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INTERNSHIP REPORT

CARBON FOOTPRINT OF VINCI'S LARGE PROJECTS

NON-CONFIDENTIAL REPORT

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Internship dates: 15/06/2020 – 31/12/2020

DECLARATION OF ACADEMIC INTEGRITY

Hereby I, Benyamin BIDABAD, confirm that:

1. The results presented in this report are my own work.
2. I am the author of this report
3. I have not used the work of others without clearly acknowledging it, and quotations and paraphrases from any source are clearly indicated.

Name : BIDABAD Benyamin
Date : 13 November 2020

Signature:

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1 Introduction

In the structure of my master studies in energy and environment, I am writing this report to share the experience of my 2nd internship held at VINCI Construction. I started working in the department of Engineering & Innovation on the 15th of June and I am supposed to conclude the internship by the end of December 2020. By the time I'm writing this report, the internship is still ongoing. I was part of a team of 12 to 16 people who kept constantly changing in size. The communication language in the office was French, but the internship report is written in English.

The office is located in the headquarters of VINCI Construction in Rueil-Malmaison. VINCI Construction is a French construction company that operates in 118 countries. It has about 70 000 collaborators with a yearly revenue of 14 billion euros. It has many sub-entities such as:

- VCF (VINCI Construction France)
- VCGP (VINCI Construction Grand Projets)
- VCIN (VINCI Construction International Network)
- VCT (VINCI Construction Terrassement[1])
- SOGEA SATOM (Division operating in Africa)
- SOLETANCHE FREYSINNET (Soil, structures and nuclear professions)
- SOLETANCHE BACHY (Foundations and soil technologies)
- ENTREPOSE (Energy Projects)

The Engineering and Innovation Department of VINCI Construction has the mission to support the other divisions in the development and deployment of cross-functional innovations such as new materials or new technologies. These innovations can help meet the challenges of climate change but can also help optimize safety and productivity on its worksites through the use of new tools.

The primary goal of this internship is to study the carbon footprint of construction projects and identify the main actors and contributors in terms of CO2 emissions. We studied many construction projects, but not just any project. We were not interested into buildings and typical construction sites. What interested us was larger projects, such as bridges, airports, metro lines and etc. These projects were accomplished by the company all around the world in Egypt, Panama, Kenya, France, Greece and etc.

[1] Earthworks

The secondary goal of this internship was to help the innovative environmental solutions in the company to rise and become operational. It also included raising environmental awareness across the group, sharing the environmental solutions developed by other divisions of the company, and helping VINCI meet their environmental goals.

1.1 Why count carbon emissions?

As the concentration of CO2 and other green house gases is raising the atmosphere, the threat of climate change is becoming more and more important. This is why it is important to be aware of our emissions learn to control and reduce them. Governments and companies are engaging in reducing the carbon emissions of their activities, and so is VINCI Construction. The construction industry occupies 30% of the world's total carbon emissions and therefore VINCI can play a very important role in reducing the pollution. The environmental objective of VINCI construction is summarized in the following three point:

- 40% reduction in CO2 emissions by 2030
- Inclusion in the objective of carbon-based neutrality by 2050 set by France as part of the Paris climate agreement
- Commitments to the circular economy and respect for natural environments

During this internship we will assess the carbon footprint of multiple projects. A carbon footprint is a quantitative evaluation of the greenhouse gas emissions (expressed in tCO2eq[2]) emitted or captured in the atmosphere over one year by the activities of a company. These emissions can be broken apart in three categories: Scope 1, Scope 2, and Scope 3.

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[2] Tons of carbon-dioxide equivalent

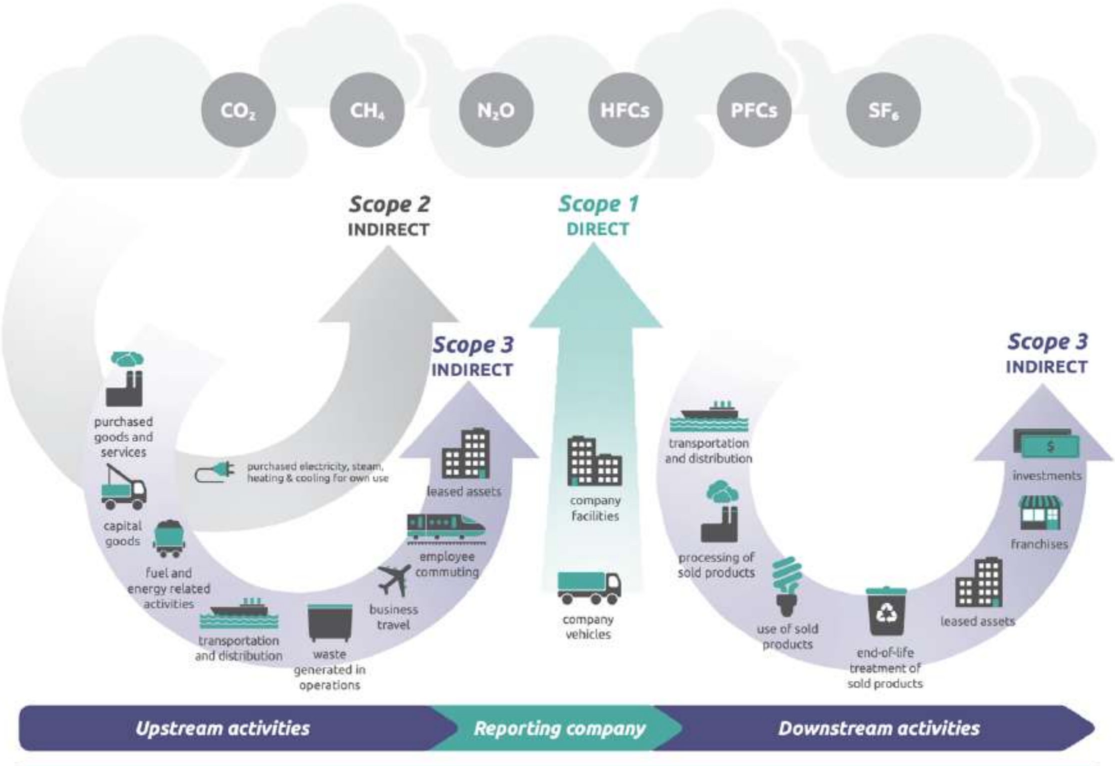


Figure 1 - Emission scopes explained

Scope 1 represents direct emissions from a company's fixed or mobile installations, i.e. emissions from sources owned or controlled by the company (combustion, biomass, heat engine, etc.).

Scope 2 represents the emissions associated with the production and consumption of electricity, heat, steam or cold imported for the company's activities.

Scope 3 represents other indirect emissions upstream and downstream of the company's activities (waste, business travel, commuting, transportation of goods, investments, use of products, end of life of products, etc.).

Scope 1 and 2 are considered direct emissions and Scope 3 is considered as indirect emission. For example, at a construction company like VINCI, the emissions from the diesel generators on worksites is considered as Scope 1, the electricity to powerup the offices is considered as Scope 2, and the material supply used for construction belong to Scope 3 emissions.

In order to perform a carbon footprint for a project, one needs to know two things:

- **The physical quantity** of the resource used in tons, m^2, m^3, and etc. For example, the quantity of steel used for the frames in tons.
- **The emission factor** associated with that physical quantity. For example the emissions associated in the supply chain of the steel to be produced, transported, and installed on the worksite.

In section 2 we will discuss our methodology on how we collected these physical quantities and emission factors.

2 Methodology

It is important to note that the goal of this assessment is not to generate an exact and complete carbon footprint for our projects, but to understand the order of magnitude of different emissions in non-typical construction sites of VINCI such as metro lines, bridges, airports, and etc. Our final goal is to identify the levers of action on reducing the carbon footprint of the worksites and projects.
In order to assess the carbon emission of these large projects, we are using past reports as a reference for our data. We contacted the responsibles of the projects and gathered as much information as possible. Most of this information is in form of REX[3] reports and/or in form of data sheets. A REX, in French "Retour d'expérience", is a large report (ranging from hundreds to thousands of pages) published after completing the construction phase of the project. These reports explain how and with what quantity of supplies the project was accomplished. We read through these large reports and try to gather as much relevant data as possible. It's important to note that the data on these reports or data sheets are not standardized for a carbon footprint assessment, so the accuracy of our results is always limited by inexistent or incomplete data. Once the data collected, we will calculate the carbon emissions by using the tools and emission factor databases at hand (See the next chapter).

The limitations of the study:

A few examples of the factors that limit us and the exactitude of our assessment are as follows:

- In general, our emission factors are limited and cannot be adapted to location. For example, for a project in Panama and a project in France, the same emission factors are used (this is not the case for electricity as we have locational emission factors).
- The emission factors are limited in time as well, we are using the same emission factor for a project done in year 2000 and a project done more recently in 2016.
- The quantity of concrete wasted/not used is not always mentioned in the reports. We have seen in some projects that the wasted concrete makes a large part of the total concrete produced. What we mean by wasted concrete is the concrete produced but not used in the main structure of the project.
- The type of concrete (low carbon concrete or normal concrete) is not always mentioned.
- The supplier of steel, whether it is recycled or not is not always evident.

[3] Return on Experience

- The source of the material supply is not always known so calculating the emission of the freight is a challenge.
- The list of machinery mentioned on the REXs are not always exhaustive.
- In calculation of the amortization of equipment, the lifetime of the machines is not a data that is commonly found in the reports. Also, we don't always know the details of the usage of the device, i.e. in which phases of the project was the machine used and how long.
- Sometimes a mere list of machines is provided without any data about their price, weight, duration of function, consumption, emissions and etc. In these situations, the list is obsolete and cannot be used in the assessment.
- The fuel consumption on the worksites is not always metered properly. Most of the times we have a total amount of fuel purchased which does not clarify how much of it is dedicated to the life bases and how much to the machines.
- The exact number of workers/engineers/managers on the worksite is often not mentioned. Instead, we have the number of hours worked. Using this and the duration of the worksite we can make rough assumptions on how many round-trip travels have happened.

These were just some examples of what could be limiting the accuracy of these carbon footprints. But in return we have some very good tools at our hand that make the job much easier. We will talk about them in chapter 3.

3 Emission assessment tools

Two main resources are used for assessing the carbon emissions. One of them is a carbon footprint tool and the other is and emission factor database. These two are presented in the following subsections.

3.1 CO2NCEREND

CO2NCERNED is a tool developed by VINCI that allows to evaluate the greenhouse gas emissions of a construction site in the project phase (call for tenders) and in the follow-up phase. It covers the following six emission items:

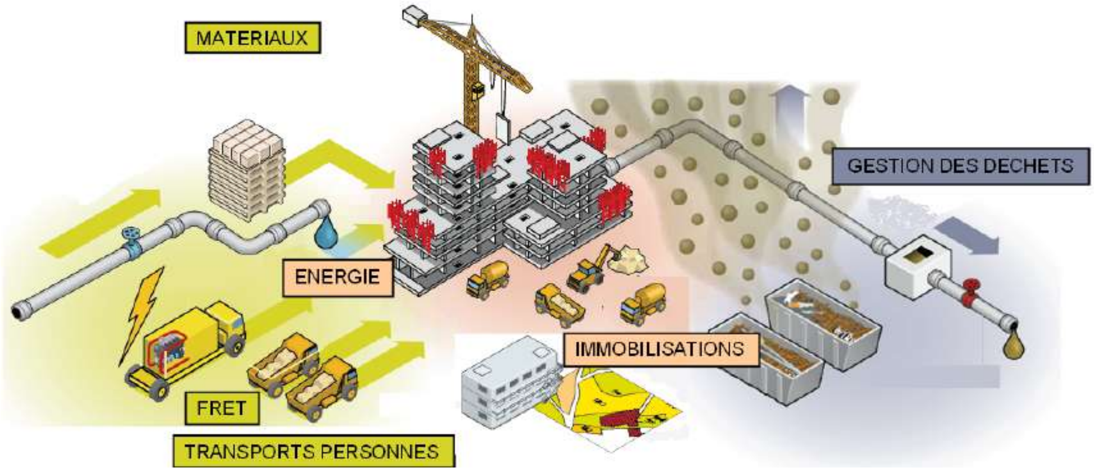


Figure 2 - The six emission items of co2ncerned

- energy
- supplies
- freight
- depreciation of equipment
- transportation of people
- waste management

It also has multiple modules adapted for different types of worksites such as buildings, airports, roads, external networks, earthworks and etc. It enables the comparison of CO2 emissions of several variants of a project in order to choose the best environmental solution.

The emission factors used in CO2NCERNED come from different databases:

- ADEME's carbon-based database (Agence de l'Environnement et de la Maitrise de l'Energie)
- EcoInvent database
- Environmental and Health Declaration Forms (FDES) of the INIES
- VINCI Group internal data

- Data from **material manufacturers**, and etc.

It has two main advantages:

- On one hand, it provides a base of **emission factors** relevant to our activities, which synthesizes the carbon base, iniès base, EcoInvent base, and etc.
- On the other hand, it uses **business ratios** that simplify data entry, such as the average consumption of typical construction machines.

The tool in excel format was developed in 2009 and updated in 2016 in collaboration with the strategy and environment consulting firm I Care & Consult and certified Bilan Carbone® (latest version 2018) by the Bilan Carbone Association until 2021. Today the tool is available in a web format which is still under development. I contributed partially to the development by providing user feedback and bug reporting.

3.2 Base Carbone

The **Base Carbone®** is a public database of emission factors necessary to perform carbon-based accounting exercises. It is administered by ADEME, but its governance is multi-actor and its enrichment is open. ADEME, the agency for ecological transition, is active in the implementation of public policy in the areas of the environment, energy, and sustainable development. ADEME provides expertise and advisory services to businesses, local authorities and communities, government bodies and the public at large, to enable them to establish and consolidate their environmental action. We use this database as the source of our emission factors. It is especially useful whenever an emission factor is not listed in co2ncrened. It is also one of the principal sources feeding co2ncerned with emission factors.

4 Atlantic Bridge in Panama

We will start presenting our projects assessment results with one of the most complete projects, the Atlantic bridge. We have information about almost all the aspects of this project so we could have a global view of the emissions and how they are generally distributed. For this project we will explain all the assumptions in detail to give the reader an idea of how the estimation is done. As for the other projects we will try to focus less on the details and more on the results.

Figure 3 - The Atlantic bridge in Panama[4]

VINCI Construction Grands Projets was mandated to build this cable-stayed, dual 2-lane, concrete roadway bridge that does 1,050 metres long, with a main span of 530 metres, pylons of 212.5 metres high, and a vertical clearance of 75 metres. The structure is located 3 kilometres north of the Gatun locks near the city of Colón. The bridge is designed to allow the passage of the huge Post-Panamax container ships as part of the Canal's post-expansion operations. It will also allow vehicles to cross the Panama Canal on the Atlantic side regardless of whether the locks are in operation or not.

[4] Source : www.vinci-construction-projets.com

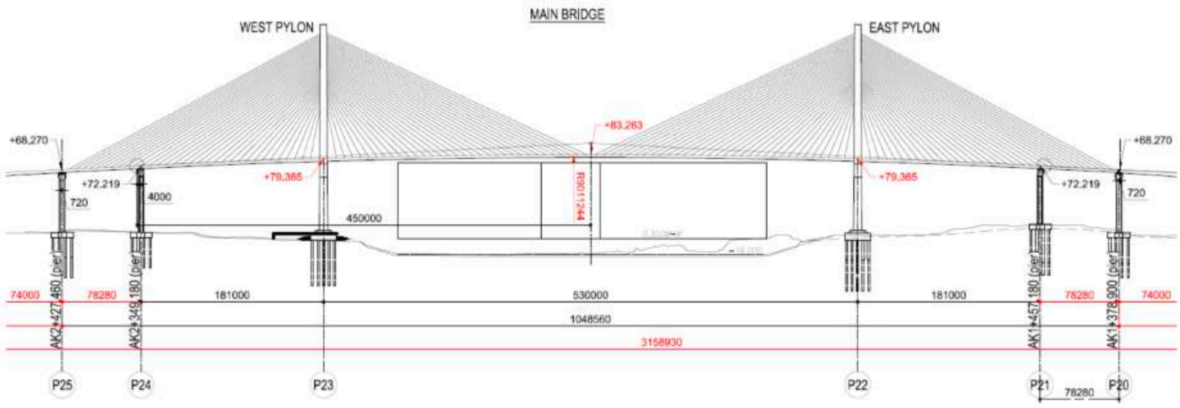


Figure 4 - The scales of the Atlantic bridge in Panama

In order to perform the carbon emission assessment of this project we referred to the REX [5]of the project and gathered as much physical data as possible. Many information were found but many were missing as well. Reasonable assumptions were made to calculate the carbon emission even without complete data.

4.1 Materials

With a global overview over the materials, the quantity of the materials is summarised in Table 1.

Table 1 – Summary of general quantities of the Atlantic bridge

Structural concrete	174,000 m3 structural concrete (250,000 m3 produced in total)
Steel	34,000 t
Pre-stressed cables	2,100 t
Suspension cables	1,860 t
Formwork	254,000 m2

The assumptions used to count material emissions are described below:

- We took a grade of C35/45 for unknown concretes when details were not available.
- We took the density of concrete equal to 2400 kg/m3 to convert it into tons.
- For the forms, we consider that they are made of 50% steel and 50% wood.

[5] Feedback of experience (in French, Retour d'experience)

- For the steel we have taken the hypothesis that 100% new steel is used. Recycled steel has a lower emission factor but the type of steel was not specified in the REX[6].
- For the rebars, they are transported from Turkey to Panama, making a freight of 11,344 km. The same assumption was made for any steel used on the site.
- For all physical quantities (concrete, formwork, cables, …), if the distance of the freight is unknown, a distance of 100 km has been estimated.

4.2 Machines and Equipment

The emissions from machinery and generators caused by their consumption are already included in the "consumables" section of the REX in the form of fuel consumption. It will therefore be crucial not to recount the consumption again when we enter the machines data in the calculation tool.

The assumptions used to count machinery emissions are described below:

- It is assumed that all machines are brought from the Netherlands with a freight of 8900 km to arrive at the construction site. With the weight of the machines we can calculate the total ton.km. It is assumed that the machines are transported by container carriers of more than 7500 TEU.
- The cost of purchasing the equipment is given (21 M€). The emissions for these machines is calculated from the monetary emission factor of the Carbon-Base (700kgCO2/k€) which is therefore 14,700 tons of CO2. The lifespan of the machines is considered to be 5 years by assumption, they are therefore 100% amortized during the duration of the construction site.
- For the tools and equipment, the data is available in currency. An estimation of 100 kgCO2/k€ has been assumed to calculate the associated emissions.

[6] Retour d’experience (Feedback of experience)

4.3 Personnel and Travel

Table 2 - Expatriate staff of the Atlantic bridge project

Catégorie	TOTAL hommes.mois	Coût total (k$)	Coût moyen mensuel par catégorie ($)
VCGP	3 197	50 283	$15 728
VINCI MOBILITY	412	4 244	$10 293
VIE	525	2 248	$4 285
FREYSSINET	467	2 319	$4 970
AUTRES EXPATRIES	735	9 442	$12 850
TOTAL EXPATRIES	**5 335**	**68 537**	**$12 845**
TOTAL CONTRATS LOCAUX	**7 848**	**28 360**	**$3 614**
TOTAL ENCADREMENT	**13 183**	**96 896**	**$7 350**

- Hypothesis for expatriate travel: two round trips by plane per year for 5 years (duration of the project).
- The total number of expats in the REX is equal to 5,335 men.months, equivalent to a total of 89 expats. (see Table 2).
- The air distance from Paris to Panama is equal to 8700 km (one way).
- The travel distance of the workers is considered 20 km by car to arrive at the construction site.
- 8 hours of work per day for the workers were considered. This is used to count the number of round trips to the construction site.

4.4 Services and Studies

The assumptions for this part of the emissions are as follows:

- Emissions from all construction services found in the report, such as electrical installation, concrete trenching, runways and earthworks, and etc. are calculated using a monetary ratio given by the Base Carbone® for construction services.
- As the project is carried out in Panama, sometimes monetary data in dollars is available. A ratio of 0.85 dollar/euro has been taken into account to unify the emission factors.
- Methods and design studies (about 23,000 k€) are neglected. Because in the CO2NCERNED tool the studies are counted as staff travels and this is already calculated using other emission factors in section 4.3.

4.5 Results

A complete summary of the results is shown in Table 3 and Figure 5. The total emissions of this project is equal to 227,000 tCO2e. Almost 66% of the total emissions is coming from the construction supplies such as concrete (29%) and steel (37%).
The energy used to powerup the construction site is responsible for the next big slice of the emissions (18%). It's important to note that the electricity used in Panama is not decarbonized like as in France. Also, the majority of the energy emissions come from the machines powered up by fuel or diesel generators (67%).

Table 3 - Summary of carbon emissions of the Atlantic bridge project

	Physical Quantity			Emissions	
ENERGY	Fuels	11.300,000	L	35,700	tCO2e
	Electricity	17,900,000	kWh	5,300	tCO2e
CONCRETE SUPPLIES	Structural concrete	250,000	m3	65,000	tCO2e
STEEL SUPPLIES	Steel	34,000	t	74,800	tCO2e
	Prestressing cables	2,100	t	4,600	tCO2e
	Suspension cables	1,900	t	4,100	tCO2e
OTHER SUPPLIES	Formwork	254,000	m2	730	tCO2e
	Equipment, joints, etc.	divers		3,000	tCO2e
	Tools	24,000	k€	2,400	tCO2e
IMMOBILIZATION	Machinery	21,000	k€	14,700	tCO2e
FREIGHT	Freight of machinery and materials	430,800,000	t.km	4,400	tCO2e
	Travel	48,725,600	km	5,470	tCO2e
OTHERS	Services	32,550	k€	6,400	tCO2e

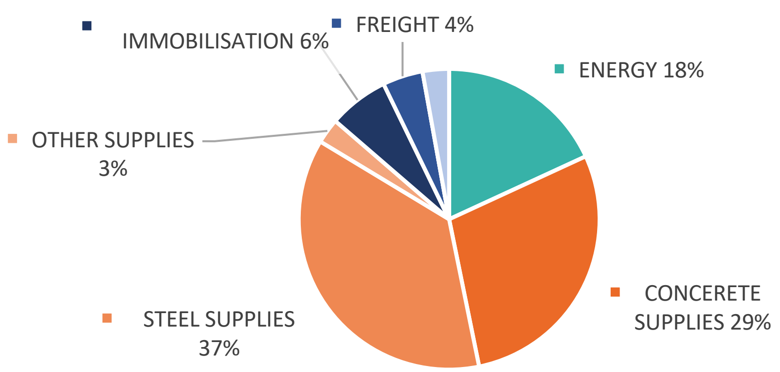


Figure 5 – Pie-chart of the emissions of the Atlantic bridge

5 Airport in Kenya

Figure 6 - The Kenya Airport

In the case of the Kenya Airport, we didn't receive a REX report but we received a carbon assessment sheet that was previously done by SOGEA SATOM[7]. We wanted to redo the carbon assessment with our own tools and emission factors.

5.1 Machines

We came across a long list of 120 machine and equipment, so we combined them and found the equivalents in co2ncerned. In some cases, there were some equipment that were too specific to this worksite and an equivalent could not be found. Using this approach, we can find the emissions from the **consumption** of the machines existing in co2ncerend. The sum is equal to **5,123 tCO2eq**.

[7] The branch of VINCI Construction operating in the African continent.


ENGINS, option 2 : Consommation détaillée de carburant

Famille	Engin	Nb	Jours	Conso énergie unitaire			Commentaires
				Ind.	Réel	Unité	
Transport sur site	Camion 6/4 14 T	1	4100	270		litres/jours	8 heures par jour
Chargeuses	Chargeuse sur pneus (15 à 20t)	1	646	176		litres/jours	8 heures par jour
Bouteurs / Niveleuses	Bouteur (25 à 30t)	1	149	211		litres/jours	8 heures par jour
Finisseurs / Alimentateurs	Finisseur (15 à 20t)	1	312	146		litres/jours	8 heures par jour
Pelles	Mécalac (14)	1	803	96		litres/jours	8 heures par jour
Bouteurs / Niveleuses	Niveleuse (14 à 20t)	1	593	152		litres/jours	8 heures par jour
Pelles	Pelle sur pneus 15 à 20t	1	477	111		litres/jours	8 heures par jour
Chargeuses	Petite chargeuse <10t	1	385	63		litres/jours	8 heures par jour
Pelles	Tractopelle	1	750	82		litres/jours	8 heures par jour

Figure 7 - A view of the con2cerned tool on the machinery page

For these machines, we also had the individual weight of each. To calculate the **manufacturing** emissions using a factor of emission per ton of equipment (5.5 tCO_{2e}/t) we take the assumption that the machines are completely amortized for the duration of the worksite. The total weight of the machines is 1300 tones which therefore gives a total of **7,150 tCO2eq** of emissions.

The data for the freight of the materials are calculated in section 5.5.

Table 4 - Emissions of the machines in Kenya Airport project

ENERGY	Energy	5,123 tCO2eq
IMMOBILIZATION	Manufacturing of machines	7,150 tCO2eq
FREIGHT	Freight of machines	calculated in section 5.5

It important to note, as we could not find some of the machines on our tool, the manufacturing emissions are exhaustive while the consumption emissions are not.

5.2 Energy

On the data sheet we had the total amount of fuel and electricity used on the worksite. Therefore, we were able to calculate the total energy emissions. As we had 3 types of fuel in the dataset, and as co2ncerend does not let us distinguish between the three, we used the Base Carbone for individual emission factors. The total emissions resulted is **3,765 tCO2eq of fuel emission**.

As for electricity in Kenya, we used the local emission factor of 0,274 kgCO2/kWh and got a total of **50 tCO2eq of electricity emission.**

Comparing these emissions to the consumption of machines calculated by co2ncerned, we can see that co2ncerned has a more pessimistic view towards machines' energy emissions. When counting the total emissions of the project, its important to exclude the machines consumption emissions as we want to avoid any overlap in the energy emissions.

Table 5 - Energy emissions in Kenya Airport project

ENERGY	Kerosene	282 tCO2eq
	Petrol	154 tCO2eq
	Diesel	3,329 tCO2eq
	Electricity	50 tCO2eq

5.3 Installation of the worksite

As far as the data we received, there were some workshops made in concrete and some life bases made in metal and concrete. Also, a parking was created. We included the consumption of water and production of waste in this section as well. We retrieved the corresponding emission factors from our database and the emissions we got summed up in a total of **278 tCO2eq** as follows:

Table 6 - Worksite emissions in Kenya airport

STEEL SUPPLY	Metal Life Bases	32 tCO2eq
	Workshops	105 tCO2eq
OTHER SUPPLY	Parking	82 tCO2eq
CONCRETE SUPPLY	Concrete Life Bases	40 tCO2eq
WASTE	Waste	15 tCO2eq
OTHER	Water	4 tCO2eq

5.4 Materials

As of the materials, we have pretty low amount of concrete and steel compared to the other projects, but we had other materials such as asphalt, cement, crushed aggregates, sand, plastic, and bitumen that were having a significant impact on the CO2 emissions. The totality of the material emissions was equal to **9,085 tCO2eq** which is distributed as described in the table below:

Table 7 – Materials emissions in Kenya airport

OTHER SUPPLY	Pure Bitumen	180 tCO2eq
	Asphalt	4,376 tCO2eq
	Cement CEM I	477 tCO2eq
	Cement CEM 2	30 tCO2eq
	Crushed Aggregates	2,486 tCO2eq
	Sand	672 tCO2eq
	Plastic	497 tCO2eq
STEEL SUPPLY	New Steel	146 tCO2eq
CONCRETE SUPPLY	Concrete C20/25	219 tCO2eq

5.5 Freight

We had some data for freight of materials, freight of machines, and travel of personnel. The freight was broken down into freight by aircraft, by ships and via ground:

Road Freight	15,107,838	tons.km	5,650,331	kgCO2eq
Air Freight	1,174,623	tons.km	693,028	kgCO2eq
Sea Freight	33,801,901	tons.km	446,185	kgCO2eq

The travel section is divided into air transport, bus transport, and car transport:

Mobility Plane	1,156,075	man.km	132,949	kgCO2eq
Mobility Bus	2,762,214	man.km	378,423	kgCO2eq
Light Vehicles	2,302,944	man.km	444,468	kgCO2eq

The resulting emissions were as follows:

Table 8 - Summary of the freight emissions in Kenya airport

FREIGHT	Freight of Materials and Machines	6,790 tCO2eq
	Travel of Personnel	956 tCO2eq

5.6 Results

The final results are summarized in the table below. The total emissions of this project were equal to 28,400 tCO_2eq.

Table 9 - Summary of the emissions of Kenya airport

	Emissions	
ENERGY	Kerosene	282 tCO2eq
	Petrol	154 tCO2eq
	Diesel	3,329 tCO2eq
	Electricity	50 tCO2eq
CONCRETE SUPPLIES	Structural Concrete	567 tCO2eq
	Concrete Life Bases	40 tCO2eq
STEEL SUPPLIES	New Steel	146 tCO2eq
	Metal Life Bases	32 tCO2eq
	Workshops	105 tCO2eq
OTHER SUPPLIES	Pure Bitumen	180 tCO2eq
	Asphalte	4,376 tCO2eq
	Cement CEM I	477 tCO2eq
	Cement CEM 2	30 tCO2eq
	Crushed Aggregates	2,486 tCO2eq
	Sand	672 tCO2eq
	Plastic	497 tCO2eq
	Parking	82 tCO2eq
IMMOBILIZATION	Manufacturing of machines	7,150 tCO2eq
FREIGHT	Freight of Materials	6,790 tCO2eq
	Travel of Personnel	956 tCO2eq
WASTE	Waste	15 tCO2eq
OTHERS	Water	4 tCO2eq

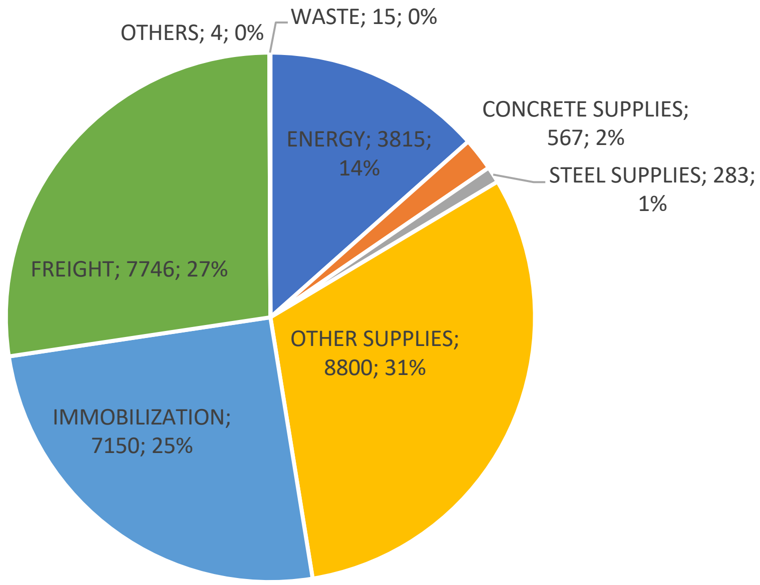


Figure 8 – Pie-chart of the emissions of the Kenya airport

What is notable about this project is that It does not have too much steel and concrete emissions, but the other supplies are taking 31% of the total. The freight also is playing a very important role accounting for about 28% of the emissions. 3rd in the list is the immobilization, which is due to the high number of machineries working on this project. What is interesting is that the water and waste emissions are pretty much negligible.

Another outcome of this study is that we realized co2ncerned is using very pessimistic assumptions for the machinery fleet compared to the Base Carbone. Usually these emission factors are from internal data of VINCI.

6 The Rion-Antirion Bridge

Figure 9 - The Rion-Antirion bridge

One of our largest projects was the Rion-Antirion bridge with a total of 14 REX reports each of about 300 pages for different sections of the project. Unique technical means were used to create a span of 2,883 metres long, that would withstand extreme conditions. Accordingly, it is resistant to earthquakes of a magnitude of 7 on the Richter scale, winds of up to nearly 250 kilometres an hour, and the collision impact of a 180,000-tonne tanker moving at 16 knots. The main technical challenge of the project was the marine subsoil in the area, which is not favourable for large-scale construction. To a depth of 60 metres below sea level, the subsoil consists chiefly of a cohesionless clay layer that is too soft for construction purposes sometimes mixed with sandy and silt-laden soil. Layers of rocky soil are to be found 500 metres below the subsoil. The only viable technical solution was to build piers with wide supporting caissons resting on the seabed. To build this bridge, a dry dock was constructed to concretize the bases of the piles. The dry dock contains two floors for the different stages of concreting, one deeper than the other. After the construction of the bases is completed, they are towed with tugs to the wet dock. The wet dock is used to build the cones of the piles. Once the construction of the cones is completed, the piles are tugged to their designated positions after the foundation dredging operations. Concreting of the piles continues in position until the piles lay on the seabed in the exact position designated for them.

We gathered as much data as we could about this project and will discuss them in the following sub-sections. Even though this project was the one that took the most time, the results were not so exhaustive. The drawbacks of this project was that the complexity prevents us from gathering complete information. For example, we could not calculate the **energy use** and **commute of personnel** of the worksite due to so many parallel worksites with incomplete data.

6.1 Materials

As for the materials, there were different set of data for each section of the project. We took some hypotheses, but as we already explained our logic for the hypothesis in the Atlantic bridge section, we shall only mention the specific ones to this project.

- We assumed the default freight for each material to be 100km to arrive on the worksite.
- We assumed the aggregates have no freight
- We assumed for the missing information about the concrete to be a C40/50 type.
- Some modifications were brought to the barges serving on the worksite. We translated the modification done to the boats in tons of steel from their monetary data.
- We assumed the steel used was firsthand steel (not recycled)

We summed up all our physical data to get these results:

Table 10 - Summary of the material emissions in the Rion-Antirion bridge

MATERIALS		Physical Quantity		Emissions	
FREIGHT	Freight of Materials	100	km/qty	10,200	tCO2eq
STEEL SUPPLIES	All Steel Products	95,730	t	152,883	tCO2eq
CONCRETE SUPPLIES	All Concrete Products	198,000	m3	60,027	tCO2eq
OTHER SUPPLIES	Aggregates	222,272	t	890	tCO2eq
	Formworks	296,744	m2	851	tCO2eq
	Cable Stays	4,500	t	18,000	tCO2eq

The totality of the material emissions is equal to 250 000 tCO2eq. We can see that steel is playing an important role in the material emissions while the effect of aggregates and formworks are pretty marginal. Also, the total freight of the materials is taking about only 4% of the emissions.

6.2 Machines and Equipment

The machinery data available differs from report to report. Sometimes you can find machinery prices, sometimes you can find their weight in tons, and sometimes you can only find descriptive details. All in all, we managed to collect data on almost 300 machines.
Dealing with multiple reports has the risk of encountering overlap. Sometimes the machines were used in several phases of construction and therefore there were overlaps in the data collection. To ensure that the footprint of a machine was not counted several times, prices were noted with references. If two machines have the same price and description and are used in different phases of the project, they are counted only once. In case the price data is not available, to check for duplicates, we just compared the name and description of the machines and removed the duplicates.

We first tried to estimate the emissions of each individual machine, but it was impossible due to the high number of machines and lack of data and emission factors. As calculating the emissions of every machine one by one seems to be impossible, we tried three different solutions to calculate the total emissions of the machines.

For the depreciation part of the equipment and machinery, the emissions of the collected data can be treated in different ways. Either the equipment and materials are divided into categories based on their weight, or the emissions are taken into account using a monetary emission factor.

First Solution (Emission factors by weight)

We took assumptions for the lifetime of the machines to calculate their depreciation. The machines and equipment are divided into 4 categories. The emission factors are based on the ADEME estimation. The duration of the worksite is 5 years, we used this number to calculate the amortization of the machines based on their estimated lifetime.

Table 11 – Emission factors for machines categorized by weight

Category	Emission to Manufacture (kgCO2e)	Estimated lifetime
Equipment (0-5t)	7,975	5
Small Machines (5t-10t)	23,925	10
Big Machines (10t-30t)	47,850	10
Very Big Machines (<30t)	127,600	10

Using this methodology our total resulting emissions were about **23 454 tCO2eq**.

Second Solution (Emission factors by category)

A second method is to separate machines, vehicles and immobile equipment and use a different emission factor for each. In this case the machines and vehicles always have the same emission factor on the ADEME carbon-based database.

Table 12 – Emission factors for machines categorized by category

Machines, Base Carbone	5500 kgCO2e/tonnes
Immobile Equipment, Base Carbone	1830 kgCO2e/tonnes
Vehicles, Base Carbone	5500 kgCO2e/tonnes

Using this methodology our total resulting emissions were about **65 922 tCO2eq**.

Third Solution (Emission factors by price)

This method seemed to be the most reliable one because it is using a scalable emission factor. And since the list of equipment and machines ranges from very small equipment to very large tower cranes and boats, it only makes sense to be able to scale the emissions. We take the monetary emission factor of the ADEME Base Carbone database which is 700 kgCO2/k.euros as an emission factor for all the machines.

Using this methodology and taking into account the lifetime of the machines, our total resulting emissions were about **55 000 tCO2eq**. We will keep this result as the most trusted one.

6.3 Results

Gathering up all we calculated we have a total of 305 000 tCO2eq of emissions which are distribute as follows:
As a reminder, the energy consumption could not be assessed for this project. In general, it represents 20% of the whole emissions.

Table 13 - Summary of emission of the RIon-Antirion bridge

MATERIALS		Physical Quantity		Emissions	
AMMORTIZATION	Machines	39,346	Million euros	55,000	tCO2eq
FREIGHT	Freight of Materials	100	km/qty	10,200	tCO2eq
STEEL SUPPLIES	All Steel Products	95,730	t	152,883	tCO2eq
CONCRETE SUPPLIES	All Concrete Products	198,000	m3	60,027	tCO2eq
OTHER SUPPLIES	Aggregates	222,272	t	890	tCO2eq
	Formworks	296,744	m2	851	tCO2eq
	Cable Stays	4,500	t	18,000	tCO2eq

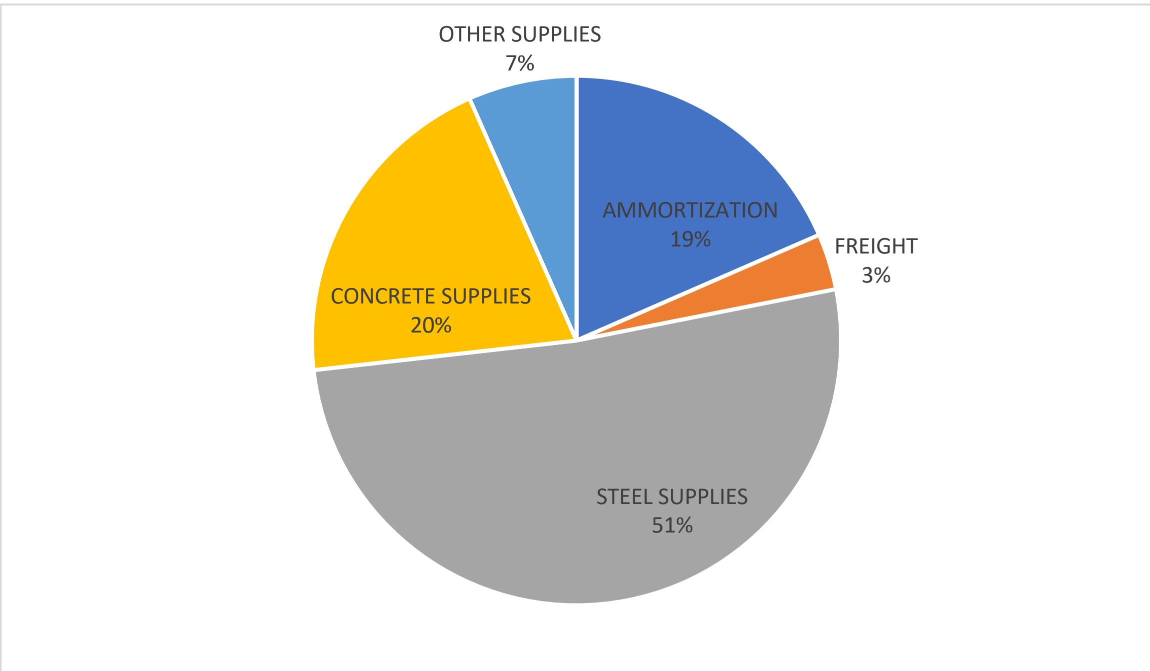


Figure 10 – Pie-chart of the emissions of the Rion-Antirion bridge

7 Viaduct of Dordogne

Figure 11 - The construction site of the Dordogne bridge

The Dordogne Viaduct project was started in July 2012 and was accomplished in July 2015 over the Dordogne river to the north of Bordeaux. It allows the passage of the TGV train line SEA (South Europe Atlantic) over the river. The structure has twenty-one supports (two abutments and nineteen piers), and consists of two access viaducts with a mixed steel-concrete structure (342 m long for the north access viaduct and 177 m long for the south access viaduct) framing a main prestressed concrete viaduct of 800 m long. Two temporary bridges were constructed on each side of the bridge to accomplish this project.

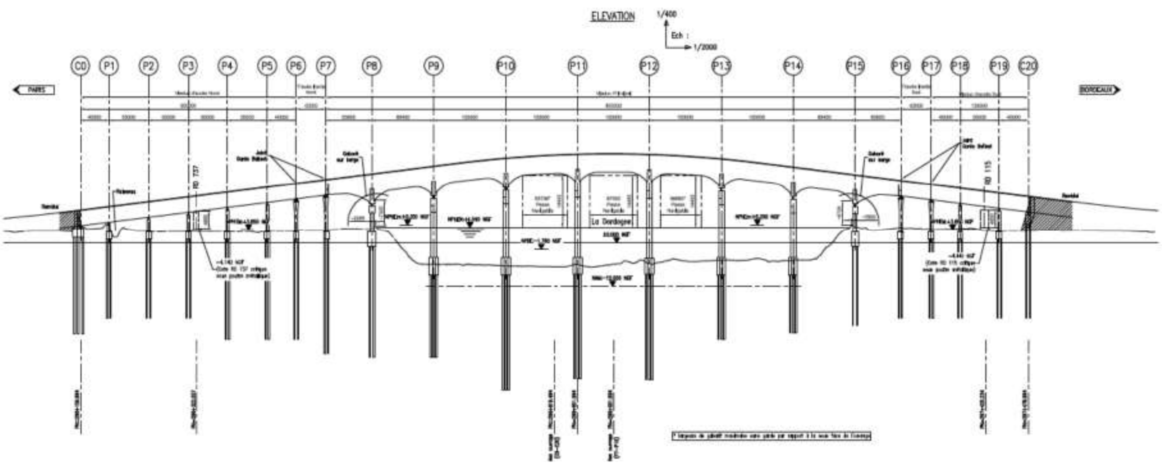


Figure 12 - The Dordogne bridge plan

The data used for the carbon footprint come from the REX of the construction site. This 100-page report provided very good information about the materials but not good enough information concerning other sections. For example, we did have a small list of the machines utilized on the worksite but without any information about how long they were used (to calculate their emission from burning fuel), or how much they cost or weight (to calculate their emission from the manufacturing process), or where they come from (to calculate their freight).

We tried gathering information from other sources, here are some examples of our endeavors:

1- We did know that there were 8 tower cranes active on the worksite. We referred to the planning of the site and tried to understand how long each crane was active. By taking some assumptions and taking into account the schedule of the worksite, we came up with this table.

Table 14 - The schedule of each tower crane working on the Dordogne bridge

Pier Number	Start Date	End Date	Duration in Days
P8	18/01/2013	18/11/2013	304
P9	15/07/2013	23/05/2014	312
P10	05/06/2013	23/05/2014	352
P11	31/10/2013	21/08/2014	294
P12	10/10/2013	21/08/2014	315
P13	24/04/2013	01/04/2014	342
P14	15/02/2013	07/01/2014	326
P15	05/10/2012	30/08/2013	329

By calculating the emissions, it made a total of 175 tCO2eq which is less than 1% of the total emissions.

2- We tried to calculate the transport of employees on the worksite and in the offices and got a total 200 tCO2eq which again is marginal compared to the other emissions.
3- We tried to calculate the surface of the worksite using google maps to understand the emissions of the worksite. See Figure 13.

Figure 13 - Estimation of the surface area of the worksite

We listed everything we had at hand and calculated the emissions. The incomplete data about transport of personnel, waste, machines, and consumption on the worksite altogether made only about 1% of the total emissions. So, we redirected this study towards understanding the distribution of the emissions in the materials of the project.

For the materials we had very detailed information on the amount of concrete and steel implemented. We had the exact quantity of materials <u>used</u> and <u>wasted</u> in each pier and each sub-section of the pier. We gathered all the information and summarized them into this table:

	Beton Totale Réel (m3)	Beton Total Theorique (m3)	Classe de Résistance (CO2NCERE	Armatures (t)	Acier (t)
Pieux	2879,5	2439,1	C25/30	928,95	
Pieux	7982	7097,4	C40/50	0	
Béton de Proprete	966,4	966,4	Beton Proprete	0	
Béton immergé	3550	3550	Gros Beton	0	
Béton Semelles	11994	11619,2	C30/37	1512,11	
VSP	2571,5	2521,86	C45/55	489,89	
VSPC	179,12	179,12	C45/55	46,11	
TSC	465	465	C45/55	87,6	
Fléaux	8285,45	8049	C45/55	1739,41	
Clavage	342,1	342,1	C45/55	57,01	
Fut et Chevetre	5509,75	5371,25	C35/45	855,63	
Bossage	38,27	38,27	C35/45	21,82	
Hourdis	2318,72	2318,72	C35/45	542,02	
Charpente métallique					2174,14
Liernes					911
Palplanches					1656
Estacade					2300
Tubes provisoires et définitifs hors estacades					1447

Figure 14 - The summary of the materials used

We did know that some parts of the structure were using low carbon concrete. So we adapted our emission factors accordingly, given in the table below as example:

Table 15 - The difference of emission factor in low carbon concrete

	Standard concrete EF default (kgCO2e/m3)	Low carbon concrete EF used (kgCO2e/m3)
Beton C45/55	347	270
Béton C40/50	334	168
Béton C35/45	334	149
Béton C30/37	308	150

As a result, we had an amount of 9,000 tCO2 (28%) emitted from the concrete and 23,000 tCO2 (72%) from the steel. The dominance of steel emissions might be due to the fact that two temporary steel bridges were constructed on both sides of the bridge. Also, in order to install the piles on the base of the river, steel sheet pilings were used to keep the water out. Last but not least, a significant amount of pre-stressed cables and armatures were used in the structure. As for the temporary bridges and the sheet pilings, they will be reused for other purposes after the worksite, so what we calculated is the emissions of the manufacturing process.

Table 16 - Summary of material emissions of the Dordogne bridge

Type of Concrete	Total Quantity (m3)	Total Emissions (tCO2eq)
C40/50	7,982	3,198
C35/45	7,867	1,341
C45/55	11,843	1,172
C25/30	2,880	1,799
C30/37	11,994	812
Bedding Concrete	966	127
Concrete fill	3,550	692

Steel	Total Quantity (tons)	Total Emissions (tCO2eq)
Reinforcements	6,280	5,216
Steel girder	2,174	4,686
Other Steel	6,314	13,145

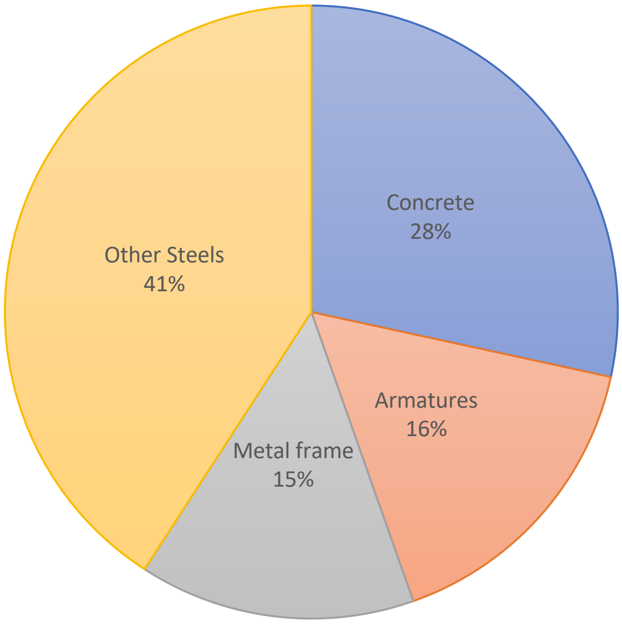


Figure 15 – Pie-chart of the emissions of the Dordogne bridge (materials only)

8 The Secondary Projects

8.1 Wednesday Webinars for Environment

Figure 16 - The Wednesday Webinars for Environment logo

As I arrived in the office, soon we started a series of weekly webinars on environmental initiatives around the company. Every week on Wednesday we had two sessions, one in French and one in English. We were organizing and animating these webinars with a different invitee speaker each week. I also once presented an initiative's work in English. We had speakers talking about many subjects: Environment awards and competitions in the company, how to count our emissions, how to optimize our machinery, how to reuse, recycle, and reduce the waste on construction sites, hydrogen projects replacing traditional diesel generators, and etc.

After the sessions, the replays were chaptered and uploaded on our SharePoint so that people across the company could reach them.

Every month we would launch a newsletter to inform people of our monthly program and we would organize the events in advance. Up until now we have animated 11 episodes and still counting. The employees across the group had a very positive feedback about these webinars.

Organizing and animating these webinars taught me how to launch, organize, and animate big group events, and it improved my people skill.

8.2 SharePoint

I also was in charge of setting up the SharePoint of the Environment group of our department alongside my tutors. To do so we made a site map and developed contents for each section of the SharePoint in French and English. The main sections were as follows:

- Understanding the environmental challenges of Vinci Construction
    - Environment at VINCI Construction
    - E-learning VINCI about the environment
    - CO2 Counting tools: A presentation of CO2NCERNED and other CO2 counting tools.
    - BeSafe (An emission reporting tool)
    - L'Epopée Verte: A card game developed by VINCI about the environment
- Wednesday Webinars for Environment
    - 13 webinar episodes and counting with replays in English and French (refer to chapter 8.1)
- The environmental offers of VINCI Construction
    - **EXEGY** It is a brand developed by VINCI Construction which designates their range of Low Carbon-based Concrete solutions for all uses. They propose three types of low carbon concrete:

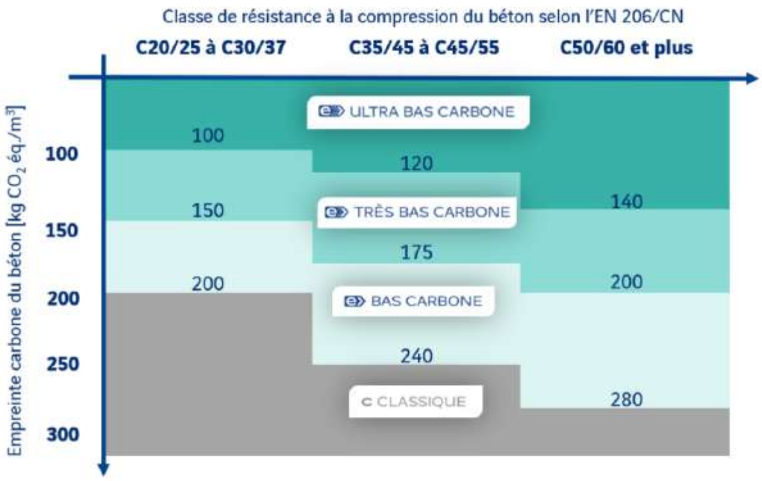


Figure 17 - Matrix of resistance vs emissions for the EXEGY solutions vs traditional concret

- Béton Bas Carbone (Low Caron Concrete)
- Béton Très Bas Carbone (Very Low Carbon Concrerte)
- Béton Ultra Bas Carbone (Ultra Low Carbon Concrete)

- REHASKEEN is the energy renovation solution developed by VINCI Construction France to meet the challenge of the massification of energy renovation. Rehaskeen takes advantage of data acquisition technologies, automation of panel layout and dimensioning, industrialization of production and optimization of implementation processes.

- ActivSkeen: Because the deployment of Energy Positive Buildings (EPOSB) requires in-situ power generation, a broad portfolio of active photovoltaic solutions that can be integrated into the building is offered. We offer countless possibilities in terms of aesthetic rendering for successful architectural integration.

- Waste Marketplace is a digital solution that facilitates the management of construction site waste and improves its recovery and traceability, at the best cost. From the construction site, a site foreman controls a waste container rotation in four clicks on the application, whose algorithm chooses the best solution for each waste within a network of partners. The recovery rates obtained exceed 80%. The system provides automatic reporting at all stages and guarantees full traceability, which in particular simplifies environmental labeling procedures.

- Equo Vivo is VINCI Construction's brand dedicated to ecological development projects. Equo Vivo is focused on the restoration of biodiversity, the design and implementation of ecological developments and the maintenance of ecological continuity.

8.3 CO2NCERNED Training

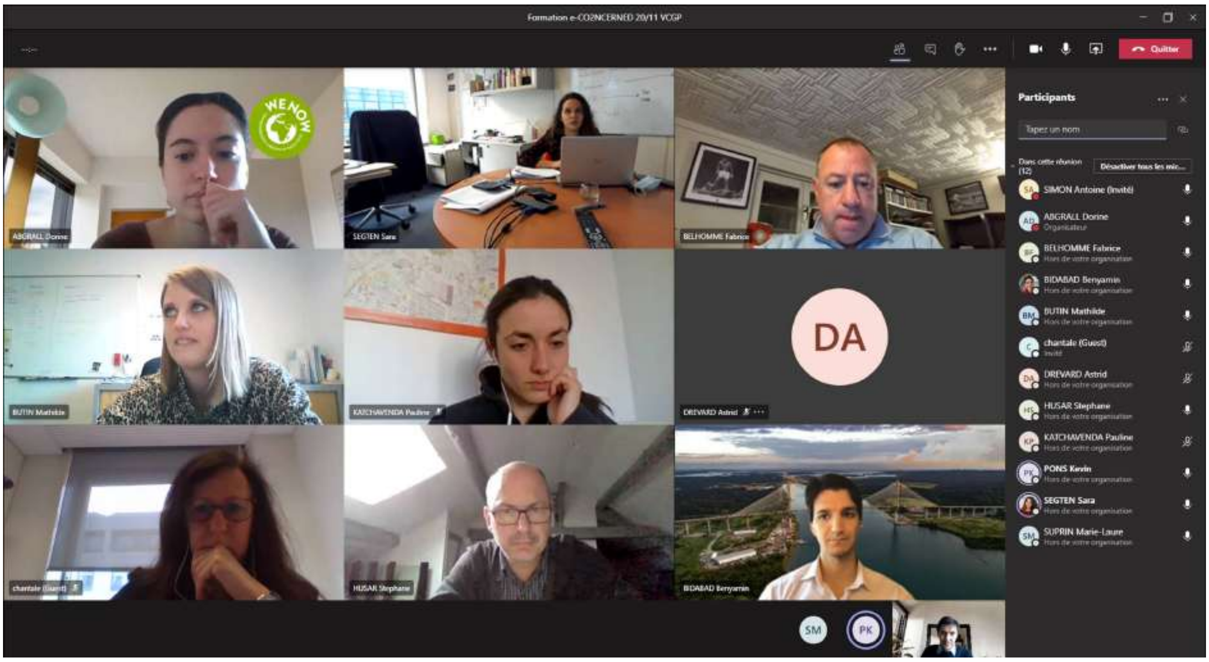


Figure 18 - Me presenting how to input data into CO2NCERNED via Microsfot Teams

As I was using CO2NCERNED a lot during my internship, the responsible for the development of the tool in VINCI asked me and my tutor to train other people in the company on why and how to use the application. I got the chance to present the tool to the heads of the HSE[8] and QSE[9] of the SOGEA SATOM and VCGP[10] divisions. For doing so, we prepared a tutorial with some sample data from the Kenya airport project to enter inside the application. After a brief presentation of why it's important to do a carbon assessment, we guided the participants step by step on how to use the tool. We presented 3 sessions by far.

I really enjoyed presenting this training because it helped me improve my French and my presentation skills. Also, I was facing people from a vast variety of cultures with more experience than me. That made it an even more interesting experience.

[8] Health, Safety, and Environment
[9] Quality, Safety, and Environment
[10] VINCI Construction Grand Projets

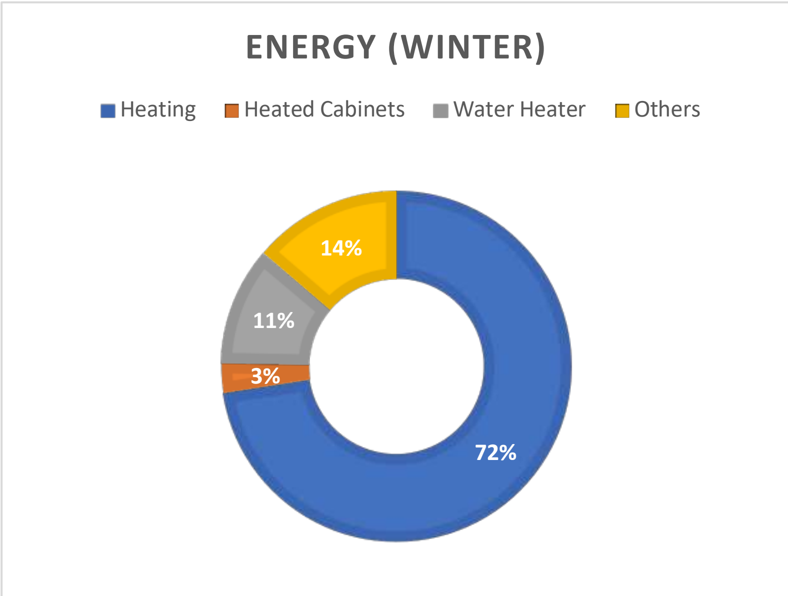
8.4 The Climate Collage (La fresque du climat)

I had the chance to host a Climate Collage along with one of my teammates in front of the employees of VINCI.
The Climate Collage (in French, La Fresque du Climat) is a serious game about climate change, based on collective intelligence and creativity. It's a card game that demonstrates the causes and effects of global warming. Although it does not provide a solution, it raises awareness for people without any prior knowledge about the issue at hand. Participants will be divided into teams to find the relation between cause & effects using the 42 cards.
I attended a session as a participant with my team. And then, I was given the chance to get trained on how to host a climate collage. Later on, during the "Day of Environment" at VINCI, I hosted a Climate Collage for the employees and received lots of positive returns from the participants.

Figure 19 - Raising awareness about climate change by animating a Climate Collage for the employees of VINCI

8.5 Workgroup on life bases

My tutor assigned me to follow a workgroup of engineers on how to reduce the emissions of the life bases on the worksites. During this workgroup we analyzed all the important factors contributing to the emissions of an office or a changing room on a worksite. I also on my own was reading through the past reports of VINCI to identify key levers that could be used to control the emissions.
In general the energy consumption of the life bases are as follows:



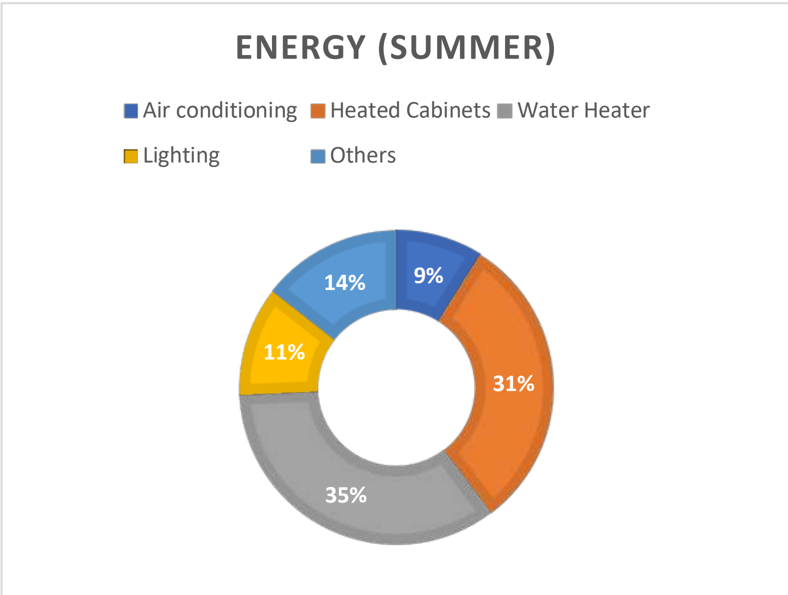


Figure 20 - Energy distribution of life bases

Many solutions were proposed in the reports to reduce the energy consumption and therefore the emissions. Some of them are as follows:

- Installation of panels on walls and roof
- Treatment of thermal bridges
- Treatment of couplings between bungalows
- Place the bungalow well on the ground, or insulate the floor of the bungalow.
- Improve the joints of the bungalows around the walls and the roof.
- Install window opening detectors
- Optimize the arrangement of the bungalows to reduce the contact surface area with the outside and therefore the need for insulation (Cantonnement)
- Double glass windows
- Setting the heating of the life bases on a clock, even if it means putting the heating back on a certain time before the arrival of the companions in the morning.
- Prefer the use of heat pumps instead of electric convector radiators.
- Limit the power of the radiators which will also limit the risks of burns and fire.
- Installation of the three-phase contactor
- Improve the monitoring of energy consumption by adding sub-meters

I summarized my findings into a matrix (see Figure 21) to identify the levers of action. The X-axis demonstrates the environmental impact of the solution and Y-axis is its ROI. So in order to add a solution to this matrix both the emission reduction in tCO2 and the ROI in months is required. Unfortunately, we found only limited information about these solutions and only few of them were able to be added to this matrix. This study is still ongoing so we are hoping we will be able find more levers of action that can be classified on this matrix.

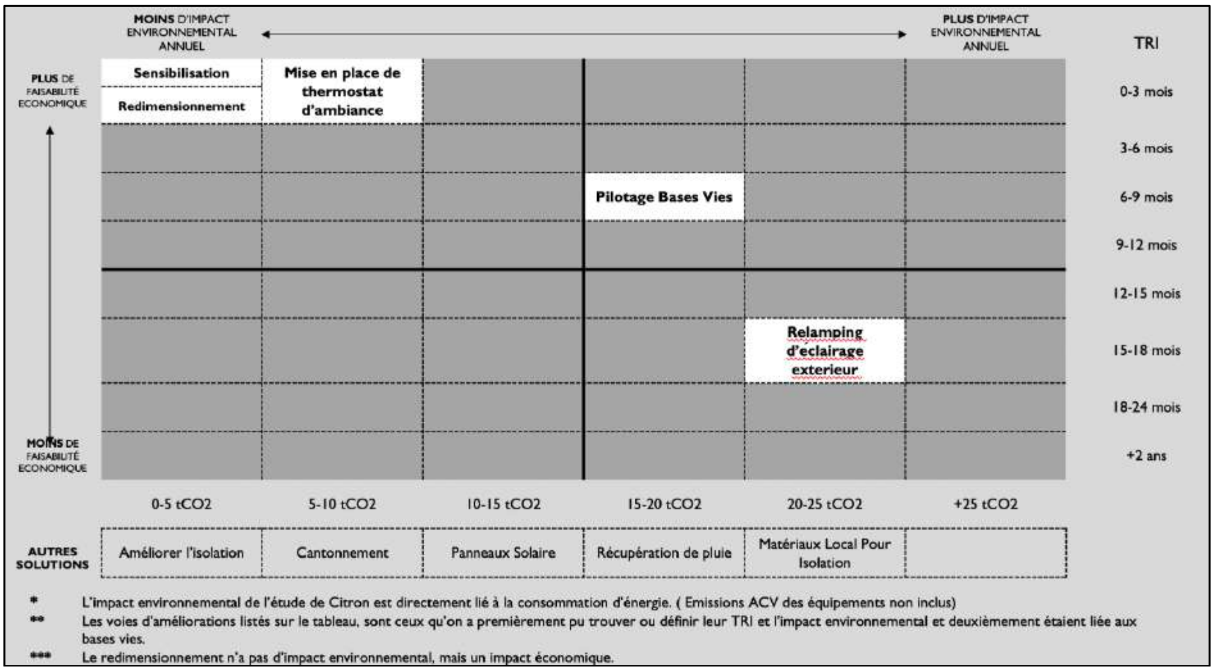


Figure 21 - Levers of action matrix for life bases

We can see that the diagnostic of the problems are more important than the solutions. For example, in a large company like VINCI we still lack enough consolidated data about our sources of emissions to decide which solution would be worth the effort.

Conclusions

We saw that the most important part of the emissions in a construction site is from the materials, and in the materials usually the steel products are dominant. The amortization and energy use of the machines is also an important part of the emissions but of second importance. Depending on the type of the worksite the machines emissions are varied. In a typical worksite, 60% of the emissions are from materials and 20% from materials. Plus, we were able to get an understanding of the magnitude of the emissions of large construction sites.

Also, we saw that the data we were gathering were not consolidated and very difficult to collect. This shows that a proper reporting system needs to exist in order for worksites to be able to calculate their carbon footprint in a trusted way. By having a structured and unified method to collect data during the construction phase (and not after), we will be able to reduce the uncertainty of our data greatly.

By doing this internship I discovered a new industry, construction, which was very enriching for me. It allowed me to understand the ways of the industry and also their challenges related to carbon emissions. I hope this study will help VINCI and other construction companies understand where their emissions are coming from in order to identify their levers of action.

References

The only reference for this study is the Base Carbone database of ADEME which can be accessed through their website (www.ademe.fr).
All other references are internal documents of VINCI construction which are not accessible to the public. Therefore, no further referencing is needed.