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ENVIRONMENTAL IMPACT SHARES OF A REINFORCED CONCRETE EARTH-RETAINING WALL WITH BUTTRESSES

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Structural engineers focus on the reduction of carbon emissions in reinforced concrete structures, while other impacts affecting ecosystems and human health become secondary or are left behind. The featured life cycle assessment shows the impacts corresponding to each construction stage of an earth-retaining wall with buttresses. In this study the contribution ratio of each input flow is analyzed. Accordingly, concrete, landfill, machinery, formwork, steel, and transport are considered. Results show that despite the concrete almost always accounts for the largest contribution to each impact, the impact shares of steel present noticeable sensitivity to the steel-manufacturing route. The parameter of study is the recycling rate, usually 75% reached in Spain. Noticeable variation is found when the recycling content increases. The relationship between the impacts of each material with the amount of material used discloses research interest.

Keywords: Life cycle assessment, Functional unit, Steel recycling rate, Concrete ratio, Photochemical oxidation, Ozone depletion, Global warming.

1 INTRODUCTION

The reduction of carbon emissions in reinforced concrete structures has been a matter of study of growing interest among structural engineers. Previous research focused on the optimization of structures through single measurement or metrics of environmental interest, such as CO_2 emissions (Yepes *et al*. 2012), embodied energy (Martí *et al*. 2016) and economic costs (Molina-Moreno *et al*. 2017). In such optimization works, the values of CO_2 per m^3 of concrete and kg of steel are invariant. However, the manufacturing technologies around the world are variable and the electric recycling of steel among countries highly depends on the availability of recycling scrap facilities. Therefore, the environmental impacts involved in the steel processing are variable among countries and must be documented.

The common route of scrap steel is electric arc furnace (EAF). EAF involves greater energy intensity than the iron ore treatment route, the basic oxygen furnace (BOF) route (Iosif *et al*. 2008). On the contrary, BOF route releases greater amounts of greenhouse gases to the atmosphere than EAF. Spanish steel manufacturing leads by far the rank of EAF steel production in Europe; a recycling rate of 75% can be reached in Spain (World Steel Association 2015). This is variable among EU countries to Egenhofer *et al*. (2013). The tradeoff between EAF and BOF is not a choice nor is currently possible to use entirely EAF as a good practice for the environment. Therefore, before any decision is made, an accurate impact assessment is crucial to obtain the burdens to the environment.

A previous study shows a noticeable reduction of several impacts when the recycling content increases (Zastrow *et al*. 2017). The relationship of the impacts of each material with the amount of material used discloses research interest because it influences the choice of designers when willing to commit to the principles of a circular economy. It is because EU countries have different recycling rates, which would imply that the environmental profile of a structure cannot be applied outside the region considered in the assessment.

It is widely acknowledged that the environmental performance of the concrete production is sensitive to the best available technology of cement manufacturing (Kajaste and Hurme 2016). In the same way, the environmental efficiency of steel depends on the steel recycling potential in the area (Gross and Perl 2016). Thus, the relationship of the impacts of each material with the amount of material used is greatly influenced by the cement manufacturing technology and the steel recycling potential in the area. This case study shows the impact contribution of each activity involved in the construction of a reinforced concrete earth-retaining wall with buttresses. Since the environmental impacts of a highly depend on the recycling rate of steel (Zastrow *et al.* 2017), the study particularly focus on how the impacts vary according to origin of production, considering country specific steel recycling rates.

2 METHODOLOGY

2.1 Environmental Assessment Methodology

The environmental assessment consists of the inventory analysis of the processes involved in the construction and the interpretation of the impacts. A normalization set is required to convert the chemicals into impact categories. The impact categories are weighted for interpretation and decision making using the values of ReCiPe 2008 (ReCiPe, 2012) for the global egalitarian perspective (World ReCiPe endpoint). The analysis considers European environmental databases with variable recycling steel rates based on Egenhofer *et al*. (2013).

To obtain the contribution of each activity to the ecosystem and natural resources, the revised version of ReCiPe 2008 method (Goedkoop *et al*. 2013) is chosen as it sufficiently provides information on impacts at a general and a particular approach. A generic assessment of three dimensions of sustainability may be obtained through the aggregated indicators *endpoint*. Within every dimension, the *midpoint* indicators show the damage involved in a particular area. Further description of the method is widely explained at (Goedkoop *et al*. 2013).

2.2 Structural Design

The design description of the wall corresponds to an optimum feasible solution previously obtained through a design parametric economic optimization (Molina-Moreno *et al*. 2017). The measurements of the retaining wall are defined by the volume of concrete, the weight of steel and the, according to the geometry of the wall. Design parameters of the wall and the soil are described in Table 1. Generally, the relative amount of steel and concrete varies with the height as much as the ground is less cohesive and presents lower bearing capacity. Previous research has analyzed the influence of the type of fill on the variables of cost-optimized solutions in this wall type (Molina-Moreno *et al*. 2017).

Table 1. Design parameters of the wall and the soil.

Max. Bearing Stress (MPa)	Density γ (kN/m^3)	Internal friction angle ϕ (º)	Wall Height (m)	V_{horm} (m^3)	m_{acer} (kg)	A_{encof} (m^2)	V_{exc} (m^3)	MT_t (m^3)	$MT_{talón}$ (m^3)	$MT_{puntera}$ (m^3)
0.3	20	30	10	5.94	281.4	27.33	7.99	11.04	9.6	1.44

2.3 Functional Unit

The environmental assessment requires defining a descriptive metric of the unit to which impacts must be attributed. This metric is named functional unit (FU). The height of the wall is generally a design parameter. The contribution share of impacts vary not linearly with the height (Zastrow *et al*. 2017). Therefore, the FU for comparison purposes is defined per wall height. The featured case study considers an earth retaining wall of 10 m height.

3 RESULTS

This section highlights the results of the application of the environmental assessment method to the reinforced concrete structure previously described. The damage to ecosystems, human health and resources are briefly described as aggregated indicators in the following subsection.

3.1 Aggregate Indicators (Recipe 2008 Endpoint)

The aggregated results on the ecosystem quality are for this method, 61.9% of concrete manufacturing and 34.11% of reinforced steel production. The production of reinforced concrete implies important damage to the aggregated category human health (28.8%) and resources depletion (33.65%). The machinery holds a noticeable share (15.3%) in the resource depletion category, due to the relevance of the fuel diesel (see Figure 1).

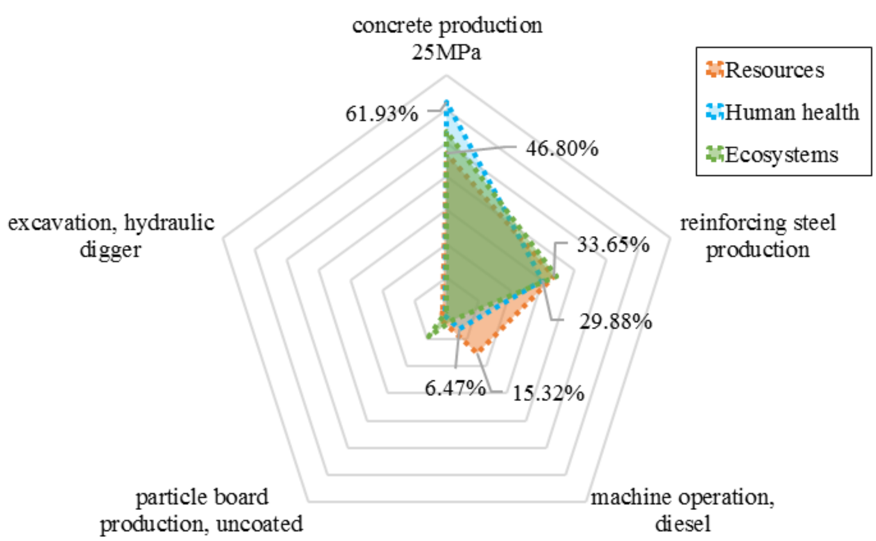

Figure 1. Damage to ReCiPe 2008 Aggregated categories per construction activity.

However, the relative share of damage to the impact categories varies among European countries because of different availability of electric arc furnace (EAF) routes. Table 2 shows the relative damage to the aggregated categories of ReCiPe method, per country. Human health and resource depletion exhibit noticeable lower values in the case of a structure with Spanish EAF rate of steel, as compared to other countries' rates.

Table 2. Relative damage to the aggregated categories.

	EAF route (%)	Ecosystems	Human Health	Resources
Spain	75.2%	0.929	0.685	0.611
The Netherlands	2.5%	0.978	0.766	0.886
Austria	9.22%	1.000	0.758	0.861
Germany	32.1%	0.929	0.733	0.774
Belgium	34.6%	0.929	0.730	0.765
Poland	49.61%	0.929	0.713	0.708
Italy	65.58%	0.929	0.696	0.647
Average EU	38.39%	0.946	0.726	0.750

3.2 Non-aggregate Indicators (Recipe 2008 midpoint)

After a first glance on the aggregated categories of the previous section, a close view of the subcategories (*midpoint*) is performed. Considering the ratio of recycled steel per country (Table 2), the differences on ecosystems, human health and resources are relevant to study. Next subsections briefly depict the implications of the recycling rate.

3.3 Contribution to Ecosystems

The quality of ecosystems is defined in ReCiPe 2008 by the subcategories defined in Figure 2. The figure shows the damage of materials to the ecosystem quality per country. It can be seen that the Spanish damage to most of the impact categories is lower than the damage of the remaining countries analyzed. However, the terrestrial ecotoxicity in the Spanish steel mix is greater than the average European. This is due to the greater electricity use and transport required in the electric arc furnace route.

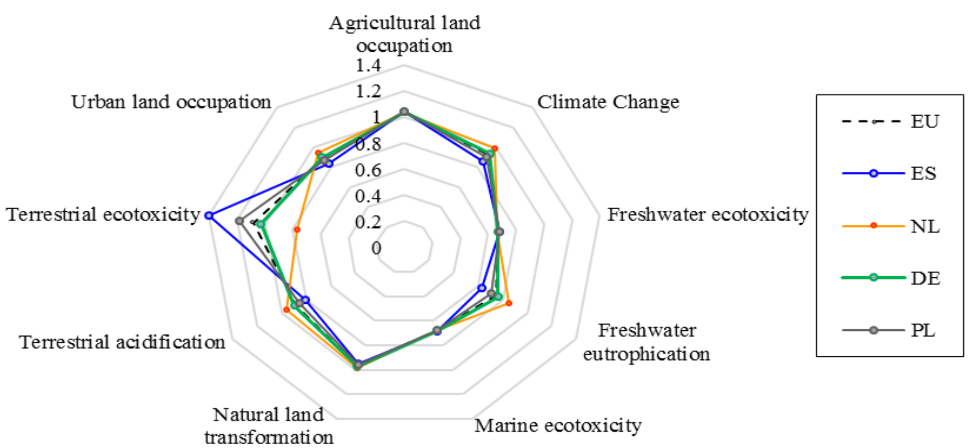

Figure 2. Ecosystems quality per country (baseline: average European).

3.4 Contribution to Human Health

The human health is defined in ReCiPe 2008 by the subcategories illustrated in Figure 3. The figure shows that particulate matter formation is the indicator with greater difference among countries. Finally, Table 3 resumes the percentage of steel production involved per country in the damages to the ReCiPe Endpoint category Human Health. Damage of the Spanish EAF rate to this category is lower than the European average.

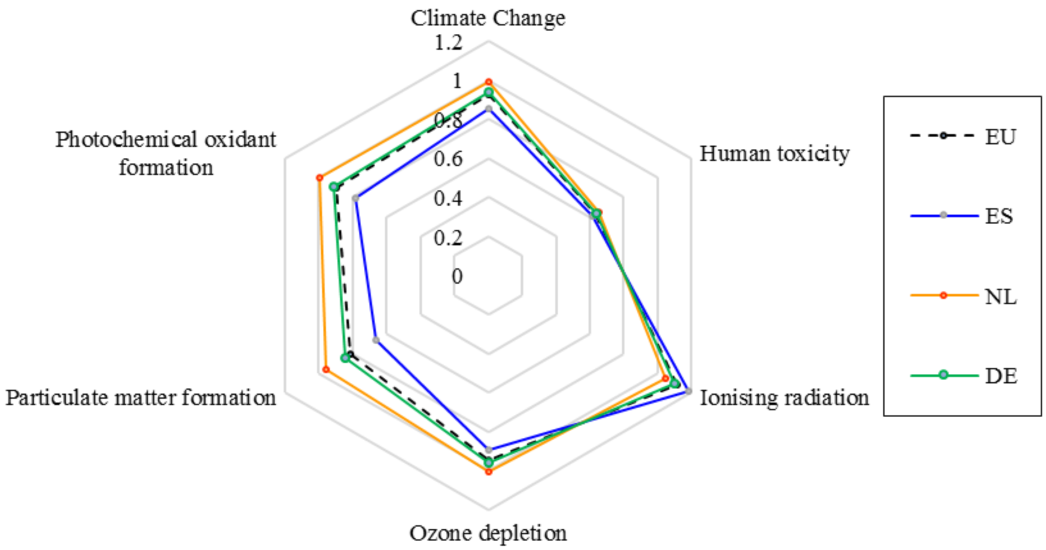

Figure 3. Ecosystems quality per country (baseline: average European).

Table 3. Damage of steel production to human health per country.

	ES	BE	DE	AT	PL	IT	NL	Average EU
% of steel production	29.88%	34.21%	34.46%	36.66%	32.67%	32.67%	37.28%	33.98%
DALY[1]	5.00E-03	6.10E-03	6.17E-03	6.79E-03	5.70E-03	5.70E-03	6.98E-03	5.91E-03

[1]Disability Adjusted Life Years

3.5 Limitations

The results on the damage to human health and ecosystems are limited by the accuracy of the sub processes involved, all of which include transport of materials. The transportation distances have been considered by European average guidelines (Weidema *et al*. 2013).

4 CONCLUSIONS

This communication presents an approximation of the environmental impacts produced in the construction of reinforced concrete retaining walls. The relative influence of impacts and processes is studied, as well as its variation for a given parameter of study, the recycling steel rate. The normalized and weighted indicators for ecosystem damage, human health and resource depletion are illustrated for the whole structure, according to ReCiPe Endpoint 2008.

The indicators show the different contribution of steel and concrete to the impact categories, as well as the variation of this categories respect to the European average. Facing the non-aggregated impact results per country specific recycling steel rate, we can conclude that the most variable impact categories to the recycling rate are terrestrial ecotoxicity (species per year) and particular matter formation (Disability Adjusted Life Years).

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