency for Development and Cooperation, a joint project with participation of Swiss, Cuban and Indian scientists has developed a new type of cement, named Limestone Calcined Clay Cement (LC^3). LC^3, a low carbon cement, which is a blended cement containing 30% of metakaolin (calcined kaolinite

G. Habert, A. Schlueter (eds.): Expanding Boundaries © 2016 vdf Hochschulverlag AG an der ETH Zürich
DOI 10.3218/3774-6_47, ISBN 978-3-7281-3774-6, http://vdf.ch/expanding-boundaries.html

clay), has been produced in Cuba in an industrial trial form 2013 and 2015.This paper aims to present the economic and ecological impact of this alternative cement when used in Cuban housing projects in the province of Villa Clara.

2 METHODOLOGY AND DATA COLLECTION

2.1 Defining the assessment protocol

In order to assess the economic and environmental contribution of LC3 in housing applications in Cuba, the following 5-phase procedure is proposed and later applied.

(i) Definition of goals and scope
(ii) Supply chain characterization and mapping
(iii) Creation of Data inventory
(iv) Setting eco-efficiency indicators and calculations
(v) Reporting eco-efficiency profile and interpretation

Phase (i) is intended to clarify the construction type and all technical features associated with the construction system to be assessed. Functional unit (F.U.) and system boundaries (S.B.) should be defined as well. Limitations or assumptions derived from F.U. and S.B. are adopted in this Phase. Alternatives, strategies or scenarios are also described if necessary (especially when comparing different technologies).

Phase (ii) characterizes all flows downstream from the target building, identifying key players over the whole supply chain and their roles on the construction system under analysis. A diagram for mapping the supply chain is recommended so that a holistic understanding could be possible by inspecting the drawing.

In Phase (iii) all required data is collected following the flow route described in Phase (ii). Background and foreground data should be clearly organized in order to further be combined into eco-indicators. All material flows generate physical quantities and monetary quantities throughout the supply chain. Building materials are needed to be traced from quarries to building (construction site), determining economic and environmental inflows and outflows (inputs and outputs).

Phase (iv) integrates all material and economic flows along the chain, yielding an overall measure for both economic and ecologic performance of the alternatives confronted. Afterwards, for interpretation purposes it is recommended to combine both dimensions by means of an eco-efficiency indicator. According to the WBCSD [2] an eco-efficiency indicator is the ratio that relates an economic performance measure to an environmental load. Damineli et alt. (2010) [3] proposed two basic eco-efficiency indicators in order to measure and assess the cement use, namely *binder intensity* (bi) and *CO_2 intensity* (ci). However, these indicators are more applicable to concrete mix design assessment, when a large number of observations or samples is taken into account. For the case of the functional unit targeted in this paper, a conventional eco-efficiency indicator proposed by WBCSD is employed, relating revenues (at the level of 1 m^2 of wall) and carbon dioxide emissions.

Phase (v) is intended to draw up conclusions as from the findings achieved in Phase (iv), setting up the eco-efficiency profile of each option evaluated. This procedure takes theoretical background from Life Cycle Assessment based on ISO 14040 (2006) [4] and the Eco-efficiency procedure has been standardised by ISO 14045 (2012) [5].

2.2 Data collection

The primary variables included in the database (foreground data) are cement, sand, gravel, calcium hydrate, crushed stone, water and hollow blocks. Data comes from the housing project design and was contrasted with the construction company as well. The concrete blocks data was taken from Vizcaino-Andres (2014, 2015) [6], [7], based on industrial blocks manufacture (for OPC-made blocks) and LC^3 blocks have been produced at local level in an *eco-materials workshop* at Manicaragua (Villa Clara). Economic and environmental inputs for cement are taken from Sanchez (2015) [8], who has assessed in-depth the cement cost and the environmental effects for different types of cement produced in Cuba, especially compared to LC^3 production. Transportation fuel consumption was obtained from the Enterprise for Construction Materials Transportation at provincial level. Fuel consumption per kg of material for different types of aggregates was obtained from Building Materials Trading Company at regional level. Electricity consumption per unit material was also gathered from the referred enterprises. In respect to background data, environmental calculations have assumed an emission factor of 3.21 kg CO_2 per kg of diesel, according to the annual report of National Enterprise for Fuel Trading (CUPET), titled *Fuel Quality Specifications*. Diesel density of 0.8379 kg/L is used for needed conversions, as disclosed in the above mentioned report. Electricity emission factor is assumed to be 7.44×10^{-4} kg CO_2 per kWh, according to a similar report from Cuban Electric Power Union. Standard unit material consumptions (material intensity) were found in Perez (2013) [9], and served as documented reference while comparing material consumption that originated from construction enterprises. Both data sources are coincidental.

3 RESULTS

3.1 Definition of goals and scope

After the first industrial trial of LC3 cement in Cuba, a subsequent use of this cement took place in the construction sector. The local government

G. Habert, A. Schlueter (eds.): Expanding Boundaries © 2016 vdf Hochschulverlag AG an der ETH Zürich
DOI 10.3218/3774-6_47, ISBN 978-3-7281-3774-6, http://vdf.ch/expanding-boundaries.html

supported the construction of one semidetached two storey row houses in the core of a slum-like settlement at Condado suburb-Santa Clara city. All masonry mortars consumed in the second floor employed LC3, which encompasses placing blocks, plastering, patching walls and all finishing activities.

Definition of scenarios

In this case study, LC3 was used in masonry activities; nevertheless, the blocks used in the whole construction were produced with cement P-35 (the Cuban equivalent of OPC). That is why three scenarios were devised in order to undertake the eco-efficiency assessment, which is described as follows:

Scenario 1: Traditional cement-Scenario, which means that blocks are made of P-35 and mortars are made of PP-25 (the Cuban equivalent of PPC), both are traditional cements in Cuba.

Scenario 2: Combined P-35/LC3 Scenario, in which blocks are made of OPC and mortars of LC3 (this is the real scenario of house built at Condado-SC).

Scenario 3: Entire LC3 Scenario, which supposes that both blocks and mortars are made of LC3.

Ecological and economic implications of LC3 use, in this case study, is assessed based on one squared meter of wall as a functional unit. As the cement sustainability assessment taken from [6], [7] and [8] starts in quarrying activities (cradle-to-gate approach), the present study covers the material cycle from quarrying up to the use phase. It ends up at the construction level and does not take into account neither the recycling of materials nor the operational emissions derived from the use phase of building.

3.2 Supply Chain characterization and mapping

Fig.1 shows the supply chain (S.CH.) from materials' procurement up to the construction site. As shown in this diagram, 12 enterprises were involved in the housing construction throughout the supply chain. Among them, 9 are producers and suppliers of raw materials (building materials), two are intermediary companies whose main function is merely a commercial entity and one is a construction company. Dashed lines indicate the links between nodes or enterprises along the supply chain, and the arrows' direction indicates the material flows throughout the S.CH. Conversely, the economic flows are traced back from the end to the starting point in the sense that each enterprise pays for the goods supplied by the preceding entity. The links are deeply important because through the economic relationship between firms the value added has been created from quarrying to the final building and, in the same principle, the environmental flows are considered as a cumulative amount.

3.3 Creation of Data inventory

Table 1 shows the unit material consumption used in one square meter of wall, which becomes the base for an economic and environmental assessment, therefore, for eco-efficiency indicators.

Materials consumed	*Cement (kg)*	*Sand (m^3)*	*Gravel (m^3)*	*Crushed stone powder (m^3)*	*Calcium hydroxide (kg)*
Blocks/materials consumed	22.36	0.052	0.078	0.013	
Mortar/Blocks placement	6.25	0.018			3.6
Mortar/Finishing	5.27	0.038			2.85
Total	**33.88**	**0.108**	**0.078**	**0.013**	**6.45**

Table 1: Consumption material 1 m^2 of wall.

It is presented separately according to the kind of masonry activity; the materials involved in the production of 13 hollow concrete blocks – those required to build up one m^2 of wall – are reported in the first row. Economic cost and CO_2 emitted were calculated on the base of material consumption stated in Table 1. CO_2 released due to transportation was calculated based on the amounts of material specified. Table 2 presents the fuel consumption and electricity consumption scaled to the level of 1 m^2 of wall. Table 3 shows the fuel consumption per kilometre according to the building material shipped.

Building material (excluding cement)	*Diesel (L)*	*Electricity (KWh)*
Blocks (U)	0.312	0.481
Sand (m3)	0.0684	0.204
Ca(OH)2 (kg)	0.0438	0.045
Total	**0.4242**	**0.73**

Table 2: Diesel and electricity consumed in material obtaining (1 m^2 of wall).

Building material	*Consumption index (L/km)*	*Load capacity*	*Unit*	*Distance (km)*
Cement	0.4504	20000	kg	188
Sand	0.4	10000	kg	96
Ca(OH)2	0.4	10000	kg	188
Block	0.3086	1290	U	110
Water	0.2222	6000	L	20

Table 3: Fuel consumption (shipping).

Load capacity is later used to derive an impact index due to transport activities. In this study, the environmental assessment covers the carbon dioxide emissions generated largely due to the embodied energy into all materials consumed in one square meter of wall, resulting from its previous production process in itself.

G. Habert, A. Schlueter (eds.): Expanding Boundaries © 2016 vdf Hochschulverlag AG an der ETH Zürich
DOI 10.3218/3774-6_47, ISBN 978-3-7281-3774-6, http://vdf.ch/expanding-boundaries.html

Input data is taken from two different sources. Cement emissions have been taken from previous research results shown in [6], [7] and [8], who have extensively examined the Cuban cement industry and its related cement types. The remaining building materials CO_2 related emissions, i.e. sand, gravel, crushed stone powder, calcium hydroxide, have been derived as a direct result of the present study. Emissions due to transportation of all building materials have been estimated in this study.

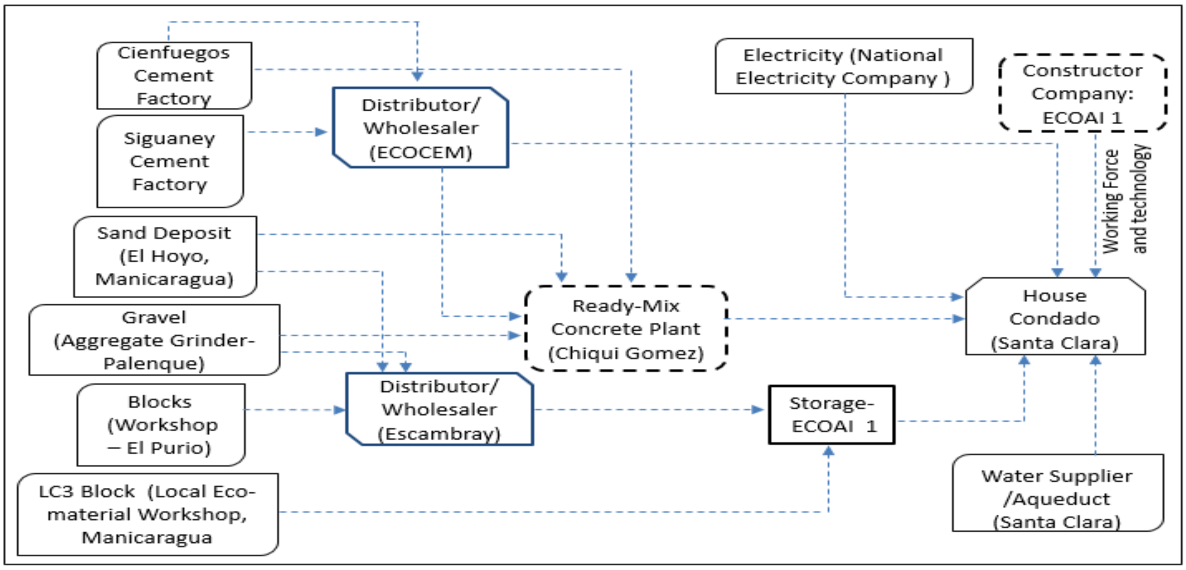

Fig. 1: Supply chain mapping for housing case study.

3.4 Setting eco-efficiency indicators and calculations

Table 4 summarizes the CO_2 emitted during obtaining the building materials involved in 1 m^2 of wall as well as the emissions derived from transporting all materials from suppliers to construction site. In this report, an allocation method is proposed, ensuring distribution of all CO_2 released during the transportation process amongst different units of material shipped. For simplification reasons, the means of transportation is not declared in table 3, although, conventional trucks, which are representative in Cuban construction sector, have been considered. The framework of table 3 lets us to apportion the fuel consumption among the truck carrying capacity (e.g. 20 000 kg of cement) by means of a conversion coefficient. Furthermore, a generic scalar value is attained when dividing consumption index (L/km) by the carrying capacity. The resulting number indicates the share of fuel consumption that corresponds to each unit quantity of material shipped (i.e., L/km/U). Afterwards, this conversion index is multiplied by the transportation distance and later by the amount of material used in real construction. This is the prior calculation needed before reckoning the CO_2 released due to transportation. Diesel engines release ~2.6 kg CO_2 per L of diesel fuel burned [10]. This reference figure was used while determining environmental loads associated with transportation.

Table 4 summarizes the environmental load of each scenario, by adding CO_2 emissions due to fabrication process to those released during shipping raw materials. The cement manufacturing impact is also summed as it appears in the first row.

Pollutant Source	*Sce. 1*	*Sce. 2*	*Sce. 3*
Cement production	32.87	30.48	22.77
Obtaining aggregates and blocks*	1.14	1.14	1.14
Transportation	1.44	1.44	1.44
Total	**35.45**	**33.07**	**25.35**

**Cement consumed in block production is counted in first row (Sce: scenario)*

Table 4: CO_2 emissions by pollutant source.

Table 5 presents the eco-efficiency upshot, according to the ratio explained in section 2.

Item	*Sce. 1*	*Sce. 2*	*Sce. 3*	*Δ (%)*	
Revenues	6.96	6.85	6.29	2 vs. 3	20
Emissions	35.45	33.07	25.35	1 vs. 2	5
Eco-indicator	0.20	0.21	0.25	1 vs. 3	26

Table 5: Eco-efficiency indicator over scenarios.

3.5 Reporting eco-efficiency profile and interpretation

It is clearly noticeable that ~92% of overall emissions embedded in 1 m^2 of wall belongs to cement, as expected (Table 4). That is why its negative impact on the environment is a global concern, therefore, it encourages this kind of research. Aggregates and blocks represent altogether the remaining 8% (roughly 4.5% each). By only switching from cement P-35 to LC3 in mortar, emission savings account for 7% (scenario 1 vs. 2). This is the real environmental

G. Habert, A. Schlueter (eds.): Expanding Boundaries © 2016 vdf Hochschulverlag AG an der ETH Zürich
DOI 10.3218/3774-6_47, ISBN 978-3-7281-3774-6, http://vdf.ch/expanding-boundaries.html

advantage of House-Condado-Santa Clara, which employed the technology depicted in scenario 2. Moving from scenario 2 to 3, which in addition means producing LC3 blocks, savings of ~30% might be achieved. This is merely the effect of introducing LC3 in block production plants. A full replacement of traditional cements currently being used in the construction sector in Cuba (P-35 for blocks and PP-25 for mortars) leads to a 40% carbon dioxide emission savings. In terms of economic cost, replacing traditional existing cements by LC3 lessens the production cost by ~11%. Looking at the joint effect (economy-environment), LC3 mortars could increase the eco-efficiency of cement use by 5%; moreover, producing LC3 blocks would raise the eco-indicator by 20%.

The combination of both (mortars and blocks made of LC3) would raise the sustainability of buildings by roughly 26%. It is difficult to mention a consideration around performance of 1 m^2 of wall, since all materials are combined in a structure. Structures like walls, floors roofing decks are built to last and provide comfort to dwellers. Nevertheless, once all building materials are embedded into a structure, properties like durability and comfort are difficult to foresee, to a large extent. It should be revisited and still is a challenge.

4 DISCUSSION

The results emerging from eco-efficiency analysis can be read as follows: 0.20 US$ of revenue per kg of CO_2 emitted is achieved in each square meter of wall when using conventional cements. When introducing LC3 in mortars, at the same level of functional unit, 0.21 US$ of revenue per kg of CO_2 would be reached. The full LC3 scenario elicits 0.25 US$ of revenue per kg of CO_2, which represents a straightforward advantage in terms of economic and environmental impact. Taking into account a 28-day compressive strength of 4.47 MPa for LC3 hollow blocks and 5.3% absorption [6], the replacement of traditional cements in blocks manufacture would be feasible from a technical, economic and environmental viewpoint. Compressive strength in LC3 mortars are in the order of 8.98 MPa and absorption by capillarity 7-days is ranking like PPC mortars (1.58 g/cm^2) (Alvarez, 2014) [10]. Additional goodness of LC3 mortars can be found in [10], like medium adherence, open porosity.

The social dimension of sustainability is understood as from the odds to use less costly building materials like LC3, which in turn allows to produce a wide range of related construction materials using the same low clinker binder. This implies a better purchase power for end consumers at existing markets.

5 CONCLUSIONS

The methodology proposed and applied in this case study is proven to be feasible and easy to handle if the purpose lies in the sustainability concept, which encompasses economic, environmental and social dimensions. The scenarios evaluated show the marginal effect of replacing traditional cements in mortars and blocks while building one square meter of wall. LC3 performs in a very costeffective way and environmentally friendly, it is ~26% more sustainable than conventional cements. Potential costefficiency and CO_2 savings would be induced if the analysis is scaled to the level of entire houses. The supply chain approach is deeply aligned with LCA methodology. Combining both provides researchers with a comprehensive framework in understanding the links between economic and environmental flows when tracing the route of building materials. The findings presented in this paper shed light on policymakers in the Cuban cement industry and governmental key players on the potential core decisions concerning construction sector investments.

6 ACKNOWLEDGEMENTS

Authors want to thank the valuable support by the Construction Enterprise committed with the social housing Condado-Santa Clara (ECOAI 1), the Cement Factory Siguaney for the successful industrial trial of LC3 and the Local Building Materials Workshop at Manicaragua, where LC3 blocks were produced.

7 REFERENCES

1. Olivier, J., et al., Trends in global CO_2 emissions: 2014 Report, in PBL Netherlands Environmental Assessment Agency. Joint Research Center European Commission, http://edgar.jrc.ec.europa.eu/news_docs/jrc-2014-trends-in-global-co2-emissions-2014-report-93171.pdf

2. Verfaillie, H. and R. Bidwell, Measuring Eco-efficiency. A guide to reporting company performance, in World Business Council For Sustainable Development Report. http://www.wbcsd.org/web/publications/measuring_eco_efficiency.pdf

3. Damineli, B., et al., Measuring the eco-efficiency of cement use. Cement & Concrete Composites, 32 (2010): p. 555-562

4. ISO 14040 (2006): Environmental Management, Life Cycle Assessment, Principles and framework.

http://www.iso.org/iso/home/store/catalogue_ics/catalogue_detail_ics.htm?csnumber=37456

5. ISO 14045 (2012): Environmental Management, Eco-efficiency Assessment of product systems, Principles, requirements and guidelines. http://www.iso.org/iso/catalogue_detail?csnumber=43262

6. Vizcaino-Andres, L., Cemento de bajo carbono a partir del sistema cementicio ternario clinquer-arcilla

calcinada-caliza. 2014, Doctoral Dissertation Report. UCLV-Library.

7. Vizcaino-Andres., et al., Industrial trial to produce a low clinker, low carbon cement, in Materiales de Construccion, Vol. 65, Issue 31, January-March 2015.

http://materconstrucc.revistas.csic.es/index.php/materconstrucc/article/viewFile/1681/2044

8. Sanchez, S., Economic and environmental impacts of LC3. Specific case of Cuba. PPT Presentation in LC3 International Meeting. Zürich, Switzerland. May, 2015.

9. Perez, Y. Evaluación de la eco-eficiencia en la cadena productiva de una vivienda construida con cemento de bajo carbono, 2013, Tesis de Licenciatura en Economía. UCLV-Library.

10. Valsecchi, C., et al., Environmentally harmful subsidies: identification and assessment, Final Report, 2009, Institute for European Environmental Policy (IEEP).

11. Alvarez, C., Evaluación de las propiedades de los morteros de albañilería elaborados con cemento de bajo carbono, 2014, Tesis de Ingeniería Civil, UCLV-Library.

G. Habert, A. Schlueter (eds.): Expanding Boundaries © 2016 vdf Hochschulverlag AG an der ETH Zürich
DOI 10.3218/3774-6_47, ISBN 978-3-7281-3774-6, http://vdf.ch/expanding-boundaries.html