# Education to Sustainable development in an engineer school: Carbon assessment ® method applied to the design of a realistic small scale house.

Ph. DONDON (1)- C.A. BULUCEA (2)- P. CASSAGNE (3)
(1) Université de Bordeaux, IPB, Av Dr. A. Schweitzer 33405 Talence, France.
(2) Faculty of electrical engineering, University of Craiova, Romania
(3) Collège CHAMBERY 33140 Villenave d'Ornon, France
Philippe.Dondon@enseirb-matmeca.fr ; abulucea@gmail.com

*Abstract:* Since Kyoto protocol and agenda 21 main directives [1], France has now to divide by 4 its greenhouse gas emission, before 2050. For that purpose, the method " bilan carbone" ® has been developed by J.M Jancovici [2], [3] and French national agency for environment ADEME [4]. Firstly it allows the quantification of greenhouse emission of any private or public company whatever the field of activity and secondly it gives some indications to help the emission reduction. The method is starting to be distributed among the academic world for sensitizing the students and for applying carbon assessment to university activities. We present here an original and pedagogical application to a true building materials small scale 1/20 house design [5]. After model parameters definition and extraction, carbon assessment is discussed. Finally, we suggest the transfer of this study towards the education field as an example of sustainable development teaching in an engineer school.

*Key words:* Education to sustainable Development, Carbon assessment, student project

## 1. Introduction

### 1.1 ENSEIRB MATMECA engineering school short overview

This study was initialized at ENSEIRB-MATMECA school: The "Ecole Nationale Supérieure d'Electronique, Informatique et Radiocommunications de Bordeaux" (ENSEIRB) which was founded in 1920.
ENSEIRB-MATMECA is now member of IPB (institut polytechnique de Bordeaux) strongly linked to the Bordeaux 1, Science and Technology University.

### 1.2 Study and project general situation

This "small scale true materials green house" project was carried out over one academic year, through national collaboration with "the House of the Nature and the Environment" (MNE) of Bordeaux, national french organism ADEME (Agency of the Environment and the Control of Energy) France, the ENSEIRB-MATMECA (33400 Talence), the colleges Chambéry (33140 Villenave d' Ornon) and Henri Buisson (33400 Talence) (professors and pupils).
Thanks to a European collaboration with Faculty of electromechanical and environment engineering (Craiova university-Romania), it was possible to establish academic connexion on sustainable development, to refine the project definition and to work on results analysis.

## 2. Sustainable Development general context

### 2.1 Necessity of sustainable development

Since Rio de Janeiro conference (1992), Kyoto protocol and agenda 21 definitions [1], the necessity of a harmonious development is now admitted by a majority of scientific and political personalities. Even if sustainable development is a complex concept, which concerns a wide range of social, scientific, economical and environmental issues, each of us is able to do something for humanity evolution [6], [7].
The good question is not "necessity or not necessity of sustainable development". We do not have anymore choice: radical cultural change is needed in engineering education to embrace broad skills, environmentally aware attitudes, knowledge and fundamental values, human behaviour, as well as a sense of ethical responsibility [8], rather than the narrowly focussed "technical excellence" which is traditionally accepted as good engineering education definition.
If each of us do not raise its own level of conscience and of responsibility, the Nature there will force us,

willy-nilly. Elsewhere, the climate changes might be the first steps towards a great re-sequencing of our planet [6], [7]? In fact, the good question is first an individual question: "how each of us, we can do something for, in our daily or professional life". Do not wait political or/ and institutional initiatives. Start first by individual action.

### 2.2 Education to responsible and sustainable development

Since the environmental problems are mainly consequences from a too strong belief in the traditional engineering, the starting step for a human society in harmony with our environment could be in training the students in the spirit of caretaking for Nature, building awareness and understanding the human industrial society as a part of the whole living world on Earth. A highly professional specialist, with availability for focusing on a paradigm shift, accepting the framework of Cleaner Production as human moral obligation, must be the higher education purpose worldwide.

### 2.3 ENSEIRB-MATMECA state of art

A recent opinion poll among ENSEIRB-MATMECA students showed that around 40% are not aware or not really involved in sustainable development. More than 60% do not know job opportunity in sustainable development field.
Lastly, only 49% of the students would like to see included a specific sustainable development teaching in engineer school.
Whereas the national statistic and predictions for the next ten years show a strong progression of jobs creation in sustainable development field [9], job opportunities in green business seems to be still fuzzy in student's mind. Thus, this questioning confirms that a big work of awareness and education is required in our electronic engineer school.

### 2.4 Aim of the small scale house project

According to the previous paragraphs, the project started through an individual questioning of a few teachers: What can we include in our research field and/or pedagogical thematic to have a concrete action in sustainable development, while respecting the mains scientific fields of our engineering school?
Thus, the « small scale green house » project was born. The main technical goals were:

- To create a demonstrator (public exhibition in town halls or local sustainable development events)
- To use it as pedagogical support for practical lessons and electronic projects, for sensitizing engineering students in first and 2nd year study to sustainable development. It will allow the design of various low consumption electronic devices and management of multi source energy (solar, wind, hydraulic, hydrogen). Quantitative thermal measurements will be performed during practical lessons etc.
- To have a pedagogical tool for training to carbon assessment ® method.

Social and human aspects were also important in this study. It was the opportunity to establish connexion between local strewn people with the same sensitivity to environmental problems and to federate energies on a multi thematic project.

The chosen scale (1/20) makes the model big enough for ergonomic uses and small enough to be carried or moved easily.

## 3. Small scale house project's state of art

### 3.1 House building

The building (with true materials) of small scale house itself has been finished last year. It took a full academic year.

Figure 1: View of the house and surroundings.

The design has been described in a previous paper [5]. Externals walls are in AAC (Autoclaved Aerated

Concrete) while three internal interchangeable insulations can be cork, polystyrene, or polyurethane.
Windows are simple glazed or doubled glazed. Figure 1 shows a picture of the finished modular 1/20 scaled model. Power supply management, electronic heating with heating floor and ceramic resistors as well as solar panels for LED lightning have been partially realised by Enseirb-Matmeca students.

### 3.2 Originality of the work

Small scale model cartoon houses already exist in private architect offices and in the national agency ADEME. They explain new available green technologies for individual and collective buildings. Many secondary schools are involved in wood or cartoon scaled model house building, to illustrate architectural and design aspects.
There exists also « green houses » full scale (1:1) demonstrator created by the French ENSAM engineer school and Nobatek company for Solar decathlon challenge [10] (which is obviously not easily transportable). And theoretical works are still done on this subject [11], [12], [13].
However, pedagogical, true building materials and fully functional (building, insulation, thermal and electronic aspects) small scale modular house do not exist till now (neither in France nor in Romania).

Our project is thus an innovative work which will give place to many multi thematic projects fully compatible with the ENSEIRB-MATMECA and Craiova university main goals.

## 4. Carbon assessment method

### 4.1 Generalities

The global world energy consumption (nuclear, hydraulic, gas, oil, carbon) has been multiplied by 2 in 20 years and by 60 in less than 200 years due to demography growth and individual consumption increase (cf. Figure 2).

Most of experts from IPCC (Intergovernmental Panel on Climate Change created in 1988), are now convinced that green house gas emission has an impact on climate change and biodiversity evolution: the necessity of "action" is becoming obvious. Thus, aims in term of green house gas emission reduction have been defined for each country during Kyoto conference. (Cf. § 4.2)

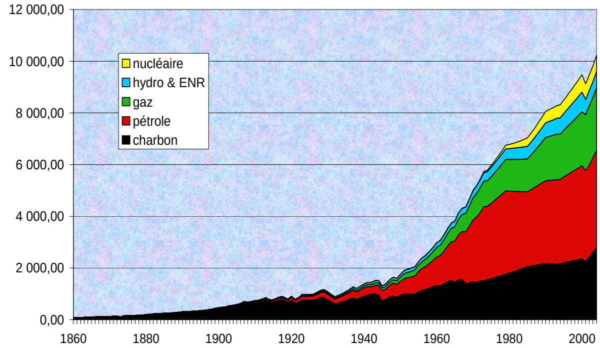


Figure 2: energy world consumption
(Vert scale MTep : Million Ton equivalent Oil)

(order of magnitude: 1 Tep ⇔ 7.3 barrels ⇔ 11 600 kWh ⇔ 1200 m$^3$ of natural gas ⇔3 tons of wood)

For that purpose, it is first necessary to evaluate the actual global and/or local emission. Thus, the carbon assessment method developed by J.M Jancovici and his consultant office "Manicore" was born.

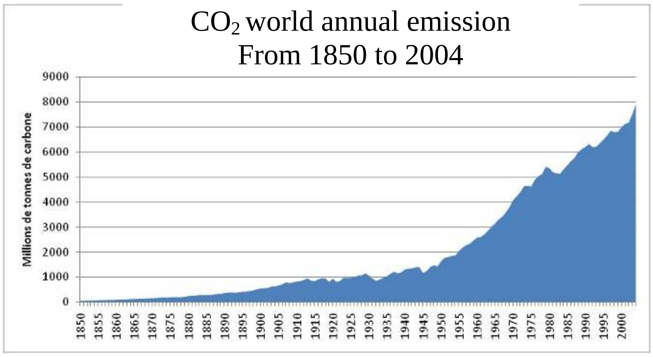


Figure 3 : $CO_2$ world annual emission

(Source : Carbon Dioxide Information Analysis Center)

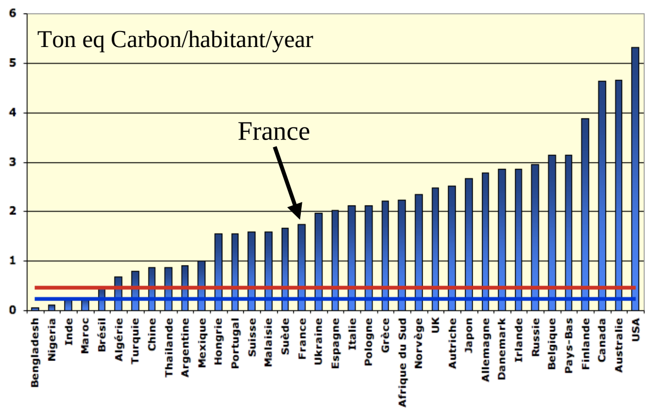


Figure 3: Carbon emission per habitant per country in 2003 in Ton quivalent Carbon per year

### 4.2 France short state of art

Kyoto protocol set up a “target” of division by 4 od green gasses emission before 2050, for France [14].
Among different consequences of this goal, the French “Grenelle 2” law n° 2010-788, voted the 12 july 2010, will make the Carbon assessment mandatory for public offices and some private offices [15] in the near future.
Energy and carbon assessment are now required in France before immovable property transaction (private flat sale). Energy saving characteristics and environmental quality of the “house for sale” are then displayed and becomes a new argument for the transaction. For that purpose, a normalized official classification is now available as indicated in figure 4 and 5. At the present moment, the average of national french house stock is in category E [16].

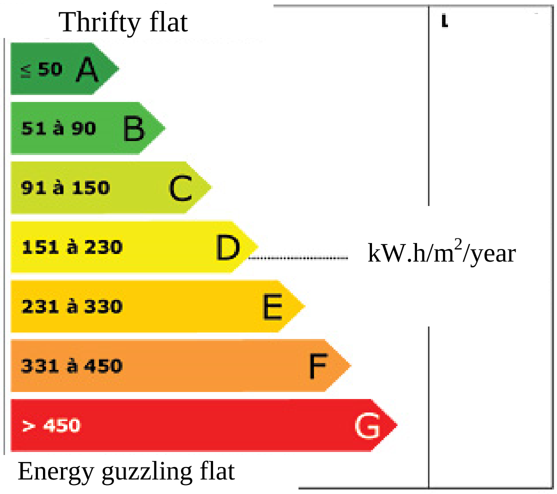


Figure 4: Energy consumption flat classification (in kW.h/m2 per year)

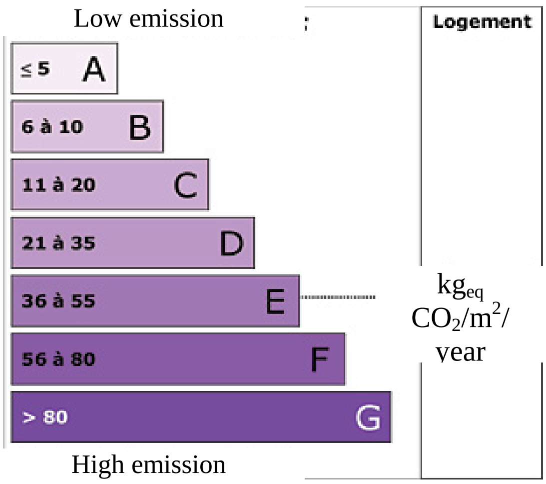


Figure 5: Carbon emission classification (in kg$_{eq}$ $CO_2/m^2$ per year)

Carbon assessment is also starting to be introduced in French universities. More generally, this kind of carbon assessment method covers a wide range of applications. Some various examples are given in references [17], [18], [19], [20], [21], [22].
Carbon assessment is thus starting to be well known and used in many fields of applications. It is important to introduce it in education field to sensitize the students.

### 4.3 Carbon assessment method short description

This method is a tool to quantify the greenhouse gas emission over one year, in any private or public company and/or activity as well as at a local level or country levels.
The greenhouse gases identified in Kyoto protocol are: $C0_2$, $CH_4$, $N_2O$, HFC, PFC, $SF_6$. Firstly, mixed emissions are globalized. That is, all emitted gases are converted in ton equivalent C or $CO_2$ (TeqC or Teq$CO_2$). Thus, each human activity generates an equivalent mass of $CO_2$. These carbon emissions can be evaluated from a national data base of Emission factors updated regularly. They have been calculated for the main activities’ sectors: energy production, transportation, building, manufacturing, agriculture, service, and so on. For example, emission factors of transportation sector have been determined by including a part of vehicle’s manufacturing “carbon cost”, and the journey $C0_2$ emission itself which depends on city or sub urban uses or road uses. A guide of available emission factors [23] and their calculation methods is edited by ADEME.
Whatever the activity analysed, a generic modelling can be used. It is shown in figure 2.

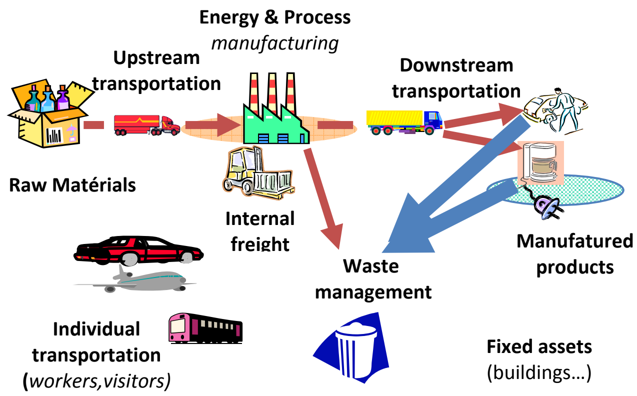


Figure 2: Activity generic model

And the “carbon assessment” takes into account the following aspects: Any factory uses raw materials and office stationery (which have their own emission factors). This generates an input transportation flux. Transformation process itself requires energy to create a manufactured product. Selling the final product

generates an output transportation flux. Product's end of life management has a cost in term of carbon emission. Workers home to working place transportation, internal freight, visitors arrival, must also be considered in the carbon assessment.
Lastly, fixed assets (factory buildings…) who have generated $CO_2$ emission while construction, are depreciated like in company annual' account.
From the emission factors data base, and from modelling, it is possible to evaluate the contribution to greenhouse gases emission of any activity.
While this model seems to be quite simple, the main difficulties are to identify each part of the model, to find the appropriated limits of the different $CO_2$ emission sources, to avoid omission or double counting, to collect and sort numerous data. Once the activity description is ended, data are entered in a complex multi sheet Excel Microsoft spreadsheet to compute the carbon assessment. Results are reported on histogram and can be sorted by activity or by product.

## 5. Application to the small scale house design project

Thus, the small scale house project is used to run the carbon assessment method. The next paragraph §5.1 is dedicated to model definition, hypothesis input data identification and calculation. Paragraph §5.2 presents some results.

### 5.1. Perimeter and model definition

As ENSEIRB and Chambery college are associated in this project, two working places are clearly identified:

- Chambery College; mechanical and assembly workshop $80m^2$, two classrooms $30m^2$ each, The occupation rate for this project was one day per week over the academic year (i.e. 40 days per year).
- ENSEIRB-MATMECA: one teacher office, $12m^2$; part time occupation for this project: around 1/20 of the total occupation.

The distance between the two working places is around 9km.

Direct energy consumption in (kWh) for manufacturing the small scale house is computed by summing all the contributions and power's quota of each activity as follow:

- Room and workshop lightning: an average value of $12W/m^2$ is admitted for a correct lightning. Occupation rates and surfaces have been given just before.
- Mechanical machine powering :
    - Mechanical stone saw (power 800W): cutting Siporex blocks (AAC) required around half hour.

Figure 3: Stone saw

Figure 4: Drilling machine

    - Milling machine (power 600W): 4 windows and one door are assembled on each internal interchangeable insulation walls. Thus, a total of 15 parts (5 parts*3 interchangeable insulations) have been milled. Machining time for one part is around 1/4hour.
    - Wood saw (power 600W): roof structure cutting and preparation, 20 parallel trusses required one hour of machining.
    - Printed circuit manufacturing and tinning (power 1000W): around half hour for the "house heating electronic control circuit".
- Classroom heating (from natural gas): an average realistic estimation is around

100kWh/an.m$^2$ for the kind of workshop which is old and badly insulated). Workshop heating quota is computed considering that it was used one day per week over the 4 winter months.

The following raw materials are identified:

- AAC (Autoclaved Aerated concrete block) for external walls.


Figure 5: AAC external wall

- Local pine wood for the roof frame coming from a local sustainable managed forest (roof frame will be considered like a carbon well for the total lifetime of the house (around 100 years for a true house).

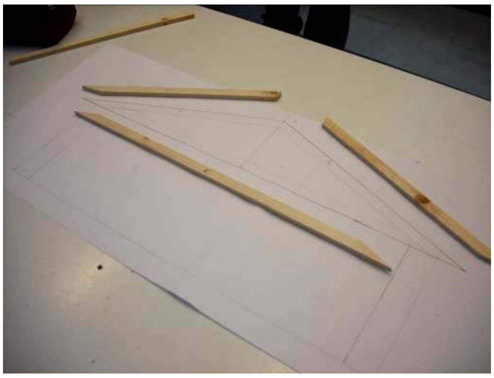
Figure 6: pine wood roof structure design

- Forex (PVC derived from oil products) for the window frames.
- Internal thermal insulators: choice of cork or polystyrene or polyurethane panels for walls and mineral wool for the ceiling.
- Terra cotta tiles for roofing.
- 180 solar cells IXYS (22mm x 6mm)
- Consumables: neoprene glue, paper, cardboard, electronic components, PVC tube for piles under the house model.
- Surroundings: green grass “carpet”, natural and artificial mosses.

The following upstream freights are identified:

- AAC comes from siporex factory located in Mios city, 39 km far from Chambery college, and it was transported by truck,
- Other raw materials (glass, insulators, wood plate, consumables…) come from a local retailer and were transported by car (2 trips). The distance retailer to college is around 15km.
- Grass carpet and other surrounding accessories come from a toys shop located at the north of Bordeaux (11km far from Enseirb-Matmeca school)
- Scaled tiles and solar cells are forwarded from a retailer in the suburb of Paris by post: the parcel weight is around 1kg. It is transported by a small truck shuttle (railway station to warehouse 2*10km) and train around 580km (from Paris to Bordeaux).

The following downstream freight is identified:

- Final shipment of the scaled house by a small truck from College to ENSEIRB (9km)
- Two local exhibitions: 2* 15km round trip.

Individual transportations related to the project are identified as follow:

- ENSEIRB: Daily trip home to working place for one teacher by feet, (no carbon contribution)
- Chambery College: Two teachers and 6 pupils were working on the project one day per week. (i.e 40 days per years academic vacations excluded)) Home to working place trip represented an average daily distance of 10 km (way and return) in the Bordeaux city suburb. Two were coming by public bus and 4 with personal car. The pupil’s lunch is on site (no transportation).
- “Internal” transportation: 6 site meetings on the building site, distance ENSEIRB-Chambery college 20km way and return.

Fixed assets are taken into account as follow:

- College building age is greater than 30 years. Thus, no depreciation was included for the building as well as for furniture.

- Because Personal Computers were less than 3 years old, informatics depreciation was included for the PC used during the project.
- Mechanical machines (milling & saw,) are depreciated over 10 years. The estimated of "carbon cost" per year is based on the machine's weights (2*250kg).

Packing of raw materials which generates "carbon cost" for manufacturing and post processing or destruction, are identified as follow:

- Plastic bag for tiles (weight around 20gr).
- Cardboard boxes for electronic components (weight around 80gr).

Lastly, wastes are identified: most of wood, plastic and papers off cut, are reused for teaching purpose. Thus, there is no "carbon cost" to post process the wastes.

Using the generic model of figure 2, our project can be customized as indicated in figure 7.

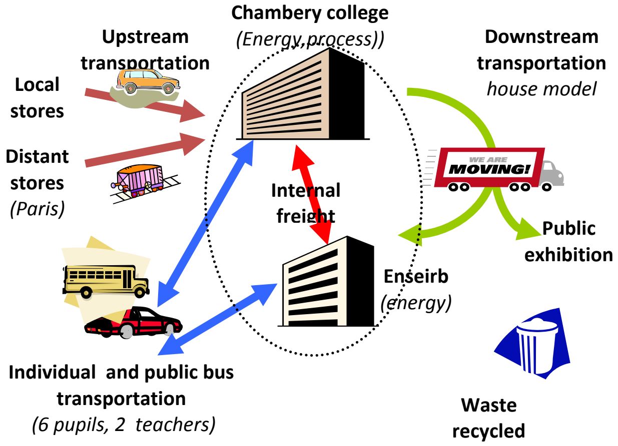


Figure 7: Process model

### 5.2 Results

After data capture and calculus of the spread sheet, some carbon assessment results are displayed and given in figure 8 and 9 below.

Figure 8 shows the $CO_2$ emission versus the type of raw materials in " Kg equivalent $CO_2$" per year.

Figure 9 shows the carbon contribution of the freight in Kg eq $CO_2$ per year. Upstream road freight is the most important part. However global emission of freight is negligible compared to the others.

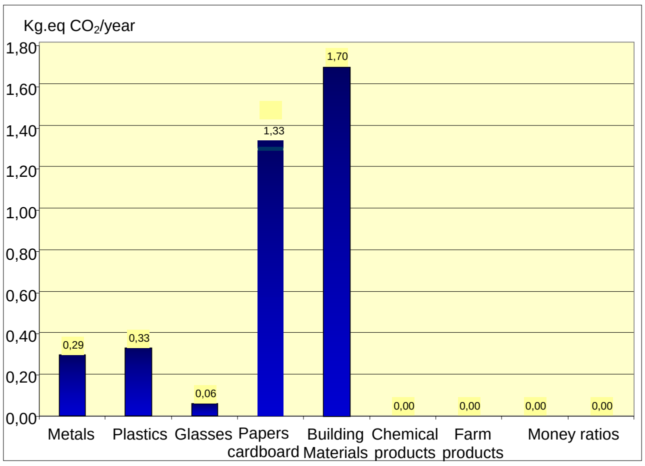


Figure 8: $CO_2$ Emission by type of input raw material

Figure 10 shows the carbon contribution of the fixed assets in Kg eq $CO_2$ per year.

Figure 11 shows the carbon quota of transportation in Kg eq $CO_2$ per year. Main contribution is "home to job place" journey. The second one corresponds to internal transportation as defined in §5.1.

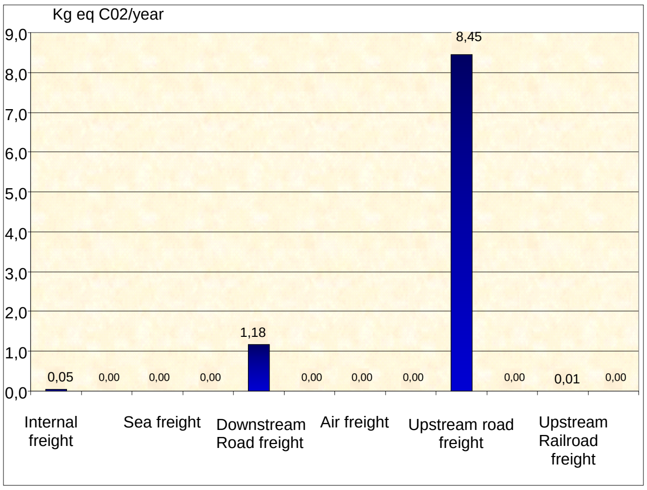


Figure 9: In/out freight contribution

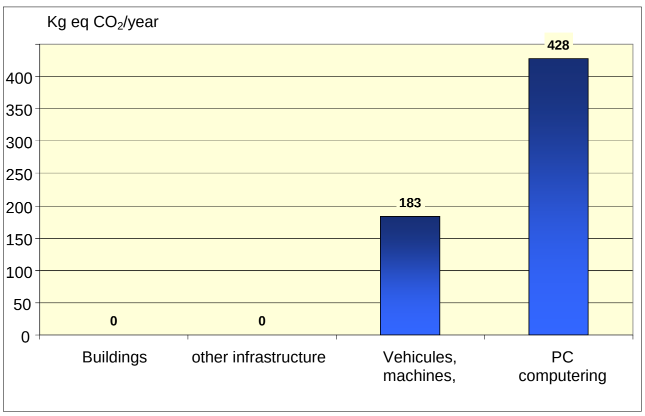


Figure 10: Fixed assets contribution

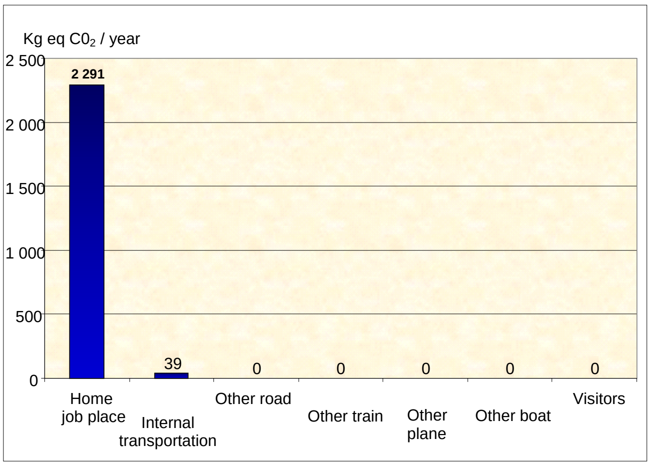


Figure 11: $CO_2$ gas emission transportation contribution

Figure 12 shows the carbon assessment of our full project in Ton eq $CO_2$ per year by main category: energy, raw materials, in/out freight, transportation (reported from figure 9), fixed assets, etc.

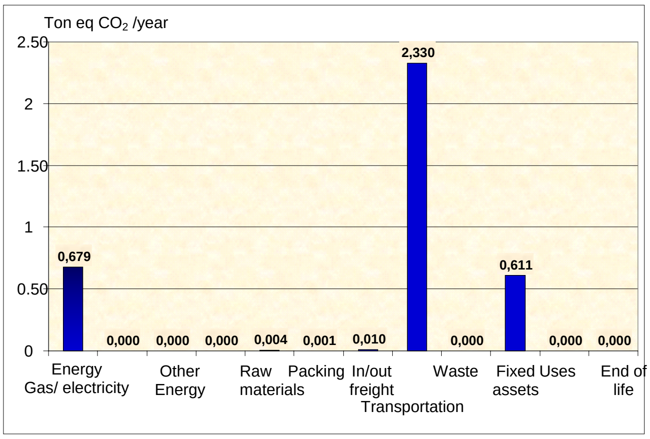


Figure 12: $CO_2$ gas emission final assessment

# 6. Discussion

This case study makes it possible to apply the carbon assessment method and to highlight the possible difficulties. It is a realistic example comparable to a true situation of a house's manufacturer doing a global carbon assessment on his activity, distributed per products (i.e. per house).

## 6.1 Result's comments and analysis

- As we are not familiar with Teq $CO_2$ unit, it is useful to give an interesting order of magnitude: natural breathing emission of an individual is around 300kg of $CO_2$ per year. Thus, the $CO_2$ cost of our project is equivalent to around ten people natural emission during one year.

-From figure 10, we can quote that carbon impact of computer hardware is not negligible compared to other equipments.

- From figure 12, people transportation is the most important $CO_2$ emitter.

- In comparison, freight is not important because there is a few and light raw materials: In a true case, theses proportions should be obviously different: impact of raw materials and freight should increase while transportation impact should remain quite constant.

- How to reduce the carbon foot print? Here, a simulation showed that using public transportation or school bus, instead of private cars would divide by more than two, the transportation contribution (cf. figure 13, to be compared to Figure 11). Walls and ceilings insulation improvement of Chambery College could reduce energy contribution by 1/3. A carbon compensation strategy could also be discussed to reduce carbon impact as it is already done in some private companies [15].

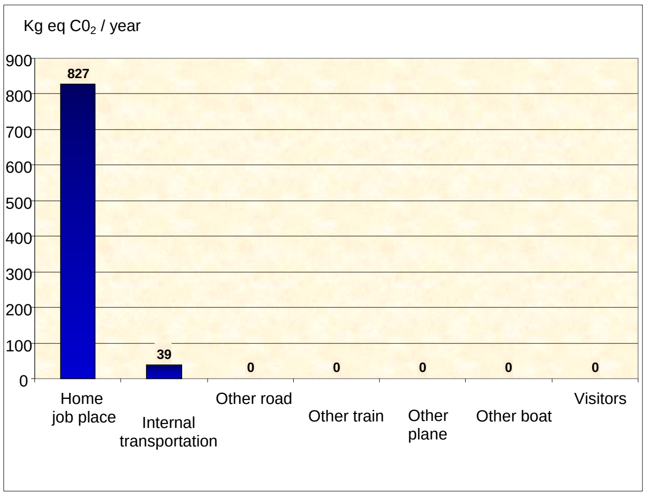


Figure 11: Simulated impact of public transportation use (reduction of carbon cost)

Generally speaking, it is extremely difficult to measure $CO_2$ emission for this kind project. Thus, it is quite impossible to check the result's validity: we have to trust the method which has been previously validated in many public and private applications. However, in the present study, it is possible for example to correlate transportation emission results with an alternative computation, that is, from the average emission of vehicles (i.e. 150gr.$CO_2$/km given by cars retailers) [24], the total distance covered, and the emission for manufacturing the vehicle itself.

Anyway, the main interest of the method is not to quantify very precisely the $CO_2$ emission but more surely, to highlight the relative impact of each contribution in the assessment.

This first $CO_2$ assessment of « small scale house building » could be nearly "included" in a top level assessment: that is, the scaled house in daily use. It should take into account the daily energy consumption (lightning and heating) and the presented assessment including depreciation over the life time of scaled house model.

### 6.2 General interests of « carbon assessment »

More generally, a carbon assessment allows to:

- To become conscious of each personal or professional activity impact,
- Obtain a state of art of green gases emission at initial time $t_o$ in order to compare the evolution a few years later,
- To make a comparison of two kind of process (here AAC house or wood house for example).
- To give a decision help to a business manager in order to engage actions for carbon impact reduction.

### 6.3 Awards

The small scale house model design, building and all related studies have been rewarded by the "Gironde administrative department council" during the Agenda 21 trophy ceremony in November 2011 [25]. It received the "heart price" in the academic work category.

## 7. Introducing sustainable development in the traditional engineer student curriculum.

Becoming aware of the main stakes for the future of the planet is one of the most important necessities that we have to understand.
Education to sustainable development is a key action to learn how to change individual and collective behaviours, how to reduce energy consumption, and how to reduce our ecological footprint. Thus, we would like to initialize a concerted action inside IPB (Institut Polytechnique de Bordeaux) to define common possible action in sustainable development thematic. In particular, we could start a global carbon assessment in each school of IPB, and define realistic aims to reduce the carbon foot print of our institutes. ENSEIRB-MATMECA sensitizing lessons (around 12 hours) including carbon assessment and practical lessons on small scale house ("clean" energy production, thermal insulation, and electronic circuits). This would make it possible to point out sustainable development needs without forgetting our initial field of study i.e. "hard" electronic. We hope to convince our staff very soon [26], [27], [28].

## 8. Conclusion

Thank to implication of some teacher, a small model of «green house » (1/20 scale) has been designed in collaboration with Chambery College. Once finished, it has been successfully used for a first implementation of carbon assessment method.
Mains steps of the method have been shown explained and validated. It is now ready to be used for the students training as sensitizing tool to sustainable development in addition to other practical lessons on the small scale house.

More generally speaking, [29], [30], [31], [32], [33], [34], this cross thematic project was an opportunity to mix sciences, technology, creative arts, hand work, and to discuss about education to sustainable development aspects. Thus, we hope that this approach will be extended step by step in our Institute.

## Acknowledgment

Special thanks to Climamundi, Cm3e, Altern consult and ADEME for the carbon assessment university training seminar.
Many thanks to all the pupils from college Chambery (Villenave d'Ornon) and H. Buisson (Talence) who worked with high motivation for house building.

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