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CEMENT LIFE CYCLE ASSESSMENT : CASE STUDY OF AN INTEGRATED INDUSTRY IN MADAGASCAR

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Abstract

The cement industry is upstream from many sectors and contributes to greenhouse gases emissions for all buildings and civil works life cycle. To reduce the emissions, it’s necessary to have the right situation about it. The aim of this studyis to estimate the greenhouse gases emission factors of the cements produced in Madagascar. For this, Life Cycle Assessment, an environmental evaluation’s key tool, normalized by ISO 14040 to ISO 14044 is chosen. The study of two types of cement manufactured by an integrated plant is carried out from the raw materials extraction to the production phase. Greenhouse gases emission factor of 1.29 t CO_2 eq is associated to one ton of clinker, generating 0.877 t CO_2eq per ton of CEM II/B-P 22.5 and 1.122 t CO_2eq per ton of CEM II/A-P 32.5 UT-PM.The results can provide a baseline for greenhousegases emission factors of cement in Madagascar and can be used for environmental impact assessment of concrete and cement based-materials.

Key words:clinker, emission factor, greenhousegases, carbon dioxyde, methodological framework.

1. Introduction

Cement is the main material used in the infrastructure [1]. The cement industry plays a crucial role in the global economy as it is used in the production of various infrastructure and construction projects [2].

Cement sector has developped very rapidely in recent years and it is the third largest source of anthropogenic emission of carbon dioxide. The cement industry is one of the important contributors to industrial CO_2 emissions [3]. The magnitude of cement production leads to more than 7% of annual anthropogenic greenhouse gases (GHGs) emissions [4]. Of the 36 billion tonnes of greenhousegases emitted in 2021, three-quarters was generated by four sectors: heating and electricity, transport, steel and iron production and cement sector. Cement alone generatesaround 2.52 billion tons.of carbon dioxyde annually [5].

In Madagascar, cement local production is ensured by one Society in 2022. It's both a productor and a distributor company. The productor plant is an integrated factory which ensures the entire cement production from raw materials extraction to the packaging. One another plant takes care of only the steps of coumponding (mixing of clinker and supplementary cementing materials) and the packaging. In 2022, the company produced 180 000 tons of cement. Right now, a new cement factory is added to the actual production unit and one million tonnes of cement will be produced in 2025. Direct Greenhouse gases emissions are generated first by the decarbonation of limestone, inevitable reaction when the clay-limestone mixing is converted to clinker, then by the combustion of fuel used in the kiln and for machinery. Indirect emission are produced by energy and non energy primary resources acquisition, their transformations into energy (electricity) and non energy (drinking water) resources directly usable [6]. Anthropogenic energy production, particularly, burning of fossil fuels are the key contributor for releasing GHGs to the atmosphere [7].

The main challenge facing the cement industry is decreasing its carbon efficient. To reduce the emission, it is obligatory to evaluate it [8].Our ultimate goal is to create especially an appropriate GHGs emission factors data base for Madagascar. Few researches about clay materials [9], woodenergy [10] [11], timber [12] and mix electricty [13], have been yet carried out and this present study is a complement of these. So, the aim of this paper is to evaluate the GHGs emission factors of the cements produced locally. Our study is focalised on the CEM II/B-P 22,5 and CEM II/A-P 32,5 UT PM cements, produced by the integrated plant.

Many organizations, such as IPCC and Cement Sustainability and Initiative (CSI), have developed methods to calculate CO_2 emissions from cement production. There are, broadly speaking, two kinds of methods to calculate CO_2 emissions from the decomposition of raw materials, namely input-output analysis methods [3]. A multitude of evaluation tool exists and Life Cycle Assessment (LCA) is the most complete baseline methodology to evaluate the environmental impact of a particular product, a service or a process during his life cycle [14]. This tool is also an analytical method and a powerful tool for quatifying the environmental impacts of materials or products by looking at a wide array of factors. [15] [16]. This methodology is adopted to the present case study of Madagascar cement industry.

2. Méthodology

Life Cycle Assessment has a methodological framework involving four key phases : purpose and scope definition, life cycle inventory, life cycle impact assessment and interpretation of the results ISO 14040 to 14044 [17] [18] [19] [20] [21] [22].

2.1. Definition of the purpose and the scope, Functionnal Unit (UF) and system boundaries

The scope is to estimate the GHGs emission factors of the cements CEM II/B-P 22,5 and CEM II/A-P 32,5 UT PM produced in Madagascar in 2022. One ton of cement is taken as Functionnal Unit (FU) and the factors emission are expressed in ton CO_2eq.The system boundaries include foreground and background processes, constituing the products system. The foreground process is composed of the cement production steps : extraction of raw materials, transport to the production plant, dosage, grinding, storage, homogeneisation, burning, cooling, addition of the supplementary cementing materials and packaging. The background process in this paper are made of electricity generation, its transport and ditsribution and finally the drinking water production (Figure 1).

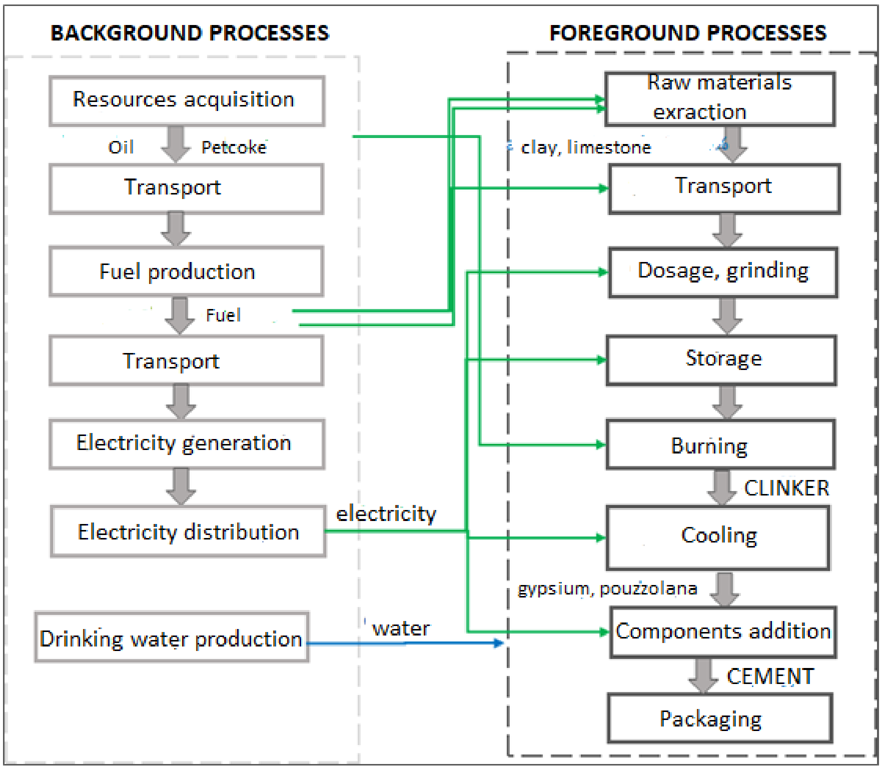

Figure 1 : Cement products system

2.2. Life Cycle Inventory

Life Cycle Inventory (LCI) is made of technical data collection of the cement industry, littérature and from GEMIS (Global Emission Model for Integrated System)framework [23] [24] [25] [26] [13].Life cycle inventory is focused on raw materials, production processes, cement type, energy sources and fuel, consumptions of energy and non energy resources, GHGs emisssion factors of some processes (sea and road transports, drinking water production, fuel production, electricity generation…).

Cements produced in the integrated plant are Portland cements with pouzzolana. Natural corrective components containing oxide such as bauxite, iron ore and sand may be added to the clinker in order to rectify the composition of the cement. The weight compositions according to the NF- EN 197-1 standard are given by the table 1.

Table 1. Weight compositions of the cement

Class of the cement	Weight composition (en %)		
	Clinker	Pouzzolana	Corrective components
CEM II/B-P 22,5	65 - 79	21 - 35	0 – 5
CEM II/A-P 32,5 UT PM	80 - 94	6 - 20	0 – 5

The main raw materials, limestone, clay and supplementary cementing materials such as gypsum and pozzolana are exploited locally. The slaughter is carried out by blasting. At least 1.5 à 1.75 tonnes of raw materials are necessary for one tonne of cement. According to the « Manuel de prévention de la pollution dans le secteur du ciment », 1.5t to 1.6t of dry raw materials are required for 1t of clnker [27].

The extracted raw materials are selected, crushed, grinded and mixed to get the grain size and chemical composition required for the process in the kiln. The process consumes around 8.8 kWh per ton of raw material, which88% of the energy are consummed during the extraction phase and there maining 12% during the grinding. Cement industry is a high consumer of heat energy for clinker burning and electric energy for its transformation to cement [28].

- Heat energy requirement

For the burning, the main energy source is the petcoke (petrolium waste) with 32 MJ/kg as net calorific value [24], imported from South Africa. This solid fuel is characterised by its high calorific value and its low ash content.

The company used also local heavy fuel of Tsimiroro for enginnering test. The fuel is compatible with the installation, the only concern is its transport because the road access from Tsimiroro to the cement industry is in poor condition.

For shaft kiln, the energy requirement for clinker burning is in range of 5 700 MJ à 6 600 MJ per ton of clinker [27]. An another study provides that 3600MJ à 4500MJ per ton of clinker is needed for this step [23]. The Assessment guide of energy consumption in cement and clinker production provide a heat requirement around 3600 MJ for one ton of clinker burning by dry process [29]. The «Institut de l'Energie et de l'Environnement de la Francophonie » estimated 3000MJ to 6000 MJ for one ton of clinker burning. According to Alsalman, 3600MJ is considered as the average energy consumption to produce one tonne of clinker [30]. This last value is taken for our study.

- Electric energy requirement

According to Hamidi paper [26], electric energy required for cement production is estmated around 800-1200 kWh per ton of cement and about 50kWh /t are for the clinker final grinding. The « Agence de l'Energie pour l'Economie » [31] provides that it takes 100kWh of electricity per tonne of cement for the machinery and for the heat furnace (rotary kiln). According to « Manuel de prévention de la pollution dans le secteur du ciment », the grinding of one tonne of raw meal requires 12 à 16kWh of electric energy [27]. For our study, mix electricity used in the cement plant is from the Interconnected Gridof Antananarivo (IGA) which the greenhouse gases factor emission is provided by a previous study [13].

- Water

In a cement plant, 0,6m^{3}is needed to produce one tonne of cement [27].

- Transport

The large masses of stones are broken down and trasported by truck to the crushing unit, and get the primary crushing. Then, the raw materials are carried by truck to the cement plant. The transport of the fuels is ensured by seaway and road.

The petcoke is trasported from Durban to the port of Toliary by ship or more accurately by bulk carriers. The road transport is provided by trucks : raw materials transport to the cement plant and petcoke transport from the port of Toliary to the factory. The distances of transportation of raw materials and petcoke are given in the table 2.

Table 2 : Transport types and transported products

Products	Road transport		Sea transport	
	Distance (km)	Means of transport	Distance (km)	Means of transport
Pet coke	760	truck	1450	bulk carrier
Clay	38	truck	0	-
Limestone	5	truck	0	-
Pouzzolana	32	truck	0	-
Gypsum	421	truck	0	-

2.3. Life Cycle Impact Assessment

Life cycle impact assessment (LCIA) methodology simplifies the input and output flowstraversing the system boundaries [16]

Greenhouse gases emissions estimated in this study are got from :

- Raw materials extraction ;
- Raw materials transport to the cement plant ;
- petcoke transport from South Africa to the factory ;

- petcoke combustion ;
- machinery training ;
- decarbonatation reaction ;
- indirect emissions related to the electricity generation and drinking water production.

Processes are developped with GEMIS in order to determine the greenhouse gases emission factor of one tonne of clinker. The clinker production steps are presented by the process« *Processing \ cement-clinker – Madagascar*» (Figure 2).

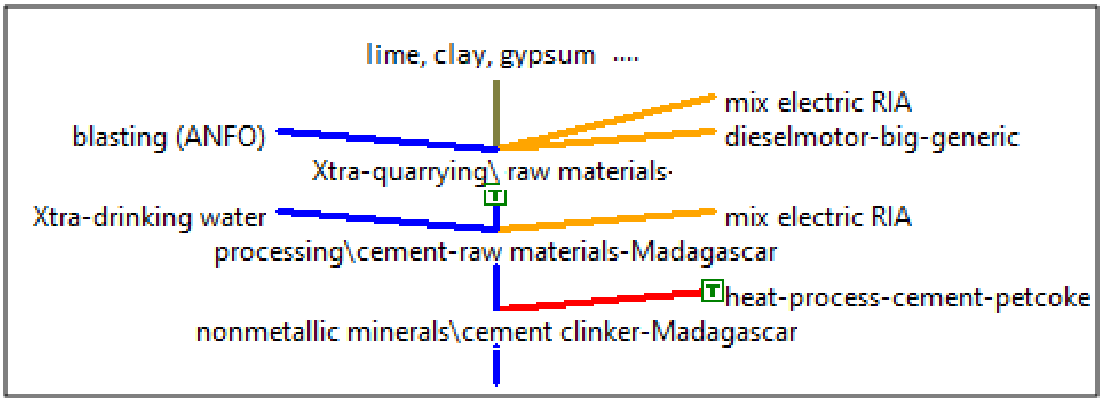

Figure 2 : Clinker production process

➢ **Raw materials extraction**

Raw materials extraction process is modeled by « *Xtra-quarrying\raw materials* » and is constituted by :

- « *blasting (ANFO)* » *:* blasting process ;

- « *mix electric RIA* » :mix electricity (from the Integrated Grid of Antananarivo) generation process which its GHGs emission factor is given by a previous study [13] ;

- « *dieselmotor-big-generic* »*:*process related to electricity production using power generation (for raw materials grinding) which GHGs emission factor is 0.3 kg CO_2eq/MJ,

- the transport of the raw materials to the cement plant is presented by T, corrresponding to the processus « *truck-big diesel rural generic* », with 0,2kg CO_2 eq/tkm as GHGs emission factor.

➢ **Burning**

Processes are developped with GEMIS :

- « Processing \ cement-raw materials – Madagascar », related to the different steps (burning excluded) of clinker production (crushing, grinding, homogeneisation, …).

- The emission results of the electricity (mix electricity of InterconnectedGrid of Antananarivo) and the water consumptions.

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- Other consumptions of lubrificant and other products used in machinery training are not considered.

- « heatprocess cement-petcoke » related to the burning. The decarbonation of limestone and combustion of the petcoke are considered.

➢ **Petcoke transport**

Petcoke transport process is presented by T (before « *heatprocesscement-petcoke* »). This process is modeled with GEMIS by adopting the « mix transport » process and takes account the transport distances shown in the table 2. This process is composed of :

- « shipocean », process related to the sea transport with a GEF equal to 0.0018kg CO2eq/t.km and

- « truck-big diesel rural generic », process related to the road transport with e GEF equal to 0.211kg CO_2eq/tkm.

-

➢ **Other production steps and packaging**

The greenhouse gases emission during the packaging and other steps (grinding, packaging, …) is given by the emission associated to the processes :

- «*Xtra*-drinking water" :production of the wate rconsumed during the cement production;

- « mixelectric RIA » generation of the mix electricity (IGA : Interconnected Grid of Antananarivo) consumed during the cement production.

3. Résults and discussion

The greenhouse gases emission factor is given first per ton of clinker and then per ton of CEM II/B-P 22,5 and CEM II/A-P 32,5 UT PM. One ton of clinker is associated to 1.29 t CO_2 eq. The extraction of one ton of raw materials is associated to a GEF equal to 6.6kg CO_2eq and 27.93 kg CO_2eq per ton of raw materials are emitted exclusively during the production steps (burning excluded). Per ton of cement, the following GFE are obtained:

- 0.877 t CO_2eq/ t for the CEM II/B-P 22.5 and
- 1.122t CO_2eq/ t for the CEM II/A – P 32.5 UT-PM.

The emission factors are presented by the figure 3. These are proportional to the clinker contents of the cements.

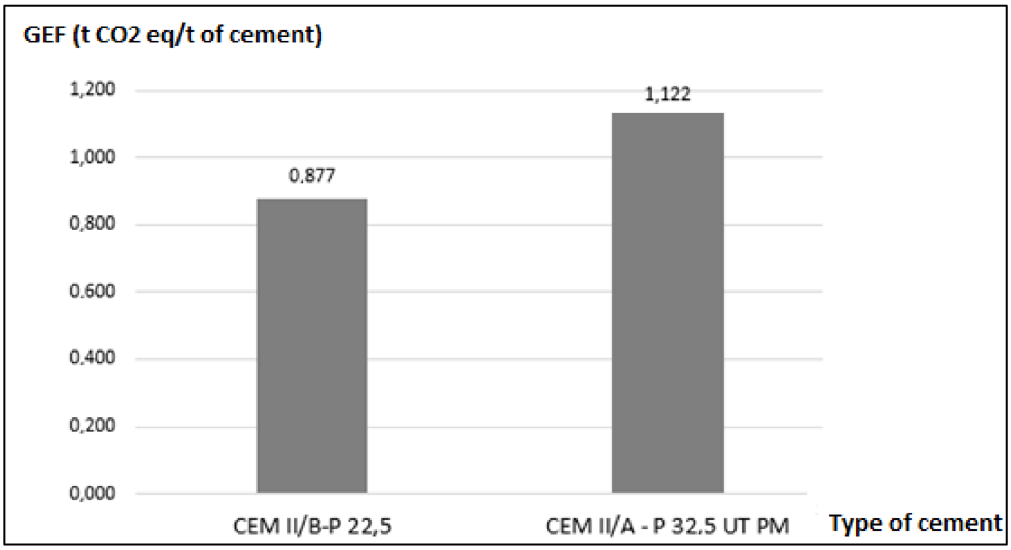

Figure 3 : GHGsemissionfactors of the cementproduced in Madagascar

In 2018, in France, 0.663 t CO_2 is emitted per ton of cement containing 76% of clinker. According to the Life Cycle Inventory of the « Association Technique de l'Industrie des Liants Hydrauliques », the emission factor of Portland cements (CEM II) is 0.74tCO_2eq/ton however the additive components (blast furnace slag or ash) [8].

An Algerian study [32] indicates that one ton of clinker is associated to 0.97t of carbon dioxide by using electricity (for steps excluding burning) and natural gas for the burning. The factor emission evaluated in our study is 25% higher than the GEF of the cement produced in Algeria. The principal cause is that the clinker is burned with petcoke in Madagascar and this solid fuel has a high content in carbon, over 90% and the GEF of this fuel is 107kg CO_2eq/GJ [24]. About the electric energy, the mix electricity of the Interconnected Grid of Antananarivo (IGA) is composed of hydroelectricity (70.26%), solar (1.19%) and heat source (28.54%). For this last, petrolium products (diesel) are used for electricity generation. The mix electricity of the IGA is associated to 0.52 kg CO_2eq/kWh [13]. Furthermore, the cement produced in Madagascar have a high clinker content ranging from 65% à 94%. To improve the cement carbon footprint in Madagascar and to reduce CO_2 emissions in the cement industry, there are several options, use of renewable energy and alternative raw materials/fuels, replacing some part of the clinker with supplementary cementitious materials (SCMs), implementation of carbon capture, utilization and storage (CCUS), and developpment of alternative low-carbon binders [2].

Conclusion

Reducing the greenhouse gas emission is a challenge for the cement industry to face climate change. For this, having informations about actual emissions is essential and a suitable tool is necessary. Our study is focused on the study of a cement industry in Madagascar producing two types of cement:CEM II/B-P 22.5 and CEM II/A-P 32.5 UT-PM which clinker content is ranging from 65% à 94%. All raw materials are extracted locally. Clinker burning is ensured by petcoke, an imported solid fuel. The electric energy is supplied by the Interconnected Grid of Antananarivo. To evaluate the greenhouse gas emission factors of the cement, Life Cycle Assessment methodology is adopted. One ton of clinker is associated to 1.29 tons CO_2eq so0.877 t CO_2 eq/ t of CEM II/B-P 22,5 and 1.122 t CO_2eq/ t of CEM II/A – P 32,5 UT-PM are obtained. We are faced with an environmental emergency, so it is unavoidable to conciliate cement sector and environment. Solutions such as replacing some part of the clinker with supplementary cementitious materials, using renewable energy and implementation carbon capture are possibilities to reduce greenhouse gas emission

The originality of this study lies on the results which can provide a baseline for GHGS emission factors of the cement produced in Madagascar. The study is important in environmental impact assessment of concrete and cement based-materials in Madagascar.

References

[1] Hashim, R. ; Khan, M.A. ; Kadhum and M. ; Abdulhadi, B. Development of green cement mortar using industrial by-product. IOP Conf. SER. Earth Environ.Sci, 2022, 1088 012001.

[2] Tkachenko, N. ; Tang, K. ; McCarten, M. *et al.* Global database of cement production assets and upstream suppliers. *Sci Data* **10**, 696. https://doi.org/10.1038/s41597-023-02599-w

[3] Nie, S. ; Zhou J. *et al.* Analysis of theoretical carbon dioxide emissions from cement production: methodology and application. J Clean Prod. 2022, Vol 334, 130270

[4] Miller, S. A. ; Habert G. ; Myers, R. J. and John T. Harvey Perspective Achieving net zero greenhouse gas emissions in the cement industry via value chain mitigation strategies. One earth, 2021, Vol 4, Issue 10, pp 1398-1411.

[5] IEA, Global Energy review, 2021. Retrieved from https://www.iea;org/reports/global-energy-review-co2-emissions-in-2021-2.

[6] Cook G. Cimate change and the cement Industry. Assessing emissions and policy responses to carbon prices. Climate strategies. 2009.

[7] Siddik, M.A. ; Islam, M.T. ; Zaman, A.K.M.M. and Hasan, M.M. Current status and correlation of fossil fuels consumption and greenhouse gas emissions. International Journal of Energy, Environment, and Economics, 2021,28(2): 103-119.

[8] ATILH. ACV des constructions et ICV des ciments, 2017, DÉCRYPTAGE N°6.

[9] Randrianarison, M.P., Randrianandrasana, N. ; Tsioritiana, A. ; Raheliarilalao, B. Etude comparative des facteurs d'émission en gaz à effet de serre des produits de terre cuite artisanaux et semi-industriels. International Journal of Progressive Sciences and Technologies, 2020, Vol. 24, Issue. 1, pp. 76-86.

[10] Randrianarison, M.P. ; Randrianandrasana, N. ; Raheliarilalao, B. Flux des émissions aériennes et de gaz à effet de serre du charbon de bois par la méthode d'Analyse de Cycle de Vie. International Journal of Progressive Sciences and Technologies, 2021, Vol. 25, Iss. 1, pp. 24-37.

[11] Randrianarison, M.P. ; Razafiarivony, N.A.T. ; Randrianandrasana, N. ; Raheliarilalao, B. Potentiels d'acidification et de réchauffement climatique des Bois-Energie à Madagascar.International Journal of Progressive Sciences and Technologies, 2020, Vol. 27, Issue. 1, pp.361-370.

[12] Randrianarison, M.P. ; Randrianandrasana, N. ; Razafiarivony, N.A.T. ; Tsioritiana, A. ; Raheliarilalao, B. Emission de gaz à effet de serre du matériau bois utilisé dans la construction par Analyse de Cycle de Vie. International Journal of Progressive Sciences and Technologies, 2021, Vol. 26, Issue 2, pp. 696-711.

[13] Randrianarison, M.P. ; Randrianandrasana, N. ; Razafiarivony, N.A.T. ; Raheliarilalao, B. Greenhouse gases emission factors of mix electricity generation in Madagascar. J. Mater.Environ. Sci., 2022, 13 (12), pp 1393-1403.

[14] Guinée, J. Life Cycle Assessment : An Operational guide to the ISO standards. Ministry of Housing, Spatial and Planning and Environment (VROM) and Center of Environmental Science (CML),Den Haag and Leiden, Pays-Bas, 2001, 704Pp.

[15] Cheung, W. M. (2022) A Cradle-to-Deposition Life Cycle Assessment of Emerging Photovoltaic Materials. International Journal of Energy, Environment and Economics, 2022, 28 (2). pp. 69-86.

[16] Marwa M. ; Soumaya A. ; Haijaji N. ; Jeday M. R. An environmental Life Cycle Assessment of an indusrial system : case study of industrial sulfuric acid. International Journal of Energy, Environment and Economics, 2020, 25 (4). pp. 255-268

[17] Sandén, B.A. ; Hillman,K.M. ; Karlström, M. ; Tillman, A-M.. LCA of emerging technologies : a methodological framework . Conference LCM 2005-Innovation by Life Cycle Management, 2005.

[18] Management environnemental - Analyse de Cyclede Vie - Principes et cadre. International. Organisation for Standardisation (ISO 14040), Genève, Suisse, 1997.

[19] Management environnemental – Analyse de Cyclede Vie- Définition de l'objectif et du champ d'étude et analyse de l'inventaire. International Organisation for Standardisation (ISO 14041), Genève, Suisse, 1998.

[20] Management environnemental – Analyse de Cyclede Vie-Évaluation d'impact du cycle de vie. International Organisation for Standardisation (ISO 14042), Genève, Suisse, 1998.

[21] Management environnemental – Analyse de Cyclede Vie– Interprétation. International Organisation for Standardisation (ISO 14043), Genève, Suisse, 2000.

[22] Management environnemental- Analyse du cycle de vie- Exigences et lignes directrices. International Organisation for Standardisation (ISO 14044), Genève, Suisse, 2006.

[23] IPTS. Energy consumption and CO_2 emissions from the world cement industry. Institute for prospective, Technological studies, 2003.

[24] ADEME. Calcul des facteurs d'émissions et sources bibliographiques utilisées. Chapitre 2 – Facteurs associés à la consommation directe d'énergie. Guide des facteurs d'émissions. Version 6.1. 2010.

[25] IEPF. Le diagnostic énergétique d'une cimenterie. Fiche technique PRISME n°1, 2001. https://pierrealainmilllet.fr

[26] Hamidi, M. ;Kacimi, L. ; Clastres P. Environmental and energy assessment of Andesite in cement. MATEC Web of Conferences 149,02048, 2018. https://doi/10.1051/matecconnf/2018490248

[27] CAR/PP. Manuel de prévention de la pollution dans le secteur du ciment. 2008. http://ww.cprac.org

[28] Bertolini, G. Les contours de la concurrence entre cimenterie et incinération spécialisée de déchet en Europe, Environnement, Ingénierie et Développement.,2008, N° 49, pp 8-13. 10.4267/dechets-sciences-techniques.1415. hal-03174403 OEE Office of Energy Efficiency. Energy Consumption benchmark Guide : cement clinker, Production. 2021. http://oee.nrcan.gc.ca/infosource.

[29] OEE Office of Energy Efficiency. Energy Consumption benchmark Guide : cement clinker, Production. 2021. http://oee.nrcan.gc.ca/infosource.

[30] Alsalman, A. Energy and CO2 emission assessments of alkali-activated concrete and Ordinary Portland Cement concrete: A comparative analysis of different grades of concrete. Cleaner Environmental Systems,2021, 3, 100047, pp1-1.

[31] JURA CEMENT. Durabilité dans la production. 2021. https://www.juramaterials.ch/fr/durabilite-production/energie;html

[32] Bouhidel,M. Application d'Analyse du Cycle de Vie (ACV) pour un développement durable : cas des cimenteries algériennes. Mémoire de magister en hygiène et sécurité industrielle option : gestion des risques. Université El--Hadj lakhdar Batna, 2009, Algerie

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