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OERCO2

ONLINE EDUCATIONAL RESOURCE FOR INNOVATIVE STUDY OF CONSTRUCTION MATERIALS LIFE CYCLE

INTELLECTUAL OUTPUT 3. OER (ONLINE EDUCATIONAL RESOURCE)

TASK IO 3.2 Testing of Interactive Tool

Erasmus+

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1. INTRODUCTION

This report will summarise the activities and tasks carried out for the implementation of Intellectual Product 3 of the OERCO2 Project "OERCO2 interactive tool for the application of CO2 calculation methodologies in the material execution of works".

This interactive tool is able to calculate the total CO2 emissions of the building from a practical and didactic point of view. The CO2 Tool is an intuitive tool in which, from the basic data of the project for the material execution of the building to be built, the results of both economic and environmental budgets are obtained.
To arrive at the final result of this tool, the characteristics of the project (materials, construction systems, etc.) must be specified and it can be verified that, depending on the elements or materials to be used for its execution, a different environmental impact is obtained.

In the following sections, it will detail the process followed until reaching the latest version of the CO2 Tool (http://co2tool.oerco2.eu/en-US), that is available on the OERCO2 project website (http://oerco2.eu/).

2. DEVELOPMENT OF CO2 TOOL

The CO2 Tool stems from several previous research studies developed by Universidad de Sevilla (USE), promotor of this project.

The first phase consisted of the compilation of building projects, as well as the identification of the most representative residential building typologies and their constructive characteristics. For that, 140 different residential building typologies from one to more than 10 floors were evaluated. Within each typology, the most representative construction solutions of the countries participating in the project were studied (Spain, Portugal, Italy and Romania).

With the aim of facilitate the comparison between construction projects, the budget of them were reorganised in a construction-work breakdown system (materials, manpower and machinery

needs). This organisation system was successfully applied to estimate the generation of construction waste and to evaluate the ecological footprint of buildings.

The second phase consists of calculating the carbon footprint of resources. To this end, the carbon footprint indicator was included in the prices of the database of the Andalusia Construction Information Classification System (ACICS), the creation of representative European construction solutions, the evaluation of the environmental and economic impact of the different projects and the incorporation of the impacts into the computer tool.
The use of ACICS is the most extended for the estimation of costs in construction sector and it is mandatory in public works in Andalusia (Spain). It is organised for work units, where the highest level is the construction site, followed by categories called chapters, each representing a construction process (for example, earthworks, foundations, installations, etc.), which are subsequently divided into sub-chapters.

For each construction project of the different buildings analysed, the coefficients of representation were calculated for each chapter per square meter constructed, expressed in units per built surface (u/m2).

The next step was the carbon footprint calculation, the tool uses a cradle-to-site LCA analysis, that is, A1 to A5 life-cycle phases, which correspond to manufacturing (A1 - A3) and construction (A4 - A5). The environmental data included in the CO2 Tool was obtained from the Ecoinvent database through Simapro tool.

In total, more than 4600 material resources and 67 different machines have been analysed in terms of basic costs (BC). These basic costs were aggregate to form auxiliary costs (AC), which usually arise from the mixing of materials such as cement mortar, gypsum plaster, or manpower teams. Simple costs (SC) were various activities or work units.

As a result of these analyses, 810 unit costs (UC) have been calculated.

Capítulo 04.: SANEAMIENTO							HC	
Subcapítulo 04E REDES ENTERRADAS							HC PBs	HC Pus
Apartado 04EA Arquetas								
Grupo 04EAB A pie de bajante								
04EAP90(u		ARQUETA DE PASO DE 63X63 cm 1 m PROF. EXC. EN TIERRAS.				210,58		0,17597
Arqueta de paso de 63x63 cm y 1 m de profundidad media, formada por solera de hormigón HM-20 de 15 cm de espesor con formación de pendientes, fábrica de ladrillo perforado por tabla de 1/2 pie, enfoscada y bruñida por								
ATC00100		3,2	h	CUADRILLA ALBAÑILERÍA, FORMADA	37,51	120,03	2,00	0,000000	0,000000
TP00100		2,6	h	PEÓN ESPECIAL	18,28	47,53		0,000000	0,000000
AGM00200		0,026	m3	MORTERO DE CEMENTO M15 (1:3) CE	67,45	1,75	1,03	0,373342	0,009707
AGM00500		0,113	m3	MORTERO DE CEMENTO M5 (1:6) CEI	50,04	5,66	1,03	0,221518	0,025032
CH04020		0,147	m3	HORMIGÓN HM-20/P/20/I, SUMINISTR	56,63	8,32		0,229569	0,033747
FL01300		0,21	mu	LADRILLO CERÁM. PERF. TALADRO F	73,92	15,52		0,479326	0,100659
SA00700		0,45	m2	TAPA DE HORMIGÓN ARMADO CON	26,13	11,76		0,015179	0,006830
					TOTAL EU	210,58		TOTAL HC	0,17597

Figure 1. Unit cost of CO2 Tool.

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While the OERCO2 team were working in the CO2 Tool, the following screen appeared on the OERCO2 website.

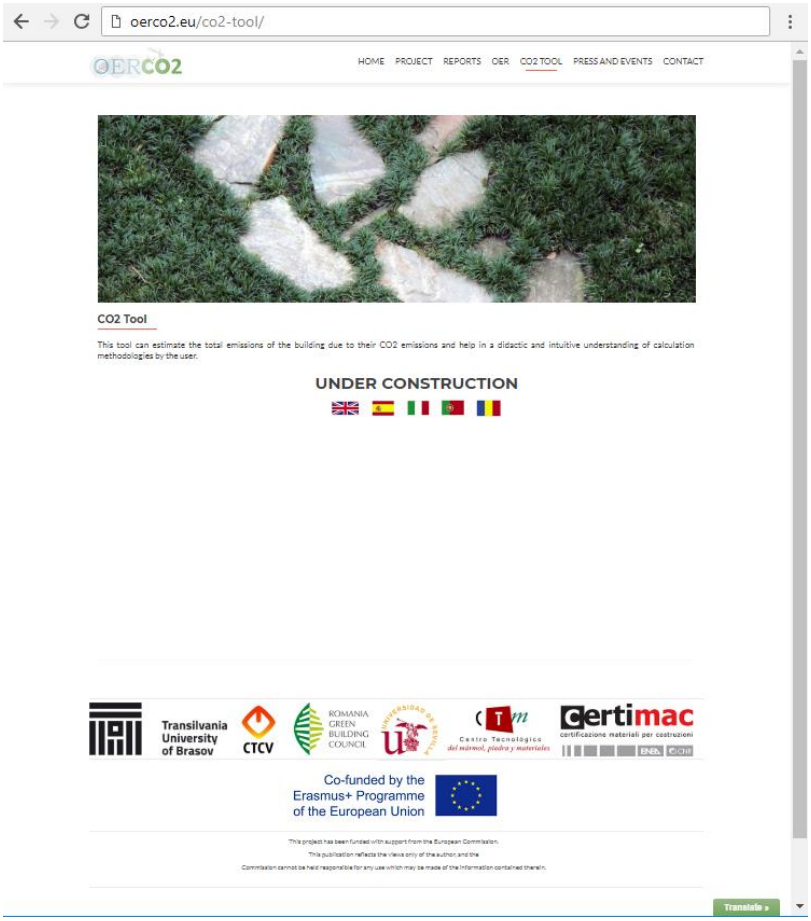

Figure 2. CO2 Tool under construction.

3. FIRST VERSION OF CO2 TOOL

The initial screen of CO2 Tool consists of the definition of a series of basic characteristics of the building project such as, number of floors, underground levels, premises ground floor, foundation and structure types and roof type. In the following images, you can see the first version of the CO2 Tool in excel format.

FLOORS	UNDERGROUND LEVELS	PREMISES GROUND FLOOR	FOUNDATION TYPE	STRUCTURE TYPE	ROOF TYPE
1	No basement	Non-commercial premises in ground floor	Strip footings	Brick walls	Flat roof
2	1 basement floor	With commercial premises in ground floor	Separate footings	Reinforced concrete	Sloping roof
3	2 basement floors		Foundation slab		
4	3 basement floors		Piling foundation		
5	4 basement floors				
more than 5					

Figure 3. First version of initial data of CO2 Tool.

Once the initial data is defined, the next step is to finalise the specific data, such as excavation, landfill, earth-moving, manhole, waste water pipe, drainpipes and drains, slab, shuttering, facade, internal separation wall, etc. This screen is called Generalities.

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EXCAVATION	LANDFILL	EARTH-MOVINGS
Excavator shovel	Manual	Manual
Backhoe loader	Mechanical	Mechanical
Non-applicable	Non-applicable	Non-applicable

MANHOLE	WASTE WATER PIPE	DRAINPIPES AND DRAINS
In situ	PVC	Sheet zinc
Prefabricated	Concrete	Sheet steel
	Fiber cement	Reinforced PVC
	Polyethylene	Polypropylene
		Fiber cement

SLAB	SHUTTERING	FACADE	INTERNAL SEPARATION WALL
Waffle slab with non-recoverable caissons	Wood	1-foot wall with air chamber, brick wall	9 cm double hollow ceramic brick
Waffle slab with recoverable caissons	Metal	1/2-foot wall with air chamber, brick wall	15 cm triple hollow ceramic brick
Unidirectional slab with infill ceramic blocks		1-foot wall without air chamber	1-foot double hollow ceramic brick
Unidirectional slab with infill concrete blocks		1/2-foot wall without air chamber	Gypsum plasterboard wall
Reinforced slab		1-foot wall with air chamber, inner wall of plasterboard	
		1/2-foot wall with air chamber, inner wall of plasterboard	
		25 cm wall with lightweight concrete blocks	

Figure 4. First version of general data of CO2 Tool.

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FLAT ROOF	SLOPING ROOF	FINISHING OF FACADE
Non-transitable flat roof,	Fiber cement corrugated sheets	Face brick
Non-transitable flat roof, non-ventilated	Sandwich panels	One-coat mortar
Non-transitable reversed flat roof	Aluminium sheet	Rendering, non-rodded and screeded
Transitable flat roof, ventilated	Polyester	Smooth plastic paint (exterior)
Transitable flat roof, non-ventilated	Slate tiles	Smooth petreus paint with mortar cement (exterior)
Transitable reversed flat roof	Ceramic tiles	Ventilated facade with natural stone panels
Non-applicable	Cement tiles	Ventilated facade with ceramic
	Galvanised sheet steel forming	Ventilated facade with resin panels
	Non-applicable	Ventilated facade with cellulose-cement panels
		Sandwich wooden panel with XPS nucleous
		Artificial stone
		Limestone
		Marble
		Granite
		Wood

Figure 5. First version of general data of CO2 Tool.

In the following step, it can find all the features related to the facilities of a construction project and it is called Facilities, as shown below.

AIR CONDITIONING	TERMINAL UNITS	DUCTS	PIPES	RADIATOR	BOILER
Compact ventilation unit	Ceiling units	Fiberglass	Built-in galvanized steel	Steel	Diesel oil boiler
Ducted system parted	Split	Galvanized steel	Superficial galvanized steel	Cast aluminium	Solid-fuel boiler
Heat Pump	Ventilation grilles	Non-applicable	Non-applicable	Cast iron	Wall gas boiler
VRF unit with inverter	Non-applicable			Sheet steel	Combi boiler
Non-applicable				Non-applicable	Non-applicable

PIPED COLD WATER	PIPED HOT WATER	WASTE PIPE	VENTILATION
Copper	Copper	PVC	Concrete
Galvanized steel	Galvanized steel	Polypropylene	Ceramic
Polyethylene	Polypropylene		Helical galvanized steel
Polypropylene			

BOILER	SOLAR PANELS	INSULATION OF PIPELINES	LIFTS
Gas boiler	Non-applicable	Non-applicable	Non-applicable
Electric boiler	Applicable	Applicable	Applicable
Non-applicable			

Figure 6. First version of facilities data of CO2 Tool.

And, finally, the screen of Finishings appears with the following options:

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CONTINUOUS VERTICAL SIDING	FLOORS	CEILINGS
Coat of plaster and setting coat of plaster	Ceramic	Continuous plaster false ceiling, suspension with
Rendering, rodded and screeded	Stoneware	Continuous plaster false ceiling,
Non-applicable	Continuous concrete floor	Detachable plaster false
	Hydraulic tile	Continuous gypsum boards
	Linoleum	Detachable gypsum boards, hidden system
	Carpet	
	Cork	
	Parquet flooring of narrow softwood slats (d=500-700kg/m3)	
	Solid wooden skid of softwood (d=500-700kg/m3)	
	Laminated wooden skid of softwood (d=500-	
	Parquet flooring of narrow hardwood slats (d=700-900kg/m3)	
	Solid wooden skid of hardwood (d=700-900kg/m3)	
	Laminated wooden skid of hardwood (d=700-	
	Limestone	
	Marble	
	Slate	
	Granite	
	Terrazzo	
	Concrete slab	

THERMAL AND ACOUSTIC INSULATION
Polystyrene
Polyurethane
Fiberglass
Mineral wool
Expanded perlite
Cork
Polyethylene
Non-applicable

Figure 7. First version of finishing data of CO2 Tool.

WINDOWS	GLASS	DOORS	BLINDS	WINDOW BARS	BANISTER
Casement window of pine wood	6+12+6 Thermo-acoustic	Wood	Manual rolling blinds of anodized	Solid and hot-rolled steel	Steel
Sliding window of lacquered aluminium	6+12+6 Thermo-acoustic. Low emissivity glass	Melamine	Manual rolling blinds of PVC	Non-applicable	Aluminium
Casement window of lacquered aluminium with thermal bridge breakage	8+14+5+5 Thermo-acoustic with argon. Low emissivity and solar control glass		Wood		Wood
Sliding window of PVC			Non-applicable		Non-applicable

Figure 8. First version of finishing data of CO2 Tool.

When all the above steps have been completed, press the Calculate key and the following results screen will appear.

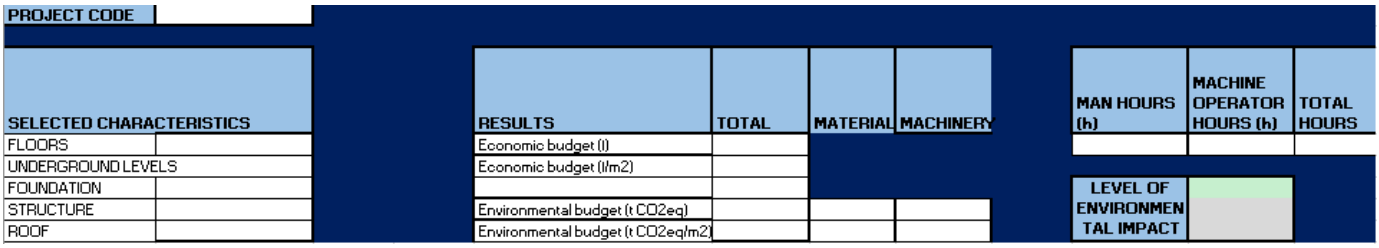

Figure 9. First version of CO2 Tool results.

4. TESTING OF THE CO2 TOOL FIRST VERSION

Once all the calculations had been made, the correct functioning of this initial model was validated with a sample of 27 projects, combining both general and specific data to test the CO2 Tool. With this verification all the characteristics and materials included in this application were covered, giving the widest possible vision to avoid errors.

This verification was an internal process among the project partners, mainly carried out by the USE and CTM.

As soon as the operation of the tool in the Excel version was approved, this document was sent to all project partners for translation into their language and English. At the same time, the online version of the tool was developed, in order to meet the deadlines established in the project's budgeted schedule.

5. ONLINE VERSION OF THE CO2 TOOL

The online version of the CO2 Tool began to run while the partners translated into their native languages (Spanish, Portuguese, Italian, Romanian and English) the different materials and construction elements included in the tool.

This first online version of the tool consisted of two data screens and a third of results. In the first two, as mentioned in previous sections, it was possible to specify the different characteristics that make up a construction project. These first two screens are the "Initial data" and "Specific data" screens.

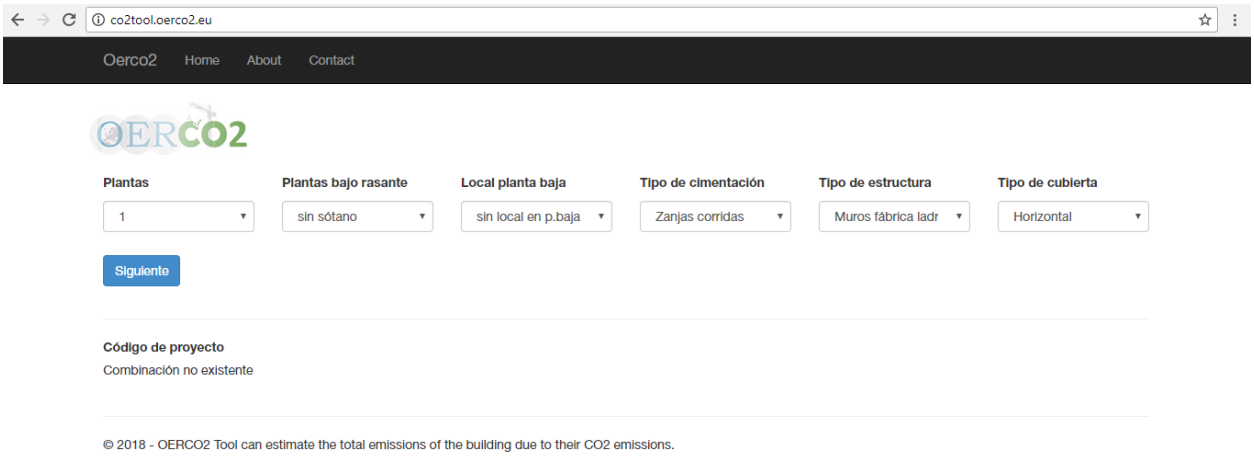

Figure 10. Initial Data of CO2 Tool.

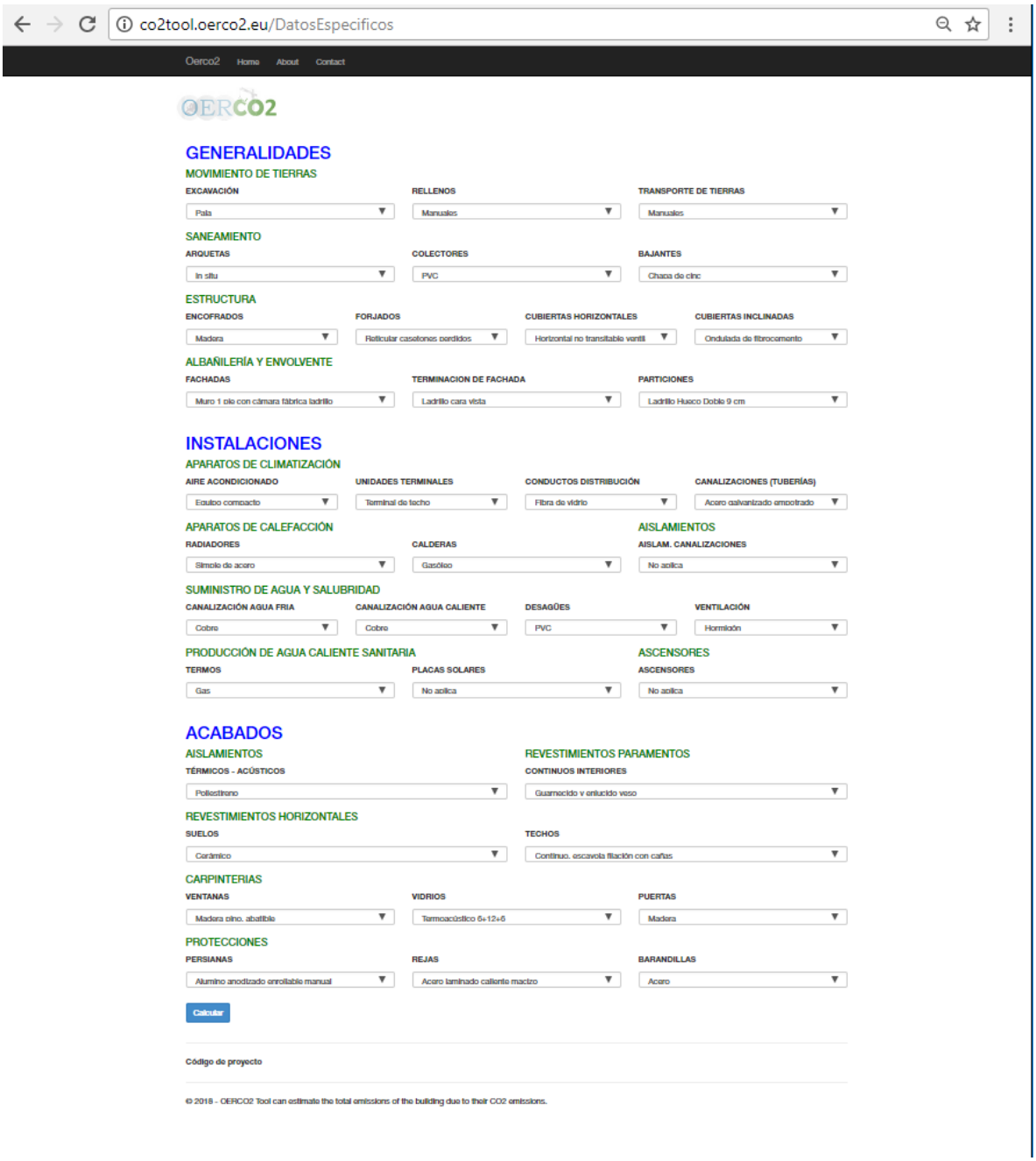

Figure 11. Specific Data of CO2 Tool.

Once the "Calculate" box was clicked, the last "Results" screen appeared.

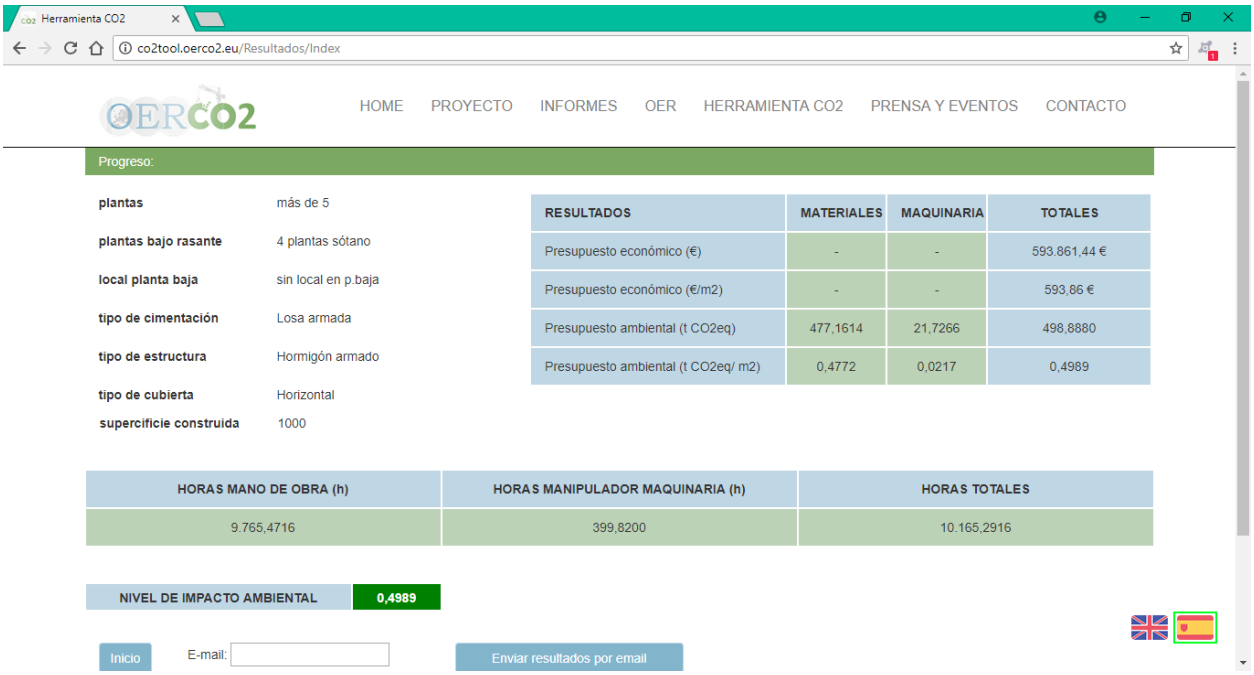

Figure 12. Results of CO2 Tool

6. TESTING OF ONLINE VERSION OF THE CO2 TOOL

At the beginning, the web version of the CO2 Tool was developed in Spanish and English since CTM was the one who was implementing it and it was easier to work in this language and be able to detect errors.

Subsequently, this tool was created in Spanish and English and finally, in the other languages of the project partners (Portuguese, Italian and Romanian).

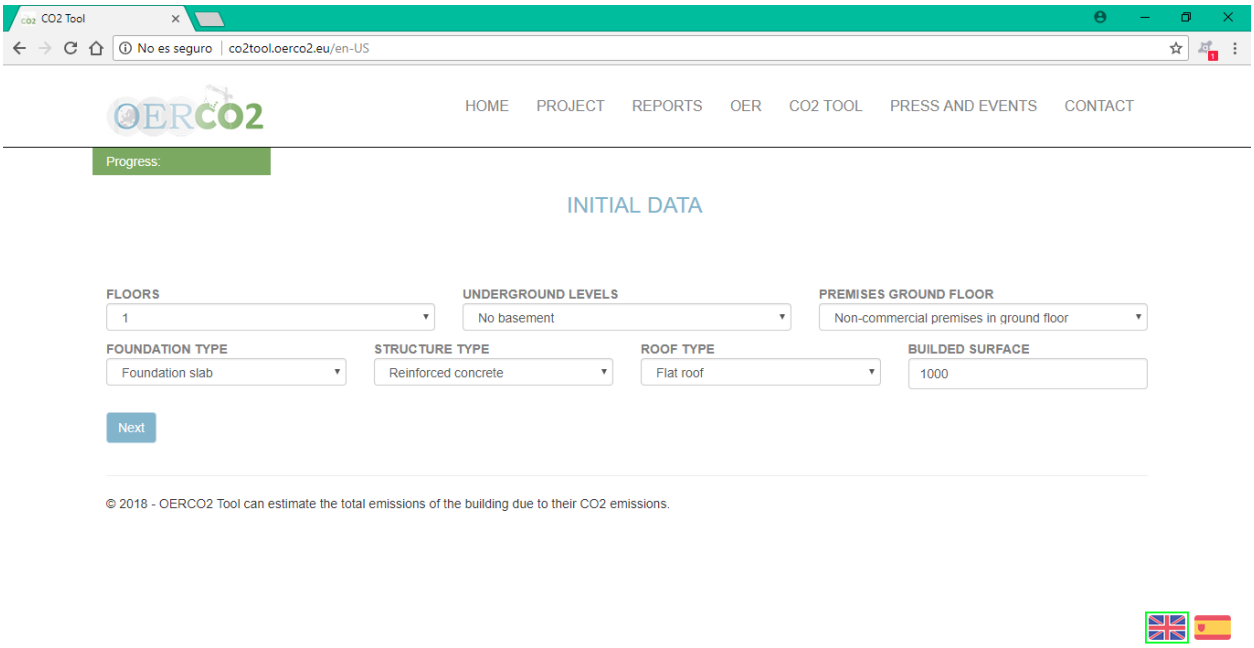

Figure 13. Initial data of CO2 Tool.

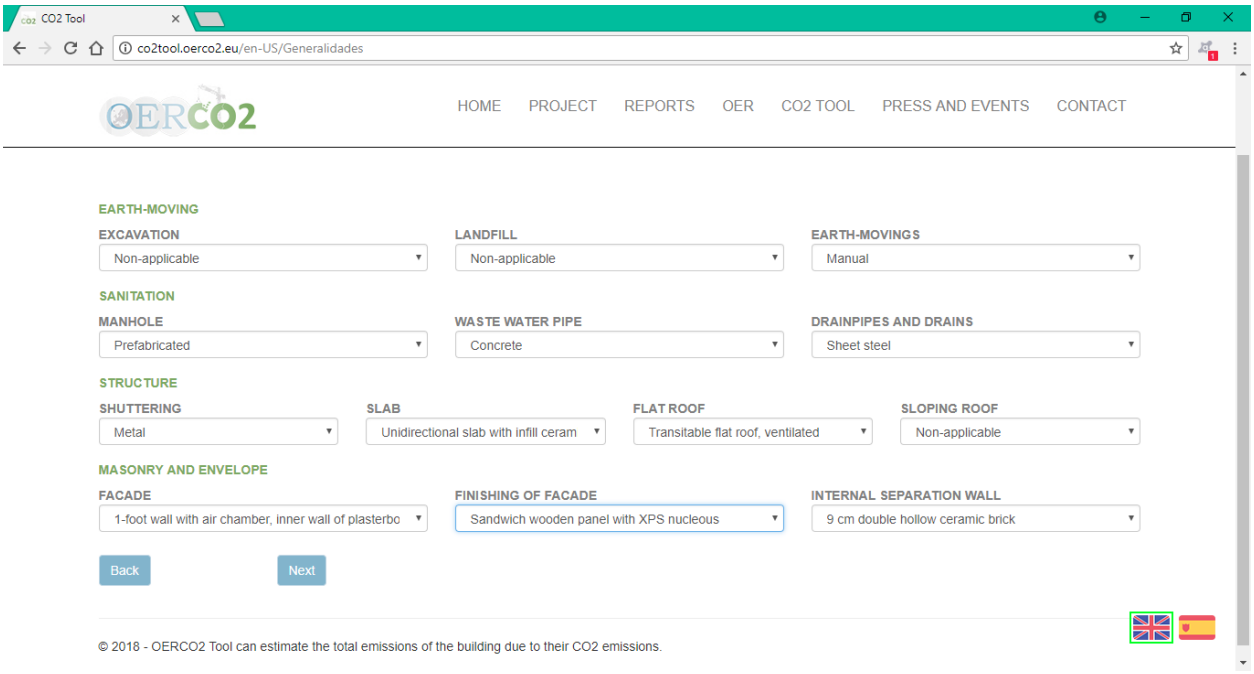

Figure 14. Generalities data of CO2 Tool.

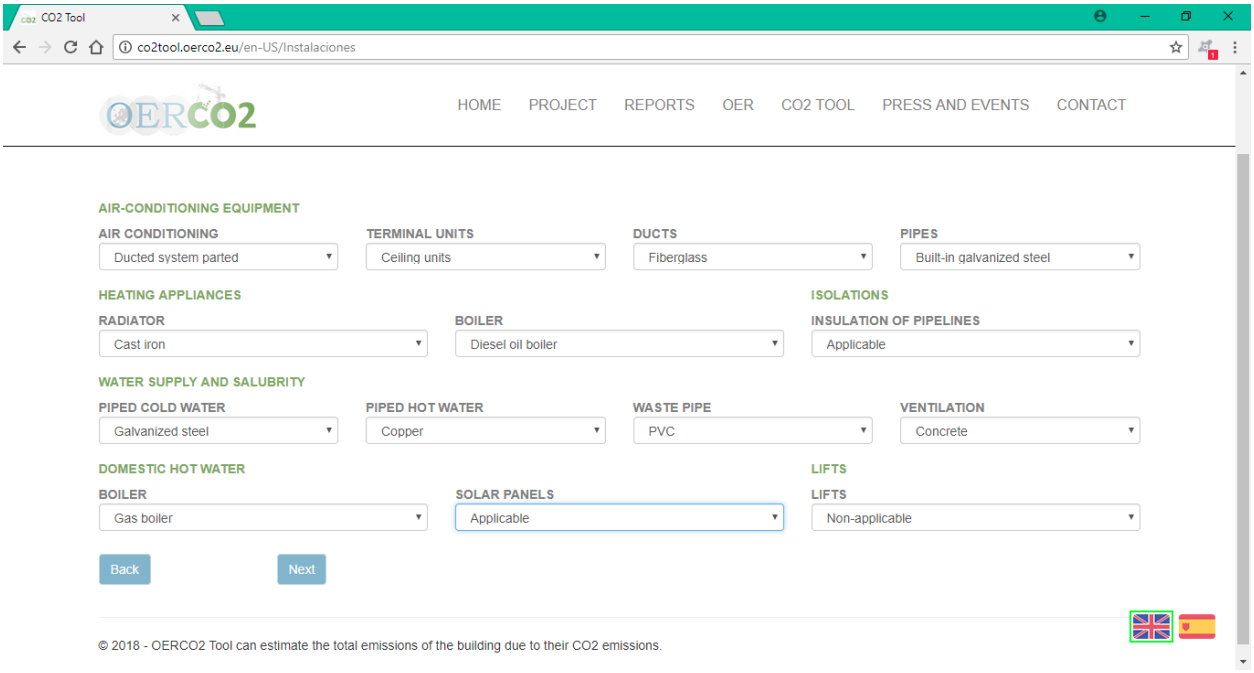

Figure 15. Facilities data of CO2 Tool.

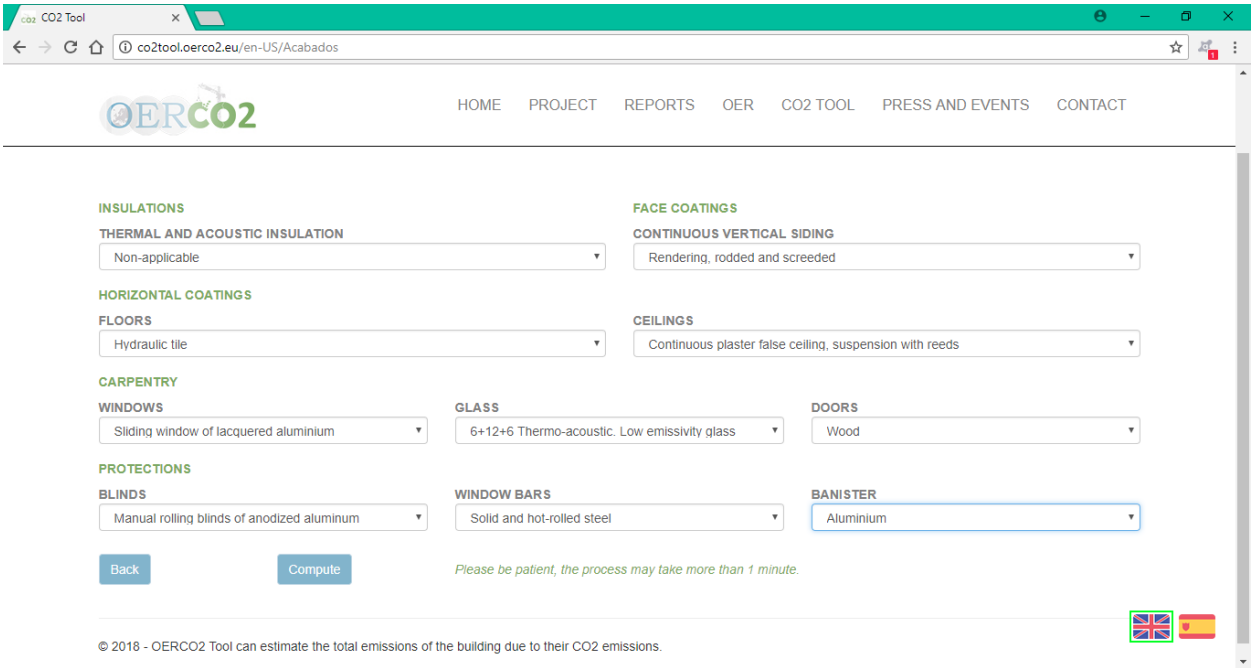

Figure 16. Facilities data of CO2 Tool.

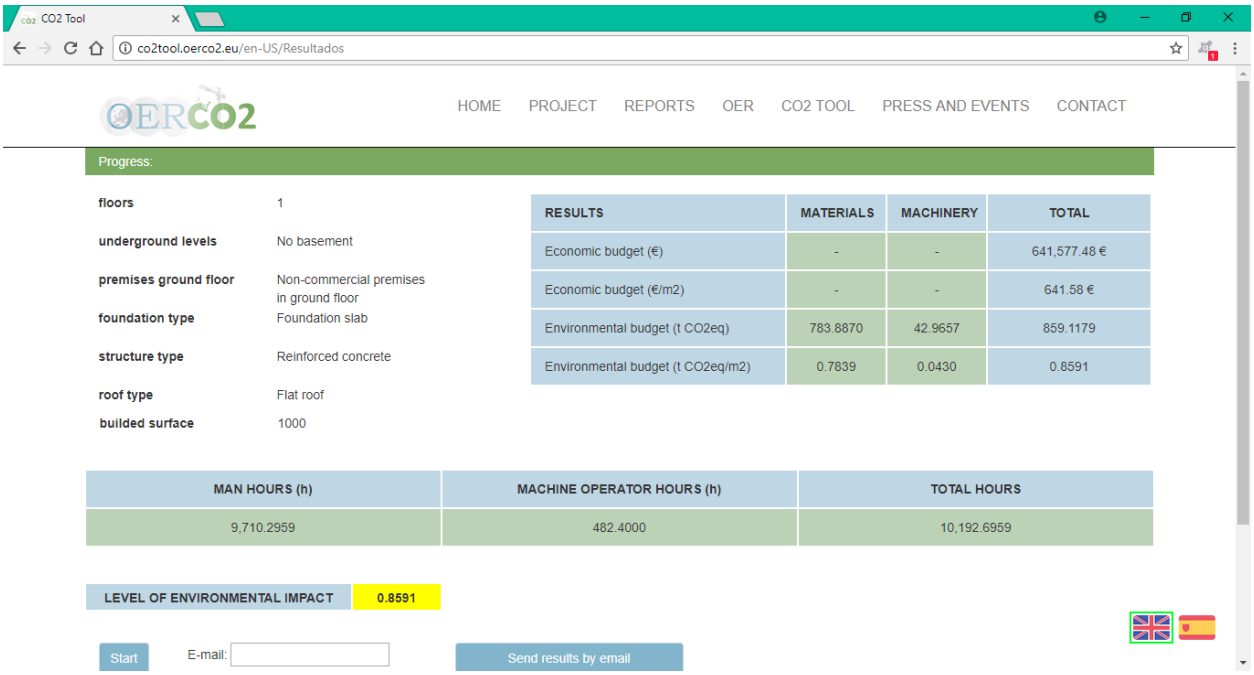

Figure 17. Final results of CO2 Tool.

The CO2 Tool suffered several types of tests:

- Internal tests. The project partners checked the correct operation of the tool and detected a series of errors, which will be detailed below:
  - The transition from one screen to the next was too slow. This was fixed when a change was made from the server where the CO2 Tool was hosted (one from the US) to one from Europe (where it is currently hosted). With this simple change, the speed of data processing and calculation of the final results was moderately reduced.

  - When you went to the penultimate screen and clicked on the calculation box, you had to wait a while (about a minute) for the final result, but most of the time, an error arose, and it was not possible to know the economic and environmental budget of our project. So, after we had completed all the steps and filled in the required data to arrive at an estimate of the environmental impact we were generating, we were not achieving anything. This error was solved thanks to a thorough revision of the tool skeleton, where it was verified that the order of some values was changed and that led to the error. As soon as those values were changed, everything worked fine.

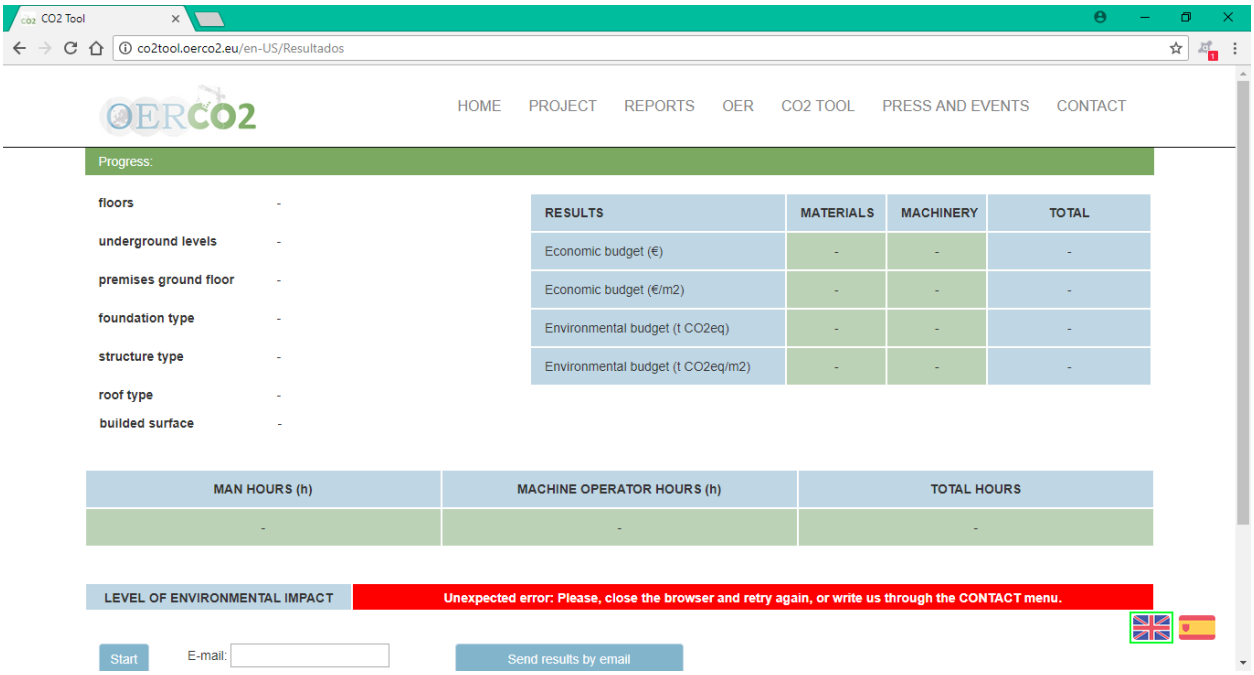

Figure 18. Unexpected error of CO2 Tool.

- At the meeting, the partners suggested to include some more materials and combinations of construction projects, for example, metallic structures. To include this new type of structure, the necessary calculations had to be made again and the process that was carried out at the beginning of the project with the rest of the materials and construction typologies had to be followed. With this modification, the tool went from 140 combinations to more than 250.
- At a meeting, another partner proposed including the legend with the range of environmental impact values for each of the colours (red, yellow and green) that are graded in the final result of the tool so that it is easier to interpret these values. To this end, the scale used for this purpose was a scientific article which reference is the following: *Chastas, P.; Theodosiou, T.; Kontoleon, K.J.; Bikas, D. Normalising and assessing carbon emissions in the building sector: A review on the embodied CO2 emissions of residential buildings. Build. Environ. 2018, 130, 212–226.*

- External tests: During the project, numerous meetings were held between the project partners and international seminars were attended by experts from the construction and environmental sectors. Also, courses have been implemented in which the CO2 Tool has been used, from a didactic point of view.

In order to know the opinions of those attending these events, different types of surveys were delivered depending on the type of event being held. These surveys and their results are posted on the OERCO2 project website (http://oerco2.eu).

The main aim of these surveys was to get feedback for the project and its products to improve them and making them more accessible to users. The attendees provided the following feedback:

- An attendee at a training session held by CTM proposed to include, next to each eligible option within the tool, the amount of CO2 emissions generated by each of them. With this modification what is achieved is to be able to see which materials are more sustainable and thus make an easier choice of materials that cause less environmental impact and not have to finish the whole process to know the final result.
- Another suggestion was to include the option that, once the process had been completed and a final result had been reached, a PDF file could be generated in which the contribution to the environmental impact of each of the elements that make up our construction project could be seen.

7. ONLINE FINAL VERSION OF THE CO2 TOOL

After implementing all the improvements detected both internally and externally, the final version of the CO2 tool is as shown in the following images:

Figure 19. CO2 Tool, Spanish final version (1)

Figure 20. CO2 Tool, Spanish final version (2)

Figure 21. CO2 Tool, Spanish final version (3)

Figure 22. CO2 Tool, Spanish final version (4)

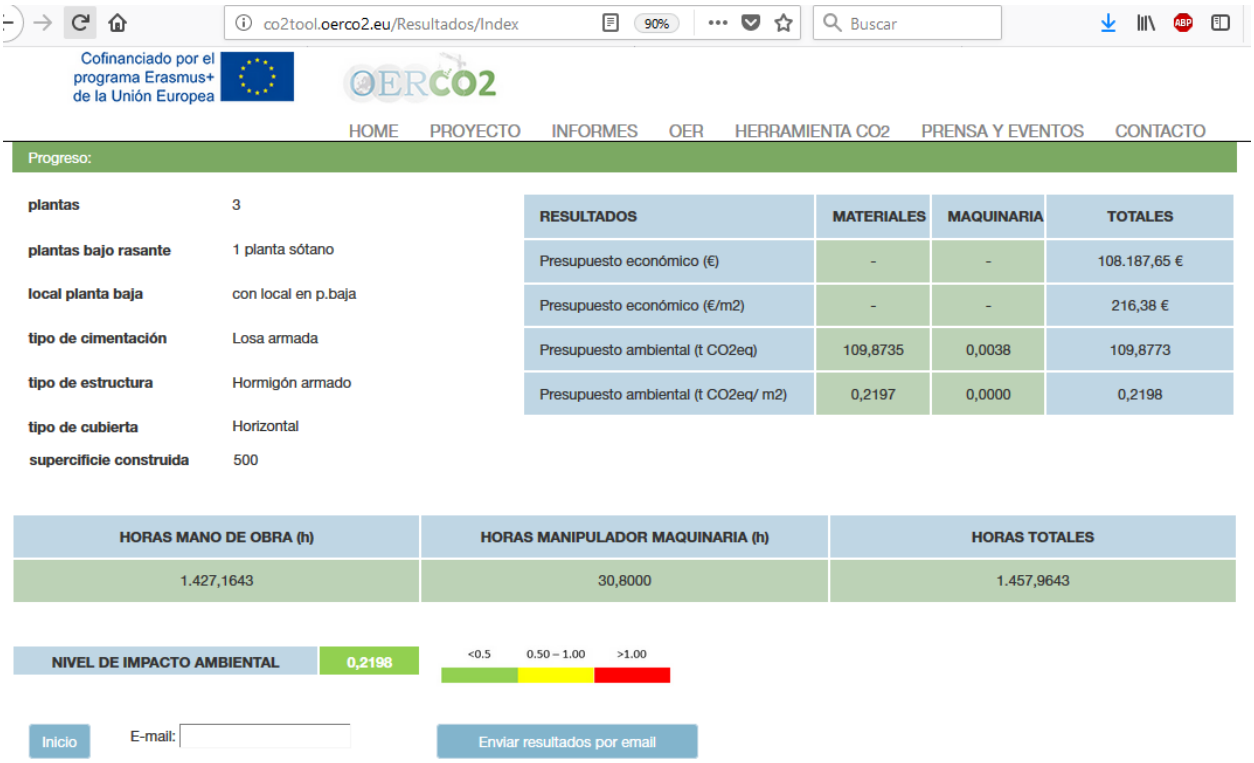

Figure 23. CO2 Tool, Spanish final version (5)

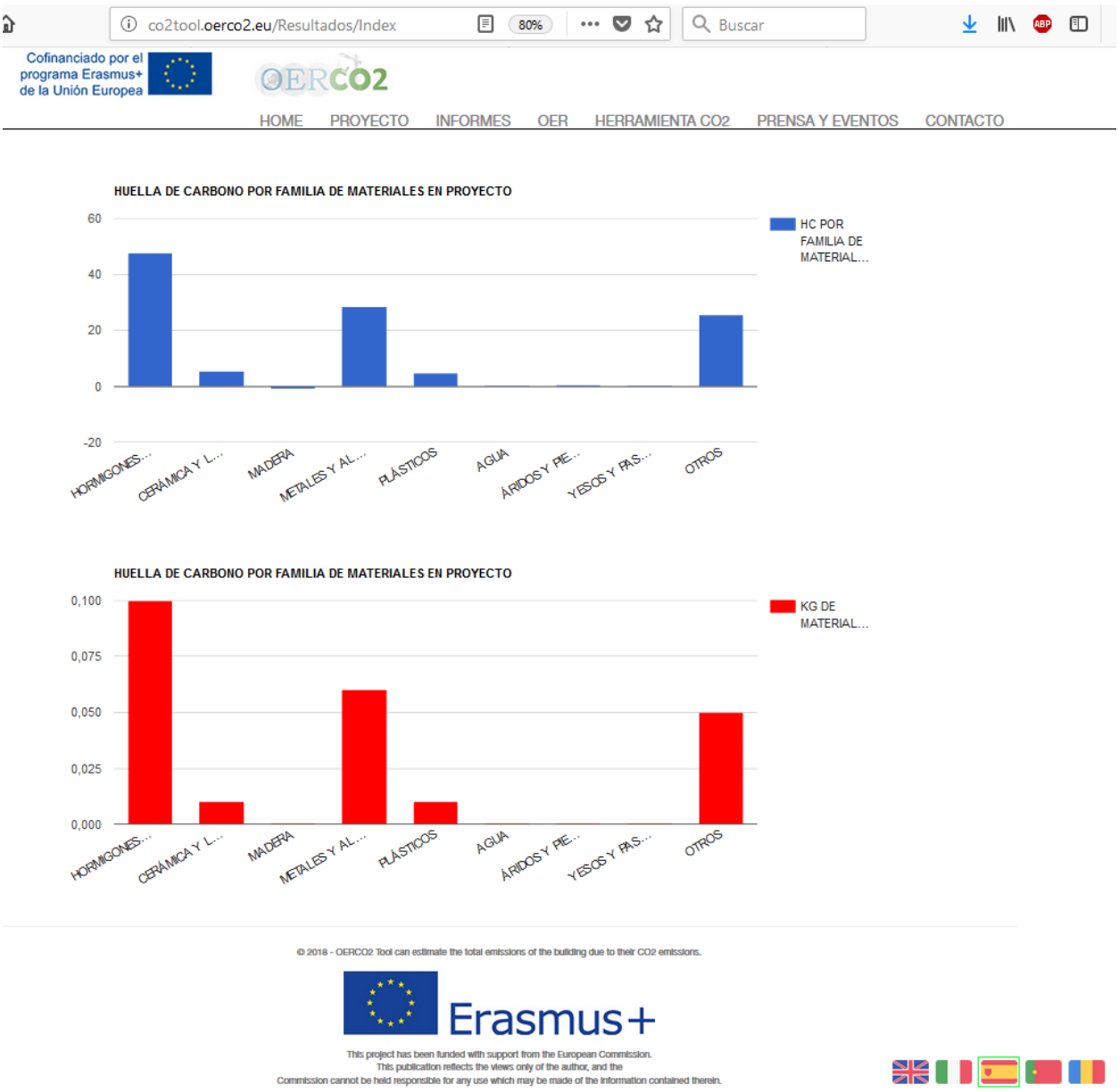

Figure 24. CO2 Tool, Spanish final version (6)

8. CONCLUSION

In general, the evaluations of the project by experts, teachers and students were positive. The opinions of responders were taken into account to improve the quality of CO2 tool in this Intellectual Output 3, as it is say above. Similarly, the evaluations during the international seminars (specially, in Sevilla) was be also taken into account in this Intellectual Output.

The implementation of improvements from beta versions to final versions has been shown in this document.

As it is said in the IO3, the final version of CO2 Tool can be found in the following link:

Final version of the CO2 Tool

http://co2tool.oerco2.eu/es-ES

In future, the feedback of scheduled courses (which it can be checked in the *IO 2.3 Implementation of courses on specialization based on the OERCO2 project*) will be used in order to improved the CO2 Tool.