LIFE CYCLE IMPACT ASSESSMENT OF RECYCLED CONCRETE AND COMPARISON BETWEEN THREE CONCRETE PRODUCTION SCENARIOS

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ABSTRACT

Recycled concrete is now used in many different applications and scientific studies have shown that they have performances similar to concretes which use natural gravel [1, 2]. With the aim to evaluate the environmental impacts of recycled concrete, a life cycle impact assessment (LCIA) has been performed and results compared with those of normal

This study is the result of a project involving the "Claie-aux-Moines (GCM)" gravel mining company and the Canton of Vaud to determine whether the impacts of transporting materials are significant for three different concrete production processes. Two relevant environmental indicators in building environment showed that the recycled concrete have relatively less impacts than normal concrete. This study also demonstrated that the material origin should be taken into account in the LCIA as transport distances have a non-negligible influence on the impacts. These findings suggest that recycled concrete could be an alternative solution to normal concrete as it contributes to reduce environmental impacts of buildings and preserve natural resources by reusing recycled gravel resources.

Keywords: Life cycle impact assessment, recycled, concrete, gravel, transport, construction

INTRODUCTION

The School of Business and Engineering Vaud (HEIG-VD) has been appointed by the Building, Inheritance and Logistics service from the Canton of Vaud and the Claie-aux-Moines gravel mine company (GCM) in Switzerland to perform a LCIA of a recycled concrete called ECOBETON®.

The development of recycled concrete is mainly due to scarcity of natural gravel as a result of political pressures (soil protection) and increase of urban development (construction areas and communication routes). Recycling concrete aggregates reduces the exploitation of raw materials and provides a very interesting secondary material for concrete production.

The GCM gravel site processes all types of gravel either for concrete production or for direct sales. In parallel, the gravel site is used to recover secondary materials to produce new primary material. The site is split into a gravel mine exploitation area and three production areas:

- Natural gravel process (gravel diameters between 4 and 32 mm, sand 0-4 mm and mud);
- Recycled material (bank gravel directly from the mine without sorting, recycled material such as concrete blocks or old tiles);
- Concrete production.

The GCM gravel mine has been producing ECOBETON® (classified and non-classified) for many years. The classified ECOBETON® is according to the EN 206-1:200 standard and according to the SIA MB 2030 technical book. At the time of this study, there was no recycled concrete dataset available in the international Ecoinvent database v2.2 [3].

There are different types of recycled concrete on the market. In order to evaluate the environmental impacts of their product, GCM decided to conduct a LCIA based on their own production process. For comparison purposes, a LCIA of their normal concrete was also performed.

The objectives of this study are:

- Evaluation of the environmental impacts of recycled concrete produced at GCM and comparison against GCM normal concrete production.
- Comparison of results between three different scenarios with normal and recycled concrete which are transported on construction site and normal concrete which are produced directly on the construction site.

METHODS AND MATERIALS

The methodology applied in this study is compliant with ISO 14'040 and 14'044 standards. All basic data concerning materials and processes to be analysed were obtained directly at the GCM company [4]. This includes raw materials, operating area (gravel mine area, construction area, etc.), type and distance of transport (train, lorry, etc.), type and amount of energy used, co-products, infrastructure and machine used, disposal of waste from process and emissions. The environmental datasets were taken from the Ecoinvent database version 2.2.

System limits

Figure 1 shows the system limits of the concrete production. The required inventory data have been collected at GCM through a variety of sources [5]. To be granted the exploration permit, GCM has prepared an environmental impacts report, which provides the basic data for the LCIA. The lifespan of the gravel site is evaluated at 20 years. By producing secondary materials, the number of years for exploitation can be extended. GCM also holds an annual inventory on which this study is based. Finally, all technical equipment and vehicles have user manuals which give the basic information needed for the study.

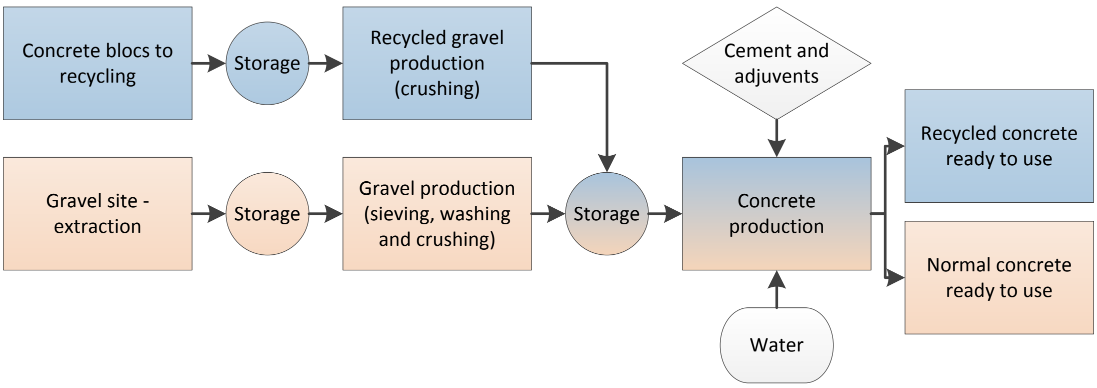

Figure 1 : System limits from the recycled and normal concrete production at GCM

Relevant building environmental indicators

Different indicators can be used to evaluate environmental impacts of a product. In this project, two indicators have been chosen because they are relevant for building materials:

- Cumulative energy demand – total (CED) – accounting for renewable and non-renewable primary energy expressed in MJ-eq.
- Global warming potential (GWP) – accounting for greenhouse gas emissions expressed in kg CO_2-eq.

RECYCLED AND NORMAL CONCRETE – THEORY, CALCULATION AND RESULTS

Gravel site

As the GCM Company wants to have their own datasets, the gravel site has been revaluated in comparison to the Ecoinvent dataset. The same methodology is taken into account, but as the function is different (producing recycled materials) and the site smaller, a new dataset has been created. . It includes buildings, vehicles, technical installations and different areas types (building, ways, vegetation, etc). The gravel site extraction area is not taken into account, in accordance to the Ecoinvent dataset.

The total production of natural gravel during the gravel site lifespan is estimated at 1’560’000 m^3, including bank gravel, round gravel, crushed gravel, sand and mud. The total mass produced is 2’964’000 tons (density of the natural gravel equal 1.9 tons/m^3). Nearly 20% of the bank gravel goes directly to the recycled storage area. The remaining is used to produce:

- Round and crushed gravel (59%),
- Sand (33%),
- Mud (8%) which are « recycled » in the system limits.

For all recycled materials, the total amount corresponds to 1’622’026 tons (density: 1.7 tons/m^3) for 20 years, based on the average results of the annual inventory. The part of recycled gravel we are interested in is the B4-32 with about 96’675 tons for 20 years. The GCM site produces about 8’000 m^3 of recycled concrete each year.

The total weight of the GCM gravel production is about 4’586’026 tons. An allocation (*Table **1***) presents the gravel production that will be used to manufacture the two types of concrete (normal and recycled).

	Mass of material [tons]	Distribution ratio [%]
Natural gravel (natural and recycled concrete) - round and crushed gravel and sand	2'377'128	52
Recycled material + bank gravel (for recycled concrete)	2'208'698	48
Total amount of material	4’586’026	100

Table 1 : Distribution of the gravel production between the two groups of products

However, all the inputs data are not on the same allocation rates as in *Table **1***. Some storage areas and machinery are use completely for the natural gravel production.

Gravel round and crushed process

The dataset for production of round and crushed gravel contains the following inputs: resources, gravel mine, infrastructures, exploitation vehicles, installations, energy vectors for process operation, replacement equipment, gravel mining area, storage area and rehabilitation of land. The outputs are the co-products, emissions to air and solid and liquid wastes. In this study, the Ecoinvent dataset “gravel/sand, at mine” was modified so that the inputs and outputs correspond to the GCM ones. All inputs/outputs are calculated for 1 kg of natural gravel. The main co-products are round and crushed gravel and sand.

Gravel recycled

For this material a new dataset has been created with the following inputs: resources, exploitation vehicles, energy vectors for process operation, equipment replacement and storage area. The outputs are the co-products, emissions to air and liquid wastes. The co-products are recycled gravel (53.6%), recycled sand (43.9%) and steel (2.5%).

The recycled blocks used as secondary materials are considered as resources. The impacts of their transportation from their site of origin (demolished building) to the storage unit are taken into account in the new dataset.

Normal concrete and recycled concrete

The resources inputs used to produce these two types of concrete are different. The rest of the system limits is identical. The real GCM production has been taken into account because the process differs from the one of "normal concrete" in the Ecoinvent dataset. The inputs for 1 m^3 of concrete are: resources, infrastructures, installations, energy vectors for process operation, equipment replacement, storage area and transports. The outputs are heat to the air, rubber waste and sewage.

Data results

The impacts of the GCM products are showed in *Figure 2*.The Ecoinvent v2.2 dataset for the normal concrete is also given for comparison purposes.

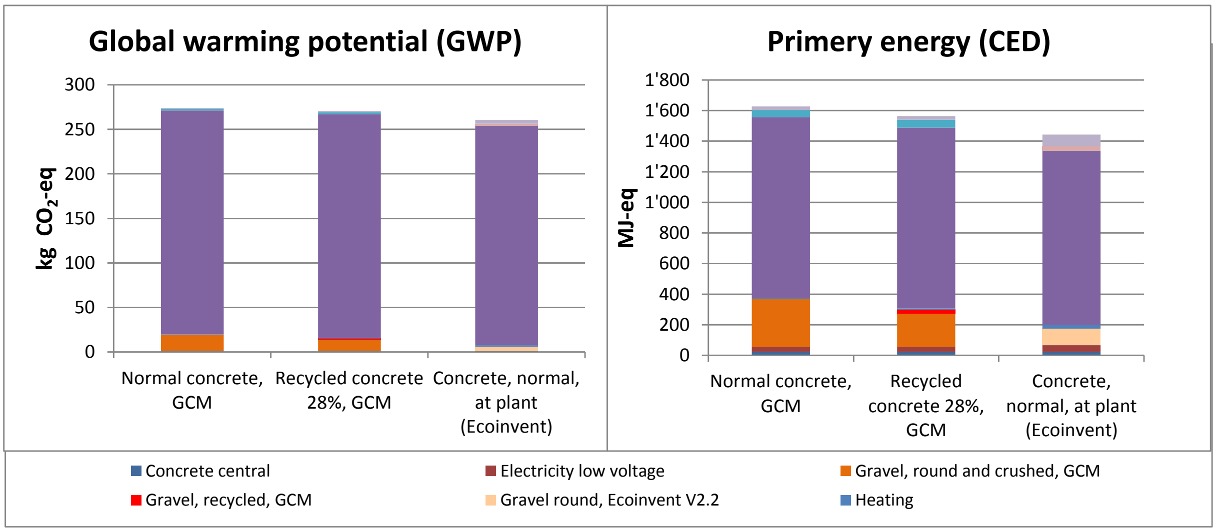

Figure 2 : Impacts for 1 m3 of concrete for the 2 indicators.

It can be seen that recycled concrete has slightly lower impacts than normal concrete with differences of about 2% for GWP and 4.0% for CED. Given that the amount of cement is the same for both concrete types, these differences are due to the recycle gravel that presents three times lower impacts than normal gravel, round and crushed, which is promising. However, differences remain small as impacts from the cement content in the concrete dominate, about 75% for CED and 92% for GWP.

For both indicators, the results from the GCM datasets are close to those of Ecoinvent. The slightly higher impacts are probably due to the higher level of detail of the GCM datasets in comparison to those of Ecoinvent. Ecoinvent only uses round gravel as primary material, which has lower impacts when compared to crushed gravel. Despite the fact of requiring more transport, no additives are taken into account.

COMPARISON BETWEEN THREE CONCRETE PRODUCTION SCENARIOS – THEORY, CALCULATION AND RESULTS

To put the new datasets into real cases, three scenarios are used to evaluate the effect of the transport:

- Reference scenario: production of recycled concrete, ECOBETON®, at the GCM site and transport to the construction site
- Scenario 1: production of normal concrete at the GCM site and transport to the construction site
- Scenario 2: production of normal concrete at the construction site. All primary materials and the concrete central installation are transported to the construction site.

Methodology

The functional unit of the system is to have "7 m^3 of concrete ready to use on the construction site". The system limits go from the extraction of raw material to the transport of the concrete ready to use on the construction site. The function of each concrete is the same. Concrete is a material with technical features and his implementation is limited in time. The radius of action after manufacturing is at most 25 km.

A reference construction site has been taken 10 km away from the GCM. To perform a sensitivity analysis, four other construction sites have been chosen with distances of 5, 15, 20 and 25 km to the GCM site. For the first two scenarios, the concrete is transported to the construction site by lorry. For scenario 2, all products come from the following production companies: concrete central (Yverdon-les-Bains), cement (Éclepens), additives (Düdingen), gravel (Bretonnière-Switzerland and Pontarlier-France).

Results and discussion

Figure 3 shows the results for the construction site situated 10 km away from GCM. To provide a better comparison between scenarios, all material transportation has been gathered together.

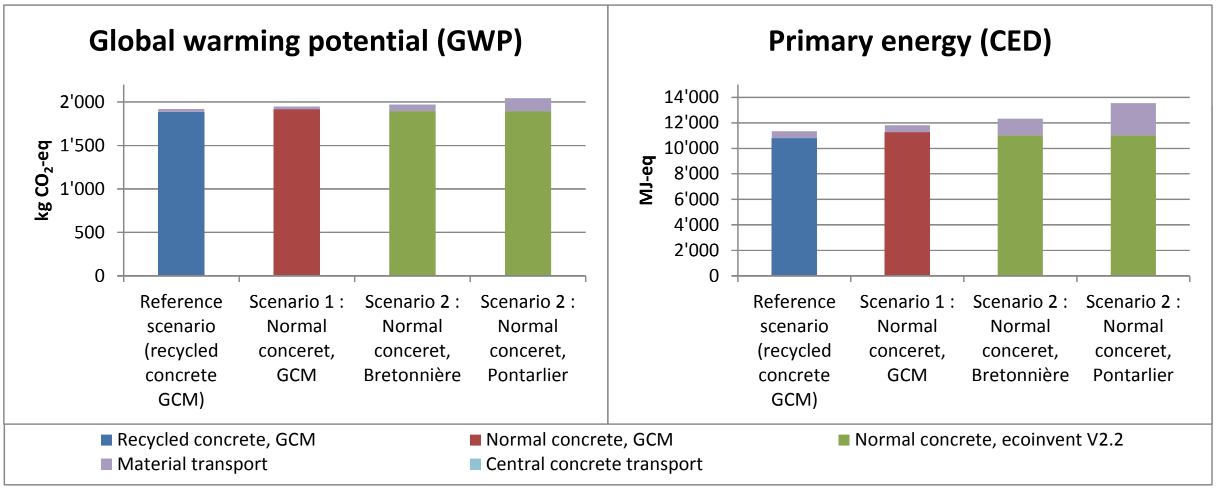

Figure 3 : Impacts for 7 m^3 of concrete ready to use on construction site 10 km away from GCM.

For both indicators, recycle concrete performs better than any other scenario. The same results appear for the other construction site distances (5, 0, 15, 20 and 25 km). The worst case is scenario 2, where the heavy transport of gravel leads to higher transport impacts. Differences between scenarios are less marked for GWP.

The difference with the reference scenario goes from 2.8% and 10.6% more impacts. The difference is mainly due to the transport of the gravel. The latter is heavy to transport and raises the impacts. When taking a construction site between the GCM site and Bretonnière, the difference gets really smaller and at one point the advantage goes to the Bretonnière scenario, unfortunately too far for GCM (more than 25 km). The second scenario with gravel from Pontarlier remains the worst of all.

For the GWP indicator, the differences between the scenarios are less marked, but the reference one stays the best. The results for the reference scenario and the scenario 2 (Bretonnière) give between 0.8% to 7.5% less impacts, depending on the distance of the construction site.

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