Life cycle assessment of the use of recycled aggregates in the production of concrete

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Abstract - The construction industry is one of the main responsible for the economic and social development of all countries but it presents serious environmental problems by consuming large amounts of natural resources and generating a large volume of construction and demolition waste (CDW). A large percentage of the CDW is deposited illegally, which causes problems for human health and the environment; therefore its correct management is very important.

To overcome the problems above, this study aims at analyzing the impacts of recycling aggregates used in the production of concrete. To do this, it proceeds with the analysis of the life cycle of the building materials under study, describing their production and the production of concrete aggregates and quantifying all its environmental impacts, based on the environmental production declaration of concrete.

Three scenarios are analyzed in order to compare the impacts of the use of natural and recycled aggregates in concrete, resorting to the help of software SimaPro that calculates the global environmental impact of all phases under study in each scenario, and with the help of data provided by the companies Unibetão and Ambisider.

Based on the analysis performed in this study, it is found that recycled aggregates have great environmental advantages over natural aggregates during the life cycle of concrete.

Keywords - Environmental impacts, CDW, ready-mixed concrete, recycled aggregates, SimaPro.

I. Introduction

The construction industry is one of the largest and most active sectors in Europe and is responsible for economic and social development of the countries. On the other hand, this industry has been seen as the most polluting sector because it causes big environmental impacts, using large amounts of natural resources such as energy, water, soil, materials, and also producing large amounts of waste which are not recycled and controlled. The research presented is going to improve the problems stated by promoting waste recycling and its legal disposal [1].

The largest amount of solid waste is generated by the construction industry with about 100 million tons per year of construction and demolition waste (CDW). In most cases, this type of waste is incorrectly managed through illegal deposits causing environmental degradation. Therefore, the proper management of most CDW is very important for sustainable development [2].

In order to achieve sustainability in the construction, the minimization of the natural resources consumption is the main factor. The incorporation of waste that the industry produces in the construction materials becomes more efficient to achieve this factor. CDW has a high recovery potential, and 80% of waste can be recycled, but it is essential to ensure its proper management. Thus, the use of recycled aggregate in concrete has been studied over the past years, proving a great economic advantage of CDW.

Day by day the use of this type of aggregates in concrete production is increasing, having a contribution to the reduction of environmental impacts at all stages of their life cycle. The life cycle is a sequence of phases related to a product, a process, a service or a company. The life cycle of a product or service is understood as: the physical life cycle, the production phases and the marketing process since the raw material in the environment until the final disposal of the waste materials going through transportation, storage, processing, maintenance and other intermediate stages [3].

A life cycle analysis (LCA) is an environmental management tool that applies to a specific product or service or a set of products and services for a certain company. LCA is used to identify the environmental aspects at the product level to determine key areas of environmental improvements with a view to the new product [3].

The used concept in this study is cradle to cradle with the introduction of recycled aggregates in concrete. Initially, natural resources are taken from the environment and it ends when the concrete is recycled and reused, assuring that its quality is equal or lower to that of the natural aggregates.

II. CDW and Management

With the evolution of civil construction, the production of CDW increased and, consequently, its management has become more difficult. The used construction techniques and materials are directly related to the nature of this waste and one of its main sources is the demolition of buildings at the end of their life [4].

CDW contributes significantly to worsen the environmental problems, especially regarding their transport and deposition. The increasing amount of waste is one of the main problems that the developed societies faced in recent decades. One of the solutions found for most of the waste is having a second life. If the waste is properly treated, it can represent an added value both in economic and environmental terms.

The recycling of CDW allows reducing the amount of CDW landfilled and the extraction of natural aggregates and their environmental impacts. As seen in Figure 1, once the production of the concrete is completed, the construction of buildings or infrastructure can proceed. When its lifetime finishes, the waste appears comes from demolition, which is recycled subsequently so that it can be reused in the manufacture of new materials [5].

Figure 1 - Life Cycle of CDW [5].

In terms of scale, internationally, the generation of CDW represents about 70 million tons in the UK and 14 million tons of waste is landfilled every year in Australia and 44% of this waste is attributed to the construction sector. In Japan around 35 million tons of demolished concrete are generated each year [6].

The demolition of buildings can be done through traditional or selective demolition. The traditional demolition is the destruction of the whole building, applying preferably an efficient method, such as explosives. This method has the advantage of being fast and cheap, because large equipment is used and there is less manpower. On the other hand, it has the disadvantage of producing mixed CDW from which it is virtually impossible to efficiently separate the recyclable packaging and hazardous components.

The selective demolition is carried out through careful dismantling of the building allowing the recovery of construction materials and providing a possible reuse and recycling. The high recovery rate of reusable and recyclable materials is the great advantage of this process, such as the production of CDW that can be converted into secondary material. However, this process is more expensive than the traditional demolition, because it consumes more time, requires well organized and controlled procedures and a greater variety of technical equipment [7].

Management of CDW in Europe and Portugal

In Europe, there are large differences between countries regarding the management of CDW; some countries have been recycling CDW as an established practice over the years, while in other countries this practice is practically nil, showing very low recycling rates.

The management of CDW includes all operations aimed at its prevention and reuse, as well as its collection, transport, storage, sorting, treatment, recovery and disposal. The recycling rates in some European countries are shown in Table 1. CDW represents 1/3 of the waste generated in Europe, with the average rate of recycling 47%. In Denmark, the waste recycling rate is about 90%, by virtue of deposition rates and extraction of non-renewable resources [8].

In Portugal, CDW has been neglected over the past few years, so there is no real data concerning the quantity of waste generated. The existing data refer only to the estimates, based on different assumptions, which indicate a variety of results.

Table 1 - Recycling rates in some European countries [8].

European countries	Recycling rates
Denmark, Estonia, Germany, Ireland and Netherland	> 90%
Austria, Belgium, France, United Kingdom and Lithuania	60%-70%
Latvia, Luxembourg and Slovenia	40%-60%
Portugal, Spain, Greece, Poland, Finland, Hungary, Cyprus and Czech Republic	< 40%
European Average	47%

Of all the waste, CDW in Portugal is the one which has been having less attention from authorities and public opinion, due to the physical, chemical and biological interaction with the environment. As a consequence, this situation leads to an almost unnoticed deposition. Considering its high volume, when waste is put into landfills, its lifespan decreases, therefore it is necessary to find other solutions with regard to landfill, in order to discourage illegal dumping.

According to a study of Coelho [9] about the management of CDW in Portugal, taking into account the type of materials, the waste composition is mostly concrete, brick and masonry (73.6%). The data regarding the composition of waste in Portugal by percentage are presented in Table 2.

Table 2 - CDW composition in Portugal [9].

CDW composition	
Concrete, brick, masonry	73,6%
Plastics	0,1%
Asphalt, bituminous	13,5%
Wood	3,2%
Metals	2,2%
Other wastes	7,4%

III. Production process of concrete

The concrete is a material composed of cement (commonly Portland cement), water, aggregates and chemical admixtures. It is the most widely used construction material in the world by humanity, since its annual production is 7.5 cubic kilometers which is more than one cubic meter for every person on Earth. Approximately 40% of this annual production of concrete is consumed by China [10].

The life cycle of concrete involves the production and transportation of raw materials, long-term management of operations and restoration of local mineral extraction, production and transportation of ready-mixed concrete and precast concrete products, construction process of concrete buildings and other structures, operational performance of buildings and concrete structures during use and demolition of concrete at the end of the life of buildings and structures [11].

Cement is responsible for around 85% of total CO_2 emissions resulting from the production of concrete, and 5% of total emissions are sent into the atmosphere. The aggregates have a relatively small contribution in the total CO_2 emissions of about 15%, and these are mainly due to the required energy for its production [12].

The aggregates occupy about 70% of the volume of concrete which may be composed of natural and recycled aggregates. The natural aggregates are particles extracted from natural deposits, such as quarries or sandpits. The recycled aggregates are the result of the reprocessing of materials from mines or quarries as well as the waste from constructions, renovations and demolitions of structures [13].

The concrete production starts with the cement that is obtained based on heating limestone to 1450 °C with clay. The action of the temperature causes chemical reactions on the cement components producing the clinker (5 to 25 mm nodules diameter) from a material synthesized by heating at high temperatures. The final operation consists in grinding of clinker in very small particle size and with dehydration of natural mineral calcium sulfate is obtained, forming a very hard and tough mass, yielding Portland cement [14].

The mixing operation occurs in a concrete mixer. The aggregates are pre-mixed or added under normal operating conditions. The mixing involves the rotation and stirring of components in order to cover the surface of the aggregates with the cement paste and mixing uniformly the other ingredients. Then, the concrete is transported to the place where it will endure the remaining operations. The most used method of transport is pumping, although there are other methods.

The placing of the concrete has three fundamental operations: the surface preparation to receive the concrete, the launch of the means of transport to the location where it will be applied, and the way it should be deposited. Casting must be done so that the segregation of the concrete components is avoided and compaction can be achieved by removing the greatest possible number of air bubbles [15]. After casting, concrete must be spread within a mould before curing. Once casting is done, concrete must be cured to prevent fast drying. While the paste solidifies, cement reacts with water to form a connection, leading to a hardened mass. The aim of the cure is to keep the concrete saturated until the originally water-filled space in the fresh cement paste is filled as desired by the hydration products of cement [16].

IV. Procurement of the aggregates

Concrete aggregates have four main phases: exploration, extraction, processing, and transportation.

The first step in the exploration of the aggregates is the site selection of the exploration. Once the selection is made, the mining of aggregates begins. This process starts with the removal of soil layers to expose the sand, gravel or stone, where the removed organic soil is separated from the rest of the material removed. The aggregated mining methods depend on the material to be excavated, the natural conditions and the desired end product [17].

Sand and gravel are extracted from opencast mines and dredged from underwater deposits.

The extraction of gravel differs from the extraction of sand and gravel, because in most situations the base should be drilled and flared. The holes are drilled into the rock and partially filled with explosives. A total blast lasts only a split second and consists of short bursts separated by thousands of seconds, breaking the rocks into pieces [18].

After the transportation of the aggregates to the plants, the process consists on the phases of crushing, grinding, washing, storage, and supply. Typically, trucks or conveyor belts move the material to a primary crusher. The material is then crushed and moved through a conveyor belt to a secondary crusher, passing through a vibrating screen, where the material is sorted by sizes. Once the separation is done, the product that is within the required standards will be transported to the warehouse of the final product. The oversized material is returned to the process of crushing. Depending on the type of processed material and the final product, the material can be washed. After screening, classification by size, and washing (if necessary), the conveyors belts transport the material to deposits and, after its sale, the product is loaded into trucks to its final destination [17].

Finally, the aggregates are transported. About 93% of them are transported by trucks, because they can be loaded quickly at the points of origin and may deliver their loads easily at its destination, besides they are able to carry about 25 tons and they have efficient delivery costs [17].

Mobile and fixed recycling plants

The recycling plants may be fixed or mobile and, as the name implies, they are central processes where the recycling of the CDW is done. The plant location is a very important aspect for the success of recycling and should be as close as possible to the production and use of CDW.

The fixed recycling plants are always in the same location (stationary), and the material needs to be transported whenever it is processed. These plants occupy a large area because they are composed of several stationary installations. Some installations occupy only the separation phase of the material flows which will be recycled later. These plants usually have several transport circuits, several screens, screening phases, and two or more crushers.

The mobile recycling plants are taken to the place where the CDW is produced having usually a single input power, a conveyor belt, a crusher, and one or two different screens. Since this type of plants is installed at the demolition site, there is no transport needed, which is a great advantage of the mobile plants [19].

The two recycling plants defined above contain several phases in order to obtain the final aggregate to be applied to the construction.

The advantages and disadvantages of mobile recycling plants in relation to fixed recycling centers are [20]:

Advantages:

• No need of large areas for deployment;

• Absence of costs and environmental impacts associated with the transport of the material processing;

• Lower costs;

• Reduced installation time.

Disadvantages:

• The fixed plants obtain recycled products more diverse and with better quality than those produced by mobile units;

• Possibility of using larger and more powerful equipment in the fixed plants that allows improving the milling process, the removal of impurities, and the screening.

V. Environmental impacts in the life cycle of concrete

The environmental impacts are changes in the environment or in some of its components for a particular action or activity. These changes in the environment can be large or small, positive or negative, needing to be quantified, since they have relative variations. With the study of environmental impacts, it is possible to evaluate the consequences of certain actions, predicting the quality of the environment [21].

The life cycle of concrete has impacts resulting from the consumption of natural resources (renewable and non-renewable), some of them are energetic, from emissions (global warming, acidification, oxidant formation and destruction of ozone) and from the release of pollutants with toxic substances (causing ecotoxicity and human toxicity) as seen in Table 3.

Table 3 - Recycling rates in some European countries.

Categories	Space scale
Global warming	Global
Acidification	Local / Continental
Eutrophication	Local / Continental
Photo oxidant formation	Local / Continental
Ozone depletion	Global
Ecotoxicity	Local / Regional / Continental / Global
Human toxicity	Continental / Global
Abiotic depletion	Global
Waste production	Local / Regional
Renewable energy	Local / Regional
Non-renewable energy	Local / Regional

Once the main impact categories of concrete life's cycle are defined, the main phases of concrete aggregates are defined taking into account their environmental impacts.

The main activities, regarding the use of natural aggregates, are the extraction and processing of aggregates at the quarry and the transportation to the place of use. The extraction comprises all phases that lead to obtain the primary aggregates (including separation and grinding in the quarry), which depend on the type of aggregate to extract, causing different environmental impacts which are geologic erosion, water, air and climate, landscape, vibration and noise. Natural aggregates processing occurs in the quarry and has main activities as separation and crushing. The main impacts of these activities are air and climate, landscape, flora and fauna, water, noise and vibration. Finally, the transportation of these aggregates, from the quarry to the place of use, is done by road, sea or rail that has air and climate, vibration, noise and visual impacts [22].

In terms of recycled aggregates, the main activities are transportation to the recycling plant (if a fixed plant is used), processing at the recycling plant, and transportation (product) to the place of use. The impacts of both transportation phases and the phase of processing in the recycling plant are equal to those in natural aggregates [22].

VI. Case study

In this phase, the use of SimaPro software was necessary in order to compare the natural and recycled aggregates which are used for the manufacture of ready-mixed concrete, and to do the global calculations of the environmental impacts. The collection of values for the two types of aggregates was provided by Unibetão (natural aggregates) and Ambisider (recycled aggregates) in order to perform the desired calculations and get the goals proposed in the dissertation.

SimaPro is a professional tool that allows the analysis of the environmental performance of products or services. This software provides easy modeling and analysis of complex life cycles in a systematic way based on the recommendations of the ISO 14040.

In this context, three scenarios were considered: the use of natural aggregates in the manufacture of concrete (scenario 1), the use of recycled aggregates in the manufacture of concrete using a recycling fixed plant (scenario 2), and the use of recycled aggregates in the manufacture of concrete using a recycling mobile plant (scenario 3).

Scenario 1: Natural aggregates

The life cycle of natural aggregates (Figure 2) has the following main stages:

extraction of raw materials, separation and crushing at the quarry, transportation of aggregates to the concrete plant, central processing of ready-mix concrete, and transportation to the place of use.

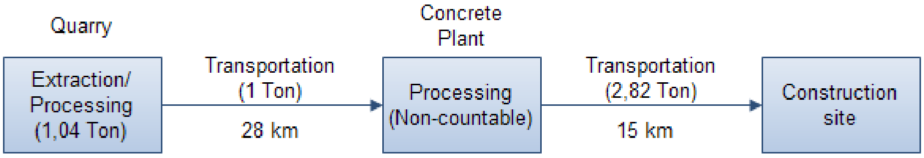

Figure 2 - Life Cycle of scenario 1.

Extraction and separation and crushing at the quarry

In the extraction phase, the raw material chosen was limestone because it is the most used aggregate in the district of Lisbon. This process includes the use of explosives to extract limestone and all the transports are carried out inside the mine. The capacity of the mine is considered approximately 380000 tonnes of limestone extracted per year, and all environmental impacts (air, soil and water emissions) caused by this stage were included in this process. During this phase, in order to calculate the impacts in SimaPro, the amount of diesel fuel consumption (17.77 MJ/ton extracted), electricity (1.29 kwh/ton extracted) and water (145 kg/tone extracted) is used as defined.

After the extraction of raw materials, the aggregates are transported to pass through the separation and crushing operations (processing). At this stage, it is assumed that, during the transportation of extracted limestone, there are losses (waste) in the order of 4%.

In terms of the impacts of this phase, the separation, crushing and transport of aggregates to the treadmill were considered. The equipment used are two crushers, two screens and two silos which have an estimated 25 years lifetime. All environmental impacts (air, soil and water emissions) caused during the processing phase were considered and calculated in SimaPro.

Transportation to the concrete plant

According to the data obtained from Unibetão, the distance from the quarry to the central concrete is 28 km. In this phase, the aggregates are transported by truck weighting between 16 and 32 tons that may carry between 9 and 23 tons, respectively. The truck lifetime is estimated as 540000 km.

The impacts of the truck, carrying 1 ton of aggregates during its journey, were calculated. This process includes the operation and maintenance of the vehicle, considering all environmental impacts (air, soil and water emissions) from the transport of natural aggregates.

Processing in the concrete plant

When the aggregates reach the concrete plant, they are mixed with the raw materials of concrete (cement, water, chemical additives), obtaining the concrete at the end. All impacts of the concrete processing phase are not counted in the calculation of the global impacts in SimaPro, because they are considered equal for the three scenarios.

Transport to the construction site

At the end of the processing phase, the concrete obtained is transported to the construction site. As the construction site varies, Unibetão provided an average distance from the concreting plant to the construction site of 15 km.

At this phase, the transportation of ready mixed concrete occurs and the amount of concrete needs to be converted to the functional unit (1 ton of recycled aggregates). Each cubic meter (2400 kg) of concrete contains around 850 kg of recycled aggregates. Based on this ratio, a ton of recycled aggregates (functional unit) corresponds to about 2.82 tons of concrete.

All impacts of 2.82 tons of concrete transportation are calculated over the 15 kilometers.

Scenario 2: Recycled aggregates using a fixed recycling plant

The life cycle of recycled aggregates using a fixed recycling central (Figure 3) has the following main stages: the selective demolition, the transportation of the non-inert aggregates to the reuse/recycling place or landfill and its impacts, the transport of the inert aggregates from the demolition site to the fixed recycling plant, the processing at the fixed recycling plant, the transportation and its impacts of the non-inert aggregates being sent to landfill, the transportation of the recycled aggregates (useful aggregates) to the concrete plant and the transportation to a new construction site to be performed.

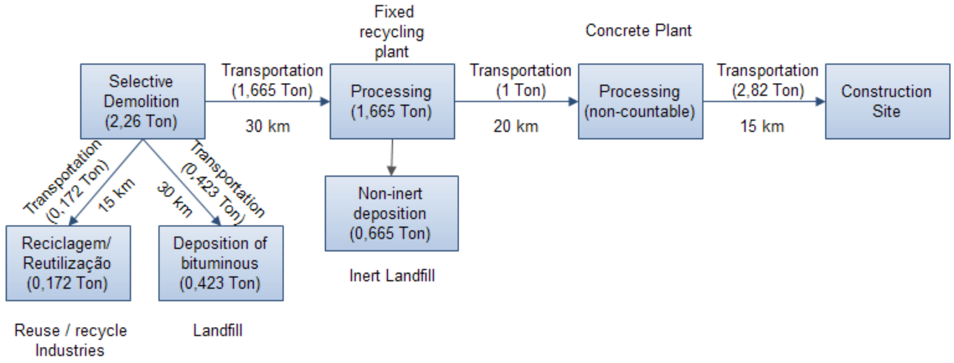

Figure 3 - Life Cycle of scenario 2.

Selective demolition

The first phase of the life cycle of recycled aggregates is selective demolition. The equipment and its consumption per ton of demolished aggregate used in this type of demolition are three tracked rotary machine equipped with bucket, hammer and scissor, which consume 0.13, 2.5 and 0.5 liters/ton, respectively. Since these three machines do not work at the same time during the demolition, an average consumption of the machine was assumed, resulting in a final value of 37.09 MJ per ton of extracted.

Based on the functional unit, one ton of recycled aggregates correspond to 2.26 tons of demolished aggregates; therefore, the environmental impacts of this phase are calculated taking into account these amounts of demolished aggregates and the avoided impacts. All of the impacts of using traditional demolition (2.26 tons demolished) and taking the waste to a landfill (2.26 tons transported and 2.26 tons staying in the landfill) are considered as avoided impacts.

Transportation of non-inert aggregates for the recycling/reuse place or landfill

Completed the selective demolition, the non-inert aggregates are transported to the recycling/reuse or to landfill (in case of not being reusable).

According to Coelho (2010), the non-inert CDW (23.6%) consist of 0.1% plastics, 2.2% metal, 3.2% wood, 13.5%, bituminous, and 7.4% other materials.

At this stage, plastics, metals and wood are transported for recycling/reuse 15 km away and all of the impacts of transportation and recycling/reuse were calculated. The bituminous do not suffer recycling/reuse, and are transported to the landfill where all its impacts are taken into account.

Transportation to the recycling plant

After the selective demolition, the inert aggregates are transported to a fixed recycling plant (location where they will be recycled). The distance of the transportation, according to Ambisider, is 30 km, and all impacts of its transportation are calculated.

Processing in the fixed recycling plant and the impacts of non-inert aggregates sent to landfill

The aggregates transported to the central processing passes through the following phases: screening, crushing and sieving, and they leave the plant already recycled. All of the impacts that occurred in the plant are calculated. The fuel required to recycle the aggregates to the plant is 23.46 MJ per ton of aggregates processed. In the plant, 40% of inert aggregates are not useful, and are sent to an inert landfill, whose impacts are taken into account.

Transportation to the concrete plant / construction site

The transportation of the already recycled aggregates to the concrete plant and subsequently to the construction site is equal to the transportation of these two phases in the first scenario. The difference to the first scenario is the distances provided by Ambisider for both phases. The distance to the fixed recycling plant is 20 km (transportation of one ton of recycled aggregates) and the distance from the concrete plant to the construction site is 15 km (transportation of 2.82 tons of concrete).

Scenario 3: Recycled aggregates using a mobile recycling plant

This scenario differs from scenario 2, because there is no transportation of the aggregates to the recycling plant, since it is mobile (moved to the demolition site). Most phases of scenario 3 (Figure 3) are equal to the phases of scenario 2. The differences from scenario 2 are the distances from the recycling plant to the landfill (30 km, transporting non-inert aggregates and not useful inert) and to the concreting plant (20 km, transporting inert aggregates), and the fact that the recycling plant is moved to the site of demolition.

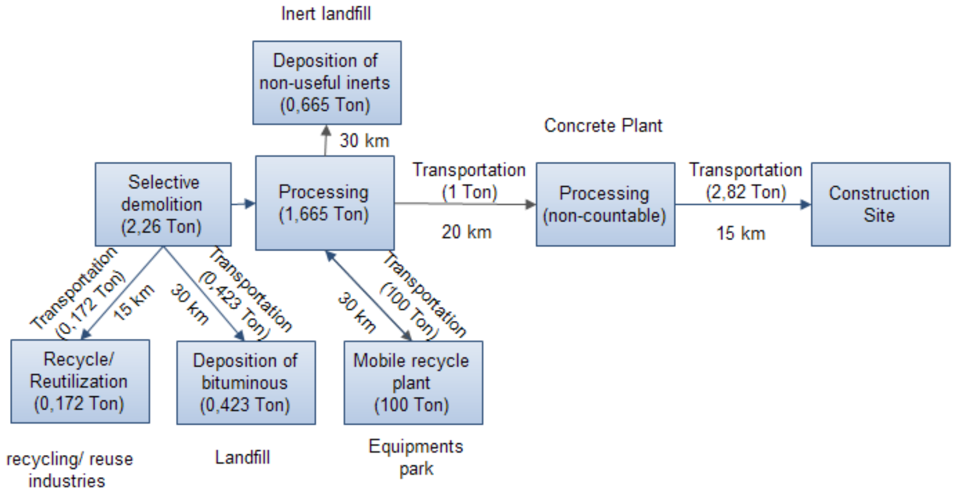

Figure 4 - Life Cycle of scenario 3.

VII. Results

The methods used in this study in order to obtain the results above were: Eco-indicator 99 (Table 4), CML Baseline (Table 5) and Cumulative Energy Demand (Table 6).

Impact category	Unity	Scenario 1	Scenario 2	Scenario 3
Total:	Pt	2,86	-18,5	-19
Carcinogens	Pt	0,043	-16,1	-16,1
Resp. organics	Pt	0,000949	-0,00149	-0,00167
Resp. inorganics	Pt	1,52	0,331	0,21
Climate change	Pt	0,103	-0,00918	-0,0372
Radiation	Pt	0,000785	-0,00134	-0,00159
Ozone layer	Pt	7,24E-5	-5,55E-5	-7,75E-5
Ecotoxicity	Pt	0,0246	-0,56	-0,568
Acidification/ Eutrophication	Pt	0,0628	0,00794	-0,00357
Land use	Pt	0,0195	-0,458	-0,462
Minerals	Pt	0,00949	-0,0362	-0,0384
Fossil fuels	Pt	1,08	-1,72	-2,02

Figure 4 - Eco-indicator 99 method results for the three scenarios.

Impact category	Unity	Scenario 1	Scenario 2	Scenario 3
Abiotic depletion	kg Sb eq	0,0985	-0,101	-0,128
Acidification	kg SO2 eq	0,103	0,0794	0,0605
Eutrophication	kg PO4--- eq	0,0251	-0,272	-0,277
Global warming (GWP100)	kg CO2 eq	14,3	-1,88	-5,79
Ozone layer depletion (ODP)	kg CFC-11 eq	2,01E-6	-1,55E-6	-2,16E-6
Human toxicity	kg 1,4-DB eq	5,42	-134	-135
Fresh water aquatic ecotox.	kg 1,4-DB eq	1,24	-243	-243
Marine aquatic ecotoxicity	kg 1,4-DB eq	2,83E3	-1,99E5	-2E5
Terrestrial ecotoxicity	kg 1,4-DB eq	0,0295	-0,00314	-0,0106
Photochemical oxidation	kg C2H4 eq	0,00265	-0,000749	-0,00134

Figure 5 - CML Baseline 2000 method results for the three scenarios.

Impact category	Unity	Scenario 1	Scenario 2	Scenario 3
Non renewable, fossil	MJ-Eq	215	-264	-324
Non-renewable, nuclear	MJ-Eq	11,1	-35,4	-38,8
Renewable, biomass	MJ-Eq	1,21	-1,83E3	-1,83E3
Renewable, wind, solar, geothe	MJ-Eq	0,225	2,23	2,2
Renewable, water	MJ-Eq	4,46	14,1	13,5

Figure 6 - Cumulative Energy Demand method results for the three scenarios.

VIII. Results Discussion

The Eco-Indicator is a method that is supported by the life cycle assessment giving a quotation to each environmental impact category. Based on scientific researches, this method gives a specific weight to each impact during the life cycle of the product. The final unit of this method is the point (pt) that corresponds to 1/1000 life years loss of a healthy European citizen. The analysis of Figure 4 gives the final results of the Eco-Indicator method which are 2.86 pts for scenario 1, -18.5 pts for scenario 2, and -19 pts for scenario 3. These values show that the use of recycled aggregates in the production of concrete (scenarios 2 and 3) has a big environmental advantage over the use of natural aggregates (scenario 1). The category of carcinogens is the most differentiated category in scenarios 2 and 3 because traditional demolition, which has a big environmental impact, is avoided.

CML Baseline 2000 and Cumulative Energy Demand are two methods based on the life cycle assessment that quantify the values of different environmental impact categories in their units. The analysis of Figures 5 and 6 shows that scenarios 2 and 3 represent negative values in a big majority of the environmental impact categories comparing to scenario 1. The categories of human toxicity and ecotoxicity (CML Baseline 2000) are the ones with the highest environmental impact values because of long-term staying CDW in the landfill caused by the avoidance of traditional demolition. In the Cumulative Energy Demand method, the renewable and non-renewable energy has the highest negative environmental impact values (scenarios 2 and 3) considering the previous explanation for the CML Baseline 2000. The same happens with the Eco-Indicator method, where scenarios 2 and 3 (recycled aggregates) have bigger environmental advantages than scenario 1 (natural aggregates).

IX. Conclusions

The construction industry is one of the largest sectors across Europe, with a large percentage of employment in European industry. This industry is responsible for the economic development of countries, and, on the other hand, the major cause of environmental impacts. The possibility of reuse of recycled aggregates is one of the aspects that ought to be analyzed from the standpoint of environmental impact.

This work discusses the use of LCA in the production of recycled aggregate. Three scenarios are compared and global calculations are made, in order to find which type of aggregates (natural or recycled) presents major environmental advantages. An analysis is made of the following scenarios: use of natural aggregates (scenario 1) and recycled aggregates (scenarios 2 and 3) in the production of concrete, using a fixed recycling plant (scenario 2) and a mobile recycling plant (scenario3).

According to the analysis conducted, it is concluded that the introduction of recycled aggregates in the production of concrete has greater environmental benefits compared to the introduction of natural aggregates. The recycling of aggregates must be made in order to achieve sustainability in construction and environmental impacts are reduced substantially over the coming years.

In Portugal, some deposition of RCD in landfills and an increase in their costs, are starting to occur, which is very beneficial and enables the reduction of the volume of RCD through its recycling and reuse, thereby protecting the environment and reducing environmental impacts produced by the sector. However, the fees are still very low (2 €/tone for aggregates and 5€/ton for non-inert) in comparison with the fees in other European countries (approximately 50 € and 100 €/tone in Denmark and in Germany).

With this dissertation, it is intended that future studies are carried out in this area and that it is an incentive for further development, since currently there are not many studies on the subject. Recommendations and future developments are presented:

- In terms of research, it is important to continue the development and developing of the quantification of impacts, consolidating the data and assumptions used, covering a larger number of organizations and data, including impacts and costs;
- As in the present study values of the major categories of environmental impact for scenarios concerning recycled aggregate were presented, the companies in Portugal should increase recycling of aggregates and EPD's concern-

ing recycled aggregates and not only natural aggregates;

- Infrastructures should begin to be built for the valuation of CWD, to make more accurate (selective) demolition and reuse more CWD;
- In Portugal, there are few recycling plants, so the number of fixed and mobile plants should increase, allowing more recycling of aggregates.

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