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Sustainability assessment in Cuban cement sector- a methodological approach

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Abstract. The search of sustainability is a need for human activities in general. Particularly, cement sector as a significant contributor to climate change has to implement strategies to reduce its environmental impacts. But, effective strategies have to be complemented by adequate methodological techniques to assess, guide and certificate sustainability. Amongst all the techniques developed by the scientific community in recent years, life cycle techniques highlight as one of the most used one due to its integrated and holistic philosophy. In Cuba, a new cement based on a combination of calcined clay and limestone to reduce clinker to 50% (Low Carbon Cement, LC³) is been developed as part of an international collaboration project. The main goal of this research is to assess sustainability of cement sector in Cuba using life cycle techniques such as: Life cycle assessment (environmental-LCA), Social Life Cycle Assessment (S-LCA), Life Cycle Costing (LCC), Economic Life Cycle Assessment (EcLCA). As part of the assessment LC³ is compared with traditional produced cements in Cuba OPC and PPC. Results show that LC³ introduction allows increasing sustainability in cement sector by reducing carbon emissions, energy consumption, costs and reporting positive effects on society.

1. Introduction

One of the most intensive industries in capital and energy is the cement industry [1]. This industry constitutes the base for the sector producing construction materials, as cement is the main ingredient of concrete, and have multiple interrelations with all sectors and economic activities that exist or must exist for the proper functioning of the economy. However, the high production volumes of this industry make it responsible for approximately 6-10% of global CO₂ emissions of anthropogenic origin and about 5% of energy consumption in the industrial sector [2].

The increase of the energetic efficiency, the use of alternative fuels, the decrease of the clinker ratio by using supplementary cementitious materials (SCM), besides the sequestration and capture of carbon, are the main strategies developed to reduce the emissions of CO₂ and energy costs associated with



cement production [2].

Low Carbon Cement (LC³) is a cement with high level of clinker substitution with addition of 30% calcined clay and 15% limestone [3]. Several articles have been published proving the technical viability of this new product [4]–[6]. Although the lower clinker content in LC³ is supposed to reduce energy consumption, associated costs and emissions and extend existing productive capacities; these assumptions need to be proven.

The Life Cycle Sustainability Assessment (LCSA) is one of the most modern tools applicable for the evaluation of investment impacts and programs oriented towards sustainability [7], [8]; nevertheless, its methodological structure is in development and its application is still limited [9-11]. In the solution of these limitations the proposal, selection and guidance for the use of indicators play a fundamental role; the availability of data and experience for its application, among others, that allow achieving the organicity of the three methodologies that make up the LCSA: Life Cycle Assessment (LCA), Life Cycle Costing (LCC) and Social Analysis of the Life Cycle Assessment (S-LCA).

2. Method for sustainability assessment

According to UNEP/SETAC (2011) the Life Cycle Sustainability Assessment considers all stages of the product and service life cycle and the complete study of its production and value chain. First ideas that guided LCSA approach can be attributed, according to Finkbeiner (2010), to the German Oeko-Institut for its method called “Product Line Analysis” (*Produktlinienanalyse*) [12]. Later, UNEP published several documents that serve as a methodological guide for the discussion and implementation of this tool [13].

In formula 1, proposed by Kloepffer (2008) [14], the LCSA is conceptually defined:

$$\text{LCSA} = \text{LCA} + \text{LCC} + \text{S-LCA} \quad (1)$$

Where:

LCSA = Life Cycle Sustainability Assessment

LCC = Life Cycle Costing

LCA = Life Cycle Assessment (environmental)

S-LCA = Social Life Cycle Assessment

The environmental life cycle assessment (environmental LCA) looks at the potential impacts of products and services in the environment. ISO standards for LCA guide these studies in four phases: (i) definition of objectives and scope; (ii) inventory analysis; (iii) impact assessment; (iv) interpretation of results; with close interrelation between the phases.

Life Cycle Costing (LCC) and financial analysis are combined with the economic analysis of the life cycle from the methodological guide proposed by Neugebauer et al. (2016) [16], understanding that the economic analysis comprises a number of variables that allow holistic evaluation of the impacts of an activity or service beyond the cost category [15], [16].

Social Life Cycle Assessment (S-LCA) were published by UNEP/SETAC in 2009 [17], then in 2013, methodological sheets for impact categories and indicators by stakeholder groups were published [18]. In this investigation the subcategories and indicators are adjusted to Cuban conditions to be evaluated. From the UNEP proposal (2013) 14 indicators are identified and 2 proposed for evaluation.

According to [14] there are at least two options to include LCC and S-LCA as part of LCSA. Option 1 is based on performing three separated life cycle assessments with identical system boundaries. Its graphical representation matches with formula 1. Option 2 is based on “a new life cycle assessment” where costs and social assessment are included as additional impact categories to the LCA (environmental). This option includes a life cycle inventory with the *inputs* and *outputs* needed to assess the three areas simultaneously and possibly to get the same protection areas.

The advantage of this option is that greater integration is achieved by having a single LCI associated with a single analysis system. However, there are reservations as to the compatibility of this variant with the ISO 14040 standard, since the standard in its introduction states that the LCA “does not usually consider the economic or social aspects of a product [...] but should be used as part of a much more

complete decision process". This clearly favours the application of option 1 in the short term, while the international standards ISO 14040-44 are revised and modified so that they comply with option 2.

For its part UNEP (2011) clarifies that although standardization, aggregation and weighting are optional steps in accordance with ISO 14040, any aggregation and weighting of the results of the three techniques used in the ASCV is not recommended because the research and implementation of this approach is at an early stage and the results of each applied life cycle technique are not yet comparable to each other.

In order with previous ideas, in this paper final results are shown throughout a methodological proposal of pared indicators following eco-efficiency philosophy. These indicators are presented in a radial chart that allows to perform a combined interpretation and decide among several alternatives.

2.1. Choice of functional unit and system boundaries

The main objective is to evaluate the environmental, economic and social impacts of the introduction of low carbon cement in Cuba comparing LC3 with cements currently produced OPC and PPC. Table 1 shows material composition of the cements compared. The analysis is performed from cradle to gate, mainly focused on the production and transport of the cement constituents, as shown in [19]. According to the system boundaries, the functional unit selected in the study is 1 ton of cement. This functional unit is commonly used for cradle to gate LCA but one of its limitations is not being directly related with cement quality, this aspect remains as an extra task for evaluators in order to get an integral assessment of this construction product. When assessing concrete performance other units suit better to explain its performance like m² of wall, m² of built surface, m² of usable floor area, etc. [20].

Table 1. Composition of the assessed cements.

Cement	Constituents (%)				
	Clinker	Limestone	Gypsum	Calcined Clay	Zeolite
OPC	0,88	0,05	0,07	-	-
PPC	0,75	-	0,05	-	0,20
LC ³	0,48	0,15	0,07	0,30	-

2.2. Data collection

Data collection for the performed LCA has been published in [21]. The economic assessment used data collected from Siguaney cement factory relative to salary, consumption indexes, cost of energy, raw materials distances, depreciation, amongst other. Data from social area was obtained from several sources like official documents like statistical year book, production reports, accounting books of industry, interviews with workers and directives of different companies. To warranty liability of data, the triangulation of obtained information in interviews was performed by reviewing official documents related to the topic.

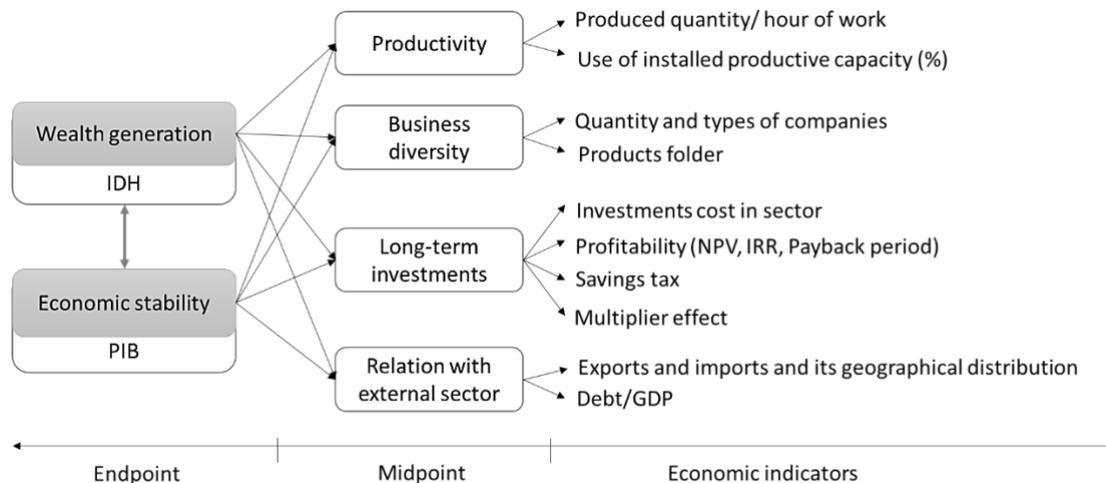
2.3. Impact assessment

In this study environmental assessment is performed applying ReCiPe impact assessment method. Specifically, for Cuban cement sector 11 midpoint categories are selected: Climate change, Ozone depletion, Chemical oxidants formation, Human toxicity, Particulate matter formation, Terrestrial acidification, Fresh water eutrophication, Marine eutrophication, Fresh water ecotoxicity, Marine ecotoxicity and Fossil fuel depletion. Three endpoint categories are analysed: Human health, Ecosystems and Resources.

Costs assessment is performed following life cycle of the product and its productive chain. Production process is divided into 5 stages: raw materials extraction, fuels extraction, transport, clinkerization and grinding plus other processes. Assessment of economic impacts (E-LCA) complements costs analysis with financial analysis of different investment scenarios, productivity and

macro-economic variables analysis. Midpoint, endpoint and indicators proposed to Cuban cement sector and its interconnections are shown in Figure 1.

Figure 1. Proposal of categories and indicators to perform E-LCA in Cuban cement industry.



Source: Proposed following [16].

Social impact assessment is performed as Social Life Cycle Assessment following UNEP/SETAC methodological proposal [17], [18]. From the proposal of UNEP/SETAC 14 indicators, 9 midpoint and 3 endpoint categories were selected to assess cement industry in Cuba as shown in Table 2.

Table 2. Sub-categories and indicators selected to social assessment in Cuban cement sector.

Categories	Sub-categories	Indicators
1. Workers	1.4 Hours of work	No. hours of work/t cement
	1.7 Health and security	<i>Incidence of diseases related to cement production/ worker</i>
	3.3 Cultural patrimony	No. of buildings with patrimonial value restorable/year
3. Local Community	3.5 Local employment	Percentage of labour work employed in locality No. employees
	3.7 Access to material resources	No. of infrastructure projects developed with access and benefit of community
	3.8 Living conditions healthy and secure	<i>Incidence of diseases related to cement production/ community inhabitant</i>
	5.1 Public commitment to sustainability aspects	Presence of documents available publicly such as agreements in sustainability topics Implementation/firm of principles or conduct codes internationally conciliated
5. Society	5.3 Contribution to economic development	% GDP relative to construction sector Number of houses built/year <i>Changes in acquisitive power of population</i>
	5.5 Technological development	Sectorial efforts for technological development Relation with programs or projects of technological transfer

2.4. Integration of results

To be able of develop the final process of integrating economic, social and environmental results, a set of paired indicators is proposed allowing to combine the three dimensions of sustainability taking into account the main findings in the evaluations carried out separately and the efficiency of them characterizing each evaluated dimension. This facilitates the integration of the results without complicating the evaluation process. It was decided to calculate the indicators for those categories of

considerable magnitude and that show greater impact for cement sector. Table 3 shows the proposed indicators, the unit of measurement in which they are expressed and their classification.

Table 3. Proposed indicators and its classification.

Indicator	Unit	Type
Production cost/ MPa*	Pesos / MPa	Technic-Economical
Investment cost/ MPa*	Pesos / MPa	Technic-Economical
Energy consumption/ MPa*	MJ/ MPa	Technic-Economical
Reduced emissions/ investment	tCO _{2eq} / Peso (MT)	Economic-Environmental
Dust emissions/ hour of work	kg MP10/ h	Social-environmental

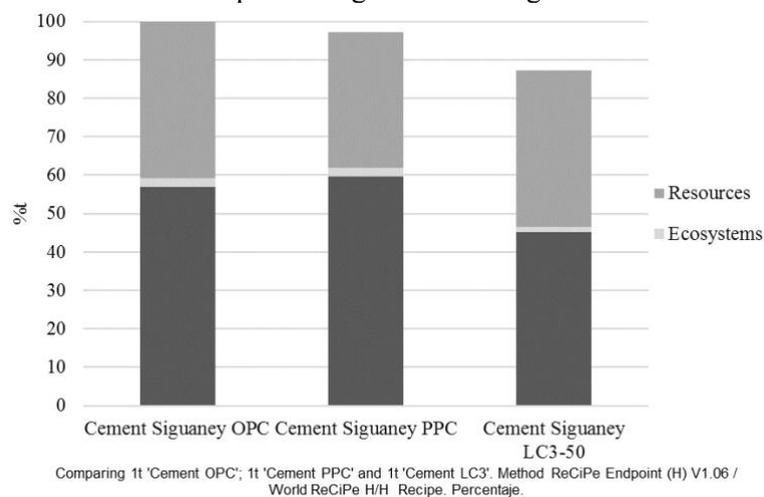
*MPa of compressive strength at 28 days

3. Results

3.1. Life Cycle Assessment

The comparative life cycle analysis of the OPC, PPC and LC³ cements is performed to evaluate 11 intermediate categories and 3 final categories of the ReCiPe methodology. The calculations are performed using the professional software Simapro vs- 8.0.3.14. LC3 presents lower impact in 8 of the midpoint categories reporting higher impact in eutrophication and ecotoxicity indicators. From the endpoint categories, the most affected category is human health, due to the damage caused by the gases emitted in the production process related to CO₂ and particulate matter. The P-35 causes greater damage to human health and the ecosystem, as shown in Figure 2. The production of LC3 is the one that most affects resources by the calcination of kaolinitic clay with Cuban crude oil which is more polluting than pet-coke assumed to clinker production.

Figure 2. Results of endpoint categories of damage OPC vs. PPC vs. LC3.



The analysis of the energy consumption shows that with the introduction of LC3 can reduce in approximately 900 MJ the energy consumption per ton of cement produced. The main savings are obtained in the processes of clinkering, extraction of fuels and grinding.

3.2. Life Cycle Costing and Economic Life Cycle Assessment

Through the LCC, the cost composition of each cement is analyzed. The main costs are reported by the extraction and transportation of energy resources, raw materials and equipment depreciation. LC3 production reports a considerable decrease in production costs mainly related with reduction of clinker

factor. Costs saving of 10-15 % are reported in Cuban conditions if LC3 is compared with PPC and OPC respectively [21].

To evaluate the profitability of the technological alternatives, 2 alternatives are compared with Business as Usual using a capital cost of 12%, discount rate of 35% and time horizon of 15 years. The results are shown in table 4.

Alternative 1: proposes the strategy of introducing the LC3 in the Cuban cement industry as the partial substitution of traditional cements from the conversion of kilns to calciners. Four calciners with capacity of 300 000 tons / year of calcined clay are estimated.

Alternative 2: Under this alternative, calcination of the clay should be done through flash calciners. Flash technology must be imported. The same amount of calciners is estimated as in alternative 1.

Table 4. Financial results for each of the investment alternatives.

Alternatives	Indicators		
	NPV (MPesos)	IRR (%)	Payback period (Years)
LC ³ _Retrofitted calciners	\$227.34	58%	3 years, 8 ^{1/3} months
LC ³ _ Flash calciners	\$123.53	33%	5 years

The internal rate of return and the payback period show that the conversion of kilns to calciners is the best alternative in the short-term. The cost of this conversion is taken from [22], where is establish a maximum retrofitting cost to produce calcined pozzolana of 12M€. Same results should be obtained if an industrial calciner is installed since recent investment costs are quite similar to this scenario [23].

Analyzing productivity aspects is expected that the introduction of Low Carbon Cement increases the productivity since a better use can be done with the same amount of clinker. In other words, decreasing clinker ratio Cuban cement industry will be able to offer a higher amount of cement to market with minor changes in its technology. This could have a positive impact on the business diversity and could stimulate exports to countries of the Caribbean and Latin American areas but this fact depends on several factors besides the level of cement production. Moreover, the reanimation of this sector would lead to a reanimation of Cuban economy due to the multiplier effect of construction as key sector for and investments and development.

3.3. Social Life Cycle Assessment

The assessment of social impacts is carried out mainly by assessing the potential for change in the selected indicators. When possible, quantitative analysis is performed. The following levels are proposed to evaluate the potential for change: a: Negligible, B. Minor, C. Moderate and D. Significant. The results of the evaluation show that 79% of the impacts present moderate or significant change potential [21].

Table 5. Potential of change (PC) of proposed social indicators

Sub-categories	PC	Indicators	PC
1.4 Hours of Work	A	No. of hours worked / t cement	A
1.7 Health and Safety	D	Incidence of diseases attributable to cement production/ worker	D
3.3 Cultural Heritage	C	No. of buildings with patrimonial value restore / year	C
3.5 Local Employment	B	Percentage of labor force contracted in the locality	A
		No. Of jobs	B
3.7 Access to Material Resources	C	No. of infrastructure projects developed with access and benefit to the community	C
3.8 Safe and Healthy Living Conditions	C	Incidence of diseases attributable to cement production / community residents	C
5.1 Public Commitment to Sustainability Issues	C	Presence of publicly available documents as agreements on sustainability issues	C
		Implementation / signature of principles or other internationally reconciled codes of conduct	D

5.3 Contribution to Economic Development	C	% GDP relative to the construction sector	C
		Number of houses / year	D
		Changes in the purchasing power of the population	C
5.5 Technological Development	C	Sectoral efforts for technological development	D
		Relationship with technology transfer programs or projects	C

3.4. Integration of results

For the integrated evaluation of the results in the economic, social and environmental dimensions, the combined analysis is proposed through scatter plots of the most significant variables of each sphere. The significance of the chosen variables is determined taking into account results of the assessment, literature review and expert’s opinion (detailed information available in [21]). In this way, decision-makers can be offered a brief and simple analysis of the most sustainable investment variant. The indicators for the case study in the cement industry are shown in Table 6.

Table 6. Indicators selected to integrate and interpret the results

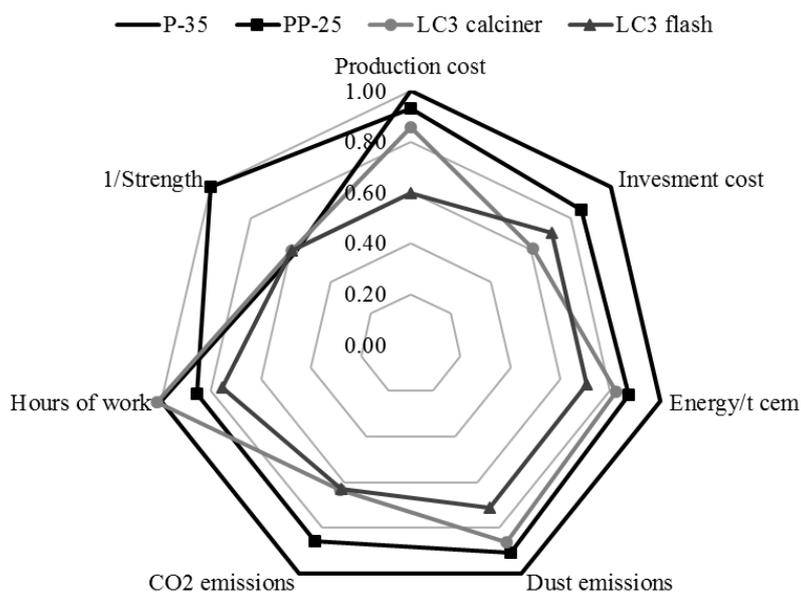
Indicators	UM	OPC	PPC	LC3 Calciner	LC3 Flash
Production cost	Pesos	187,70	174,55	160,86	112,12
Investment cost	USD	159,57	135,99	97,39	112,54
Compressive strength 28 days	MPa	43,07	25,00	42,08	42,08*
Energy consumption	MJ	5292,38	4626,33	4367,53	3254,22
Dust emissions	kg PM10eq	15,10	13,69	13,00	9,75
Carbon emissions	kg CO2eq	890,63	764,92	564,39	559,73
CO2 emissions reduced	kg CO2eq	-	125,71	326,24	330,90
Time of labor	Hour	0,035	0,030	0,036	0,027

* to LC3_Flash is assumed equal compressive strength than obtained in the industrial trial with the calciner.

Source: [21]

To analyze results in an integrated way figure 4 is proposed, showing all indicators together.

Figure 3. Integrated assessment of impacts. Case study: introduction of LC³ in Cuba.



The results of the economic, social and environmental evaluations show the positive impacts (see figure 3) of introducing low carbon cement in Cuba. The main impacts are associated with the reduction of emissions of greenhouse gases and dust, which could influence in the reduction of diseases associated with the production of cement; the saving of energy that influence in the reduction of the cost of production and the consequent impact on the purchasing power of the population. A revitalization of the cement production in Siguaney and consequently in Cuba, that would allow to satisfy the internal demand and increase the exports of this good, and the increase of the productive capacities through small investments with high profitability and short period of recovery.

4. Conclusions

The results of the Life Cycle Sustainability Assessment carried out show that the main impacts are associated with the reduction of greenhouse gas emissions and dust, which in turn influences the reduction of diseases associated with this type of production; the energy saving that is translated in the reduction of the cost of production and the consequent impact on the purchasing power of the population; the revitalization of the cement production in Cuba and in particular in Siguaney, which would allow to satisfy the domestic demand and to increase the exports of this good; in addition to the increase of productive capacities through small investments with high profitability and short recovery period.

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