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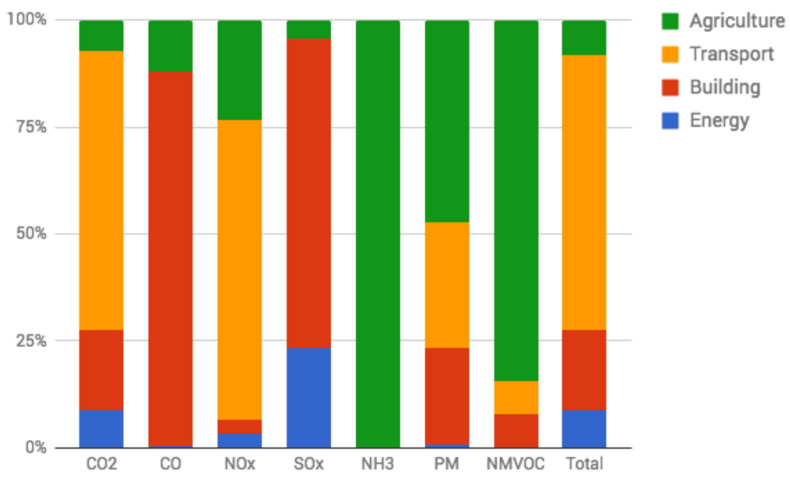

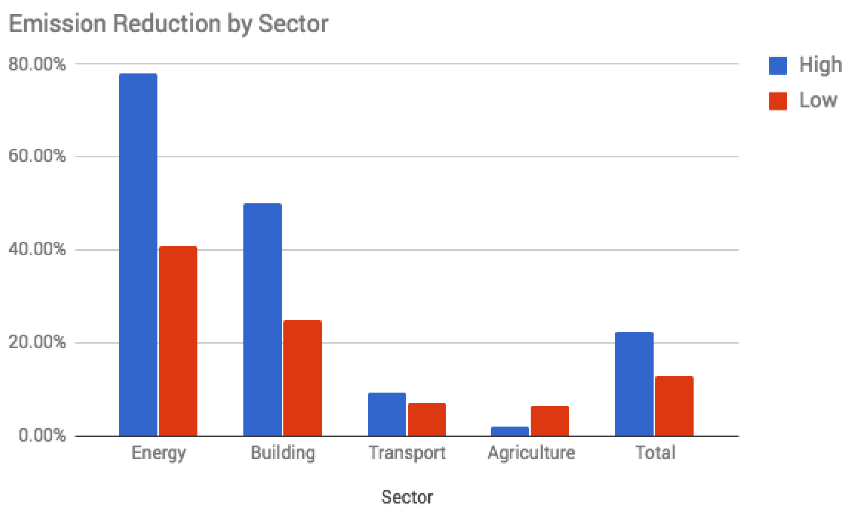

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1. EXECUTIVE SUMMARY

This report presents long term strategies to address climate change, air quality, energy and their interconnection for the region Pays de la Loire, France. Indeed, the focus on the latter interconnection is a critical point. Solving the three main environmental issues carbon, air quality and energy independently could lead to several counter-productive actions afterwards.

The emission factor methodology will be used to formulate efficient strategies based on the current situation. Therefore, the first step would require defining emission factors (based on fuel, technology or distance) as well as activity data to evaluate the impact of several activities on air quality. More precisely, a focus will be on formulating strategies targeting the energy, transport, agriculture and buildings (heating) sectors.

Results show that in the energy sector an optimum reduction of 78.16% could be achieved by shifting to wind energy. Regarding the transportation sector, shifting from cars to walking/biking could result to an overall reduction of 9.25% and a slightly lesser amount could be obtained by using electric cars instead. In the building sector, 50.00% to 25.00% of greenhouse gases could be avoided by combining energy efficiency with the use of renewable energies for meeting heat demand. In the agriculture sector, by decreasing the mineral fertilizer doses and improving manure application, 0.31%of NOx emissions can be reduced, while 9.75 to 29.11 % of emissions NH_3 can be avoided. Globally, the presented strategies were able to decrease the pollutants up to 22.43%.

2. CONTEXT, POSITION AND OBJECTIVES OF THE PROJECT

2.1. CONTEXT, SCIENTIFIC, SOCIAL AND ECONOMIC ISSUES

Global air pollution has been increasing throughout the years, as shown by the 1970-2012 data from The World Bank (Figure 1). According to the World Health Organization (2016), more than 80% of people in urban communities are exposed to unacceptable air quality levels. The decline in urban air quality is linked to increased health risks, such as stroke, heart disease, lung cancer, and chronic respiratory illnesses.

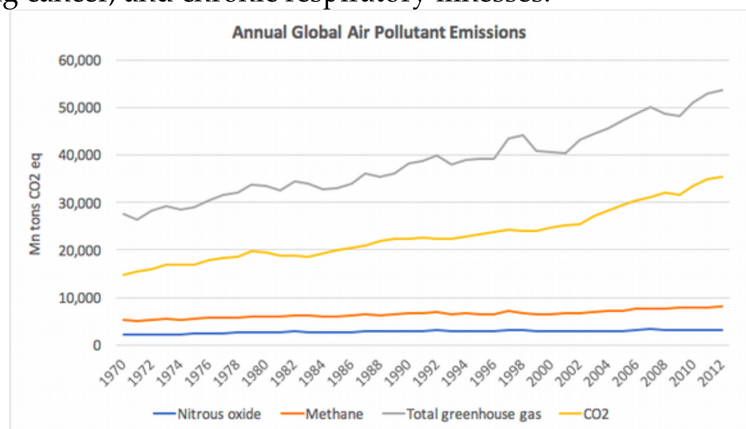

Figure 1. Global air pollution emissions (The World Bank, 2012)

World leaders have been uniting to solve this common and shared problem, as evidenced by several international discussions and meetings like the 2015 United Nations Climate Change Conference (COP 21) which was held in Paris. The agreement calls for zero net anthropogenic greenhouse gas emissions to be reached during the second half of the 21st century (IEA, 2016). In order to comply to these international agreements, countries must develop and implement air pollution mitigation strategies at different levels i.e. national, federal, state, local, tribal, and sectoral. Figure 2 shows the major sectors contributing to carbon dioxide emissions in the world, as of 2014 (The World Bank, 2014).

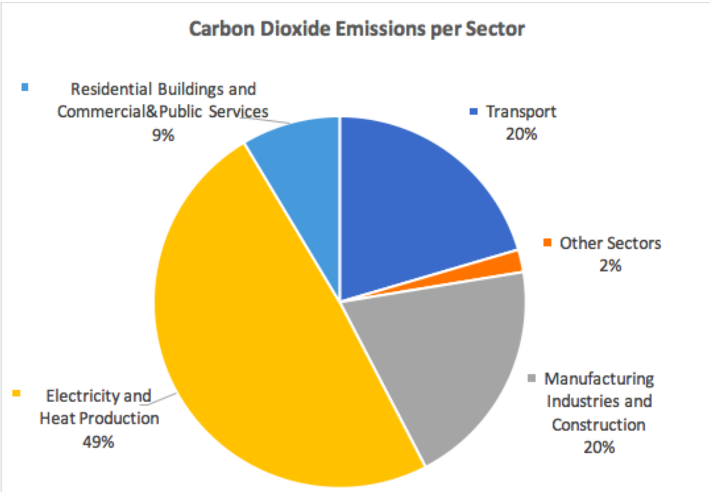

Figure 2. Global carbon dioxide emissions per sector (The World Bank, 2014)

To guide air quality management decisions and develop emission control strategies, governments make use of emission factors (EF) (United States Environmental Protection Agency, 1995). Emission factors are a collection of data across different industries, indicating the amount of pollutant released in the atmosphere per unit of human activity. For example, there is an emission factor for the amount of carbon monoxide released in the atmosphere for every ton of coal burned in a thermal power plant (kg CO/kg coal). By having these standard numbers, and knowing the extent of human activity in each sector or region, an inventory of the total emissions produced can be obtained. From this inventory, specific problem areas can be identified, and strategies can be developed accordingly (IEA, 2016).

2.2. POSITION OF THE PROJECT

This project is especially relevant today because of the pressure for governments to adhere to the targets agreed upon with the international community. Therefore, regional and local plans (regional air-energy climate plans, territorial energy climate plans, regional energy transition strategy, etc.) must be made intelligently and effectively. Collective strategies involving all major activity sectors must be developed.

This project builds upon already existing emission factor databases and pollution inventories. It integrates information across chosen industries, and overcomes the lack of standardization often encountered in cross-sectoral data.

2.3. STATE OF THE ART

Several guidebooks provide the structure for calculation emission inventories, and also provide a compilation of emission factors for several industries. An example of this is *AP-42, Compilation of Air Pollutant Emission Factors*, published by the US. Environmental Protection Agency. It contains emission factors and process information for more than 200 air pollution sources. The emission factors have been developed and compiled from source test data, material balance studies, and engineering estimates.

The European Environment Agency (EEA) also produces an annual greenhouse gas inventory report on behalf of the European Union. Estimates of greenhouse gas emissions are produced for a number of sources which are delineated in sectors primarily according to the technological source of emissions, as devised by the Intergovernmental Panel on Climate Change (IPCC).

Several emission inventories are also available on a regional level. For example, in the *Pays de la Loire* region in France, the Regional Directorate for Environment, Planning and Housing (DREAL) has published an Energy and Air Pollution Inventory last 2014. This was carried out using standard methodologies like BASEMIS®. Basically, this method also employs emission factors on a more localized, detailed, and sophisticated manner - with the aid of software and gathering massive data from different government agencies and private companies. Air pollution mitigation strategies are also already existing. However, these are published per sector or per region, and are not integrated nor exhaustive. (DREAL, 2012).

2.4. OBJECTIVES, ORIGINALITY AND INNOVATIVE NATURE OF THE PROJECT

Up to now, many of the strategies to tackle tenacious issues such as global warming, energy use, and air pollution have been formulated and implemented separately, resulting often in a disconnection between the objectives that policies and strategies are trying to achieve in each area. Furthermore, methodologies such as emission factors and emission inventories have been developed to measure the impact of the aforementioned.

Taking the previous into consideration, the aim of the project is to use the emission factor methodology to formulate, evaluate and link strategies for climate change, energy and air quality of the region *Pays de la Loire*. The strategies will be targeting the following four sectors:

- Energy,
- Transport,
- Agriculture,
- Buildings: with focus on heating.

To achieve this goal, relevant emission factors will be defined for each of the target sectors according to guidelines from the European Union. Activity data will be collected for the Pays de la Loire region. Finally, mitigation coefficients will be used along with these to formulate, evaluate, and link strategies that respond to the main issues identified in each sector.

3. METHODOLOGY

3.1. SCIENTIFIC METHODOLOGY

The project was divided into four major air polluting sectors in Pays de la Loire - energy, heating, transportation, and agriculture. For each sector, an inventory of the major pollutants was first carried out. Strategies to mitigate these emissions were then developed and evaluated based on the following equation:

$$E = AD \times EF \qquad \textit{(Equation 1)}$$

where E = emissions per pollutant,
AD = activity data,
EF = emission factor per pollutant.

Activity data refers to the major quantifiable sources of pollution, or to the extent to which a human activity takes place. Meanwhile, the emission factor is the amount of pollutant released for each unit of AD. These emission factors were collected from existing databases from the European Environmental Agency's Air Pollutant Emission Inventory Guidebook (EEA, 2016) and International Energy Agency's Energy Statistics Manual (OECD/IEA, 2005). Alternatively, some of them were calculated based on already established emission inventories (DREAL, 2012). The methodology for completing the air pollution emission inventory, as well as developing the strategies for each sector, is detailed below in sections 3.1.1. to 3.1.4. Finally, the strategies from the four sectors were integrated in order to propose a holistic emission reduction plan for the region.

3.1.1. Energy

For the evaluation of the emissions of energy production, 25 air pollutants were calculated. In order to facilitate the comparison of the different scenarios, the main pollutants of interest for monitoring air quality were presented: carbon monoxide (CO), nitrogen oxides (NO_X), fine particulate matter (PM10, PM2.5) and non-methane volatile organic compounds (NMVOCs), plus the most common GHG, CO_2. Emissions strongly depend on the fuel, technologies, as well as on operational practices and maintenance. The main categories considered are summarized in the table below:

Table 1.Types of energy to obtain emission factors and calculate air pollutant emissions

Type of Energy	Fuel Used
Thermal Energy	Charcoal
	Oil Products
	Cogeneration
	Incineration
Renewable Energy	Other*
	Biogas
	Incineration OM

Other*: Wind, Hydropower and photovoltaic energy.

These categories are based on the energy generation matrix of Pays de la Loire (EDF, 2014).

Two different methods are considered for estimating Energy generation activity emissions depending on the data available: based on the technology used and based on the type of fuel used.

If there is enough information, the first one to consider should be **technology-based method** as a more robust methodology than fuel-based method:

$$E_{pollutant} = \text{Electricity generated}_{technology} \times EF_{technology\text{-}pollutant} \qquad \textit{(Equation 2)}$$

Here, the activity data is the amount of energy generated. The EF (Emission Factors) are presented in mass of pollutant emitted per unit of energy generated (normally g/KWh), depending on the type of technology, and subdivided per the different types of fuel used in each technology. If EF is in g/kWh, the Electricity generated will have to be in Kilowatt hour (kWh). These Emission Factors are added in Appendix 1.

The second is the **fuel-based method:**

$$E_{pollutant} = \text{Fuel consumption} \times EF_{technology\text{-}pollutant} \qquad \textit{(Equation 3)}$$

Here, the activity data is the fuel consumption and is assumed an average or typical technology implementation. The EF is presented in mass of pollutant emitted per energy released (normally g/GJ) for each of the type of fuel used.

Each type of fuel has a NCV (Net Calorific Value) which is the amount of usable heat energy released when the specific fuel is burned. The NVC of each type of fuel and the efficiency assuming an average or typical technology is introduced into the EF to obtain the energy generated per fuel consumed and is presented in energy released per mass (GJ/ton). The fuel consumption should be presented accordingly.

EF values for each type of fuel are presented in Appendix 1. NCV values were taken from Energy Statistics Manual (OECD/IEA, 2005).

3.1.2. Buildings

In the building sector, emissions of greenhouse gases and pollutants are still predominantly (91%) present due to combustion. More precisely, the latter combustion could be divided into two categories:

1. Combustion related to electrical generation
2. Combustion related to heating (except electrical heating)

As the part focusing in combustion linked to electrical production is part of the energy sector, the main objective of the buildings section was analyzing the effect of their heating on air quality. More precisely, the study was emphasizing on 6 main air pollutants considered as the major ones for the building sector: carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NOx), sulphur oxides (SOx), Particulate Matter (PM), and Non-methane Volatile Organic Carbons (NMVOCs). The analysis was divided into residential and tertiary sectors.

Residential Sector

In 2014, homes in Pays de la Loire consumed 2.1Mtep of final energy. Furthermore, an analysis by use shows that 59% of the energy consumed is used for heating, 13% for hot water and 8% for cooking. The remaining 20% corresponds to specific electricity. Therefore, it could be deduced that the residential heating amount to **1.239 Mtep** or **14 409.57 GWh** (BASEMIS, 2014).

The figure below shows the repartition of fuel used for residential heating (BASEMIS, 2008). The latter distribution along with heating consumption based on 2014 data was used in order to estimate the consumption in kWh per fuel used (activity data).

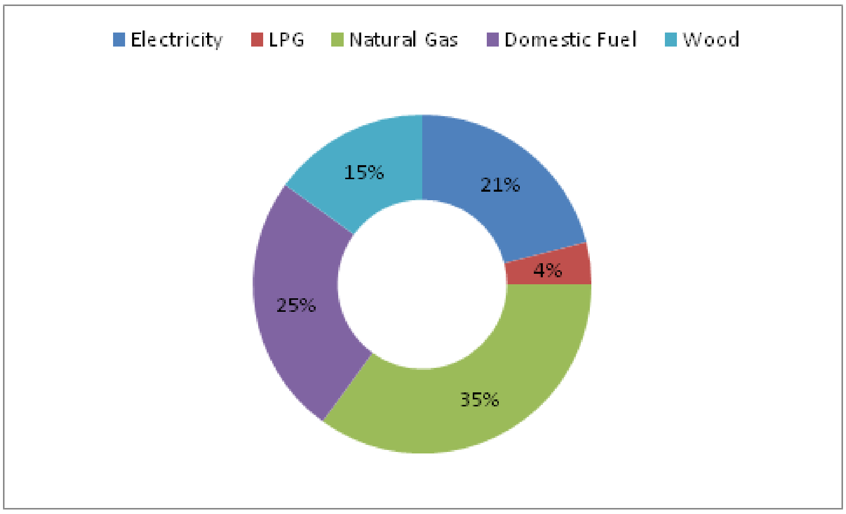

Figure 3. Distribution of the residential sector heat consumption per fuel used (BASEMIS, 2008)

Based on the presented consumption, the fuel source ought to be focused on for this sector are:

- Natural Gas
- Wood
- LPG
- Domestic Fuel

Emission factors for each fuel were obtained according to the ones presented in the National Atmospheric Emission Inventory. Additionally, the **fuel based method** described in Section 3.1.1 was used as limited activity data could be obtained per technology in Pays de la Loire.

Tertiary Sector

A similar methodology as the residential sector was used for the tertiary sector. In 2008, the energy consumption for heating was estimated at **5 000 GWh** (BASEMIS, 2008).

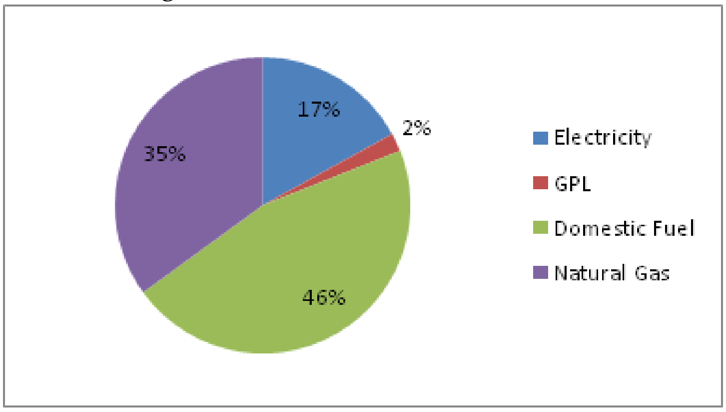

Figure 4. Distribution of the tertiary sector heat consumption per fuel used (BASEMIS, 2008)

The fuels focused on for the sector were the following:

- Natural Gas
- LPG
- Domestic Fuel

As in the residential sector, emission factors were derived from the National Atmospheric Emission Inventory and the fuel based method was used to estimate the emissions.

3.1.3. Transport

The major air pollutants in the transport sector are: carbon dioxide (CO_2), nitrogen oxides (NOx), Particulate Matter (PM), and Non-methane Volatile Organic Carbons (NMVOCs) (DREAL, 2012). The major factors that dictate the emission factors and activity data are: ***sub-sector, type of vehicle, and fuel used***. The main categories considered are summarized in the table below:

Table 4. Categories to obtain emission factors and calculate air pollution emissions in transportation

Sub-sector	Type of Vehicle	Fuel Used
Road	Passenger Vehicles (cars)	Gasoline
		Diesel
		LPG
	Heavy Goods Vehicles (including coaches and buses)	Gasoline
		Diesel
	Light Commercial Vehicles	Gasoline
		Diesel
	Motorcycles	Diesel
Railway	Train	Diesel

Airway	Airplane	Aviation Gasoline
Fluvial	Ferries	Diesel

These categories are based on the major air pollution sources identified by Pays de la Loire's Regional Directorate for Environment, Planning and Housing (DREAL) in their Energy and Pollutant Emissions Inventory (2012). Note that electric vehicles are not considered, since their emissions are already considered in the analysis of the energy sector earlier. Also, maritime transportation was not considered in the analysis, as this is mainly industry-based and not passenger-based. Only 6% of the sub-sector's energy consumption is passenger-related. The rest are used for the transport of gas, petroleum products, and container and bulk carriers (DREAL, 2012).

There are two major ways of calculating for the emissions in this sector: fuel-based and distance-based. In the fuel-based method, the fuel consumption is multiplied by the emission factor for each fuel type:

$$E_{pollutant} = \text{fuel consumption x heating value x } EF_{pollutant} \qquad \textit{(Equation 4)}$$

where, **fuel consumption** can be in liters, m^3, or tonnes, depending on what unit is most appropriate for the type of vehicle. Heating value is the amount of energy released per unit of fuel (GJ/L, GJ/m^3 or GJ/tonnes). $EF_{pollutant}$ is the amount of pollutant released per energy released (kg pollutant/GJ). In the distance-based method, the emission factors refer to the pollutants emitted per **distance travelled** by the vehicle:

$$E_{pollutant} = \text{distance travelled x } EF_{pollutant} \qquad \textit{(Equation 5)}$$

The emission factors take into account the sub-sector, type of vehicle, and fuel-used. They are expressed in terms of the amount of pollutant released per distance travelled (kg pollutant/km travelled). For this sector, the EF used came from reports of the World Resource Institute (2015) and Intergovernmental Panel on Climate Change (2006). Activity data were derived from DREAL's Energy and Pollutant Emissions Inventory (2012).

Both methods were used in calculating the air pollution emissions, depending on the available data. However, upon comparison with the actual inventory of DREAL, the fuel-based method proved to be more accurate. Thus, this method was used for all the categories. Also, for pollutants where no EF data was available, the EFs were calculated using the emissions and activity data from DREAL.

Upon completion of the inventory, major actionable areas were identified, and two strategies were developed tackling these areas. Finally, the emissions were re-calculated employing the strategies, and the emission reductions were calculated. The results can be found in Section 4, and the emission factors and activity databases in the Appendix.

3.1.4. Agriculture

The European Environmental Agency (2016) classifies the emission factors from agriculture in the following categories:

- Manure management

- Crop production and agricultural soils
- Agriculture including use of pesticides
- Field burning of agricultural residues

For each one of these categories, emission factors from main pollutants and the related activity data (AD) is defined in order to calculate emissions. The specifics of the methodology used to define and measure the values and the methodology can be consulted in the reference for EMEP/EEA air pollutant emission inventory guidebook (European Environmental Agency, 2016).

Manure management

Five main sources of emissions from livestock husbandry and manure management are defined, along with their corresponding pollutant:

- livestock feeding
- manure generated in livestock housing and on open yard areas
- manure storage
- field-applied manure
- excreta deposited during grazing

This section provides a method to calculate such emissions in different stages of manure management including emissions from livestock buildings, open yard areas and manure stores, together with the emissions that occur after the application of manures to land and from excreta deposited in fields by grazing animals.

In order to calculate the emissions, the first step is to know the number of animals in each category. The aim of this categorization is to group types of livestock that are managed similarly, and some examples are dairy cattle, non-dairy cattle, sheep, and swine, among others.

The second step is to decide for each cattle or pig livestock category whether manure is typically handled as slurry or solid.

The objective of Step 3 is to find the default EF for each livestock category from Appendix 1. Emission Factors Database.

The objective of Step 4 is to calculate the pollutant emissions ($E_{pollutant\_animal}$) for each livestock category, using the corresponding annual average population for each category (AAP_{animal}) and the relevant EF ($EF_{pollutant\_animal}$):

$$E_{pollutant\_animal} = AAP_{animal} \times EF_{pollutant\_animal} \qquad \textit{(Equation 6)}$$

where AAP_{animal} is the number of animals of a particular category that are present, on average, within the year

Crop production and agricultural soils

The four main sources of emissions from this category are the following:
mineral N fertiliser, livestock manure and organic waste application (NH_3);

- soil microbial processes (NO);
- crop processes (NH_3 and NMVOCs);
- soil cultivation and crop harvesting (PM).

In order to calculate the amount of NH_3 and NO pollutants emitted, the following algorithms are presented using the general equation:

$$E_{pollutant}=AR_{N\_applied} \times EF_{pollutant} \qquad \textit{(Equation 7)}$$

Where $E_{pollutant}$ is the amount of pollutant emitted (kg/year), $AR_{N\_applied}$ is the amount of N applied in fertilizer or organic waste (kg/year) and $EF_{pollutant}$ is the amount of pollutant (kg/kg).

In order to calculate the amount of NMVOC and PM emissions , the following general equation is used:

$$E_{pollutant}=AR_{area} \times EF_{pollutant} \qquad \textit{(Equation 8)}$$

Where $E_{pollutantis}$ the amount of pollutant emitted (kg/year), AR_{area} is the area covered by crop (in ha) and $EF_{pollutant}$ is the EF of pollutant in kg/year x ha. The value of AR_{area} is equated to the utilised agricultural area (UAA), which includes all cropland, permanent pasture and rough grazing land.

The Emission Factors can be obtained from Appendix 1. Emission Factors Database.

Agriculture other including use of pesticides

This category includes emissions that could not be placed in any of the previous ones. However, the emissions of carbon species from the applications of pesticides are emphasized.

It is estimated that more than 99% of the total pesticide emissions in Europe have their origin in agriculture. They consist of Persistent organic pollutants (POPs), which are chemical substances that persist in the environment, bio-accumulate through the food web, and pose a risk of causing adverse effects to human health and the environment. This group of priority pollutants consists of pesticides (such as DDT), industrial chemicals (such as polychlorinated biphenyls, PCBs) and unintentional by-products of industrial processes (such as dioxins and furans).

In order to calculate the emissions from pesticides, the following equation is defined:

$$E_{pest}=(m_{pest\_i})EF_{pest\_i} \qquad \textit{(Equation 9)}$$

Where E_{pest} = total emission of pesticides (in t/year), m_{pest} = mass of individual pesticide applied (t/year), EFpest = EF for individual pesticide (kg/kg). The Emission Factor can be obtained in Appendix 1. Emission Factors Database

Field burning of agricultural residues

Legislation within the European Union has largely outlawed practices of field burning of agricultural residues, however it is practiced in a minor scale as a way of cleaning land rapidly and inexpensively. Burning of crop residues is a minor source of emission of atmospheric pollutants such as ammonia (NH_3), oxides of nitrogen (NO_x), non-methane volatile organic compounds (NMVOCs), sulphur dioxide (SO_2), carbon monoxide (CO) and particulate matter (PM) including black carbon (BC). Burning these residues will also give rise to emissions of heavy metals (HM) and dioxin. The following equation is defined to calculate the pollutant emissions:

$$E_{pollutant} = AR_{residue\_burnt} \cdot EF_{pollutant} \qquad \textit{(Equation 10)}$$

Where $E_{pollutant}$ is the emission of pollutant (kg), $AR_{residue\_burnt}$ is the mass of residue burnt (kg dry matter), and EFpollutant is the emission factor (EF) for pollutant (kg/kg dry matter). The Emission Factor can be obtained from Appendix 1.

The total annual amount of residue should be used for this equation. Under the Intergovernmental Panel on Climate Change (2006) terminology, $AR_{residue\_burnt} = A \cdot M_b \cdot C_f$, where A is the area burnt in hectares, M_b is the mass of fuel available for combustion, in tonnes per hectare and C_f is a combustion factor (dimensionless). For default values the 2006 IPCC Guidelines, Vol. 4, Chapter 2, Table 2.6 can be consulted.

Activity data should include estimates of land areas for each crop type, which are then used to estimate residues that are commonly burned, the fraction of residue burned and the dry matter content of residue. Expressed formally, the mass of crop residue burned can be calculated from the following equation;

$$AR_{residue\_burnt} = A \text{ x } Y \text{ x } s \text{ x } d\text{x } p_b \text{ x } C_f \qquad \textit{(Equation 11)}$$

Where A (ha) is the area of land on which crops are grown whose residues are burned, Y (kg/ha fresh weight) is the average yield of those crops (e.g. grain), s is the ratio between the mass of crop residues and the crop yield, d is the dry matter content of that yield, p_b is proportion of those residues that are burned (as opposed to being incorporated in the soil, consumed by livestock on the field or removed from the field for use elsewhere) and Cf is the combustion factor (proportion of the fuel present at the time of the fire that is actually burned).

It is assumed that country statistics giving the area of cropped land will always be available. In the absence of better data, the following values should be used. Default values of s can be obtained from the table in Annex 6.1 Table 21, assuming d = 0.85, for wheat: Y = 3.6, Cf = 0.9; for maize: Y = 11.8, Cf = 0.8; rice: Y = 4.6, Cf = 0.8. If pb is not known, the value of 1 should be used. For crops other than wheat, maize and rice, the values for wheat should be used.

3.2. PROJECT MANAGEMENT

The project was performed with the guidance of Adrien Buozonville of Atmoterra. Atmoterra is a French independent consulting company working internationally with clients; providing expertise in innovative and sustainable environmental studies. After the first meeting when the project objectives were clarified, a workflow schedule was developed by the group. The team individually worked on the four sectors of concern: energy, buildings (heating), transportation, and agriculture. But, the team met every one to two weeks to ensure that everyone is aligned and that each person is knowledgeable about the other sectors as well. This was important as the final goal of this project is to develop an integrated strategy that will encompass all sectors. The team mostly worked through a shared folder. Hours of work are logged in order to monitor the project's total carbon footprint. Minutes of the meetings were also sent to the tutor after each consultation.

4. EXPLOITATION OF RESULTS

4.1. OVERALL RESULTS

The major pollutants identified across all the sectors are carbon dioxide, carbon monoxide, nitrogen oxides, sulfur oxides, ammonia, particulate matter, and non-methanolic volatile organic compounds. The following chart and table shows the results of the air pollution inventory conducted by the group, based on the emission factors and activity data collected.

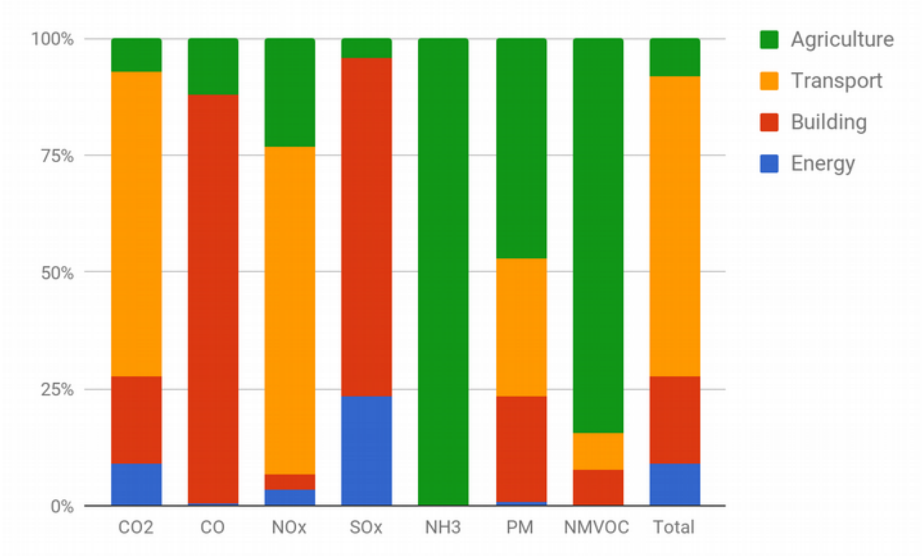

Figure 5. Air pollution inventory per sector and pollutant in Pays de la Loire

Table 5. Air pollution inventory per sector and pollutant in Pays de la Loire (ktons)

ktons	Energy	Building	Transport	Agriculture	Total
CO_2	1,010.03	2100.00	7,356.31	801.85	11,268.19
CO	0.18	31.60	-	4.38	36.16

NOx	1.57	1.59	33.45	11.1	47.71
SOx	3.98	12.3	-	0.74	17.02
NH_3	-	-	-	63.79	63.79
PM	0.15	5.07	6.48	10.5	22.20
NMVOC	0.01	3.94	4.04	43.02	51.01
Total	**1,015.93**	**2154.50**	**7,400.28**	**935.38**	**11,506.09**

Based on these inventories, two strategies were developed per sector showing high and low reduction values. These strategies, and the resulting pollutant mitigation derived from each, are summarized in the following tables. The development of each strategy are discussed in detail in Sections 4.2-4.5.

Table 6. Description of the air pollution strategies developed per sector

Sector	High Scenario	Low Scenario
Energy	Switch 83% of Thermal Energy production to Energy production with Wind Turbines	Switch 41.5% of Thermal Energy production to Energy production with Wind Turbine
Buildings (Heating)	Improve buildings energy efficiency by 35% 15% of heat consumption connected to a renewable heating network	Improve buildings energy efficiency by 15% 10% of heat consumption connected to a renewable heating network
Transport	Switch 10% of the active population from travelling by car to walking/biking	Switch 10% of the active population from travelling by car to electric car
Agriculture	Strategy 1 : a)Reduction of 60 kg-N/ha in the dose of fertilizers b) Reduction of 15 kg-N/ha due to improved seasonal application of fertilizer Strategy 2: 90% reduction of NH3 emissions from manure application (by soil injection)	Strategy 1: a)Reduction of 15 kg-N/ha in the dose of fertilizers b) Reduction of 10 kg-N/ha due to improved seasonal application of fertilizer Strategy 2: 30% reduction of NH3 emissions from manure application (by trailing hose)

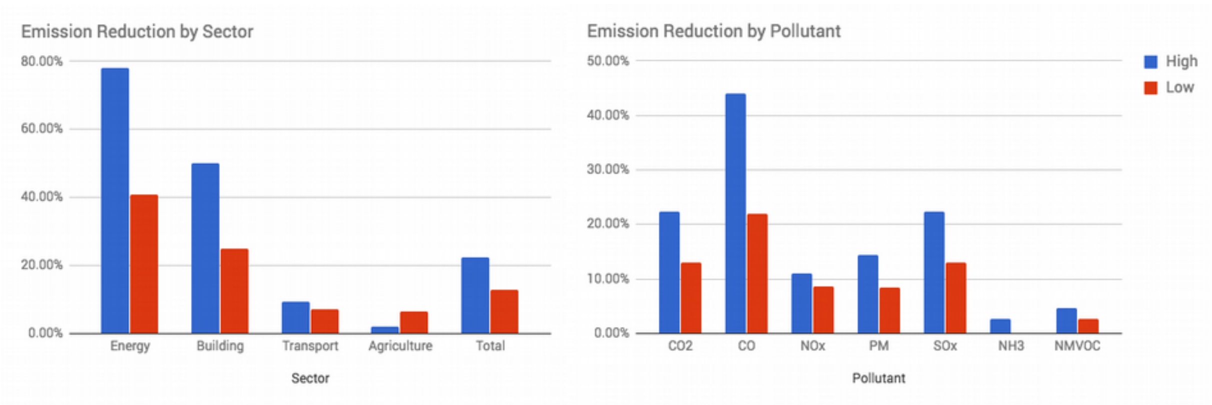

Figure 6. Summary of emission reductions from the developed strategies per sector (left) and per pollutant (right)

4.2. ENERGY

The total energy consumption in 2014 in Pays de la Loire was around 24.000 GWh, Most of this energy comes from nuclear power stations in the center region of France. Only 21% of the energy consumption, around 4945 GWh, is produced in the region, coming from two main sources, renewable energy which represents 33,4% of total energy production in the region and thermal energy which represents the other 66,6%. The thermal plant "Cordemais" produced 2.736 GWh in 2014, 83% of the Thermal energy production.

Base on this, the strategy proposed is the replacement of the Cordemais plant for renewable energy. Two possible cases are raised:

Energy - Strategy #1: Switch 83.0% of Thermal Energy production to Energy production with Wind Turbines.

This strategy contemplates the possibility to shot down Cordemais plant and replace the total energy generated, 2736 GWh, by renewable energy. These abrupt changes usually can not be carried out so that a less traumatic transition to labor force is contemplated in the following strategy.

Energy - Strategy #2: Switch 38% of Thermal Energy production to Energy production with Wind Turbines.

This second strategy takes in account the transition of the labor force, training and adaptation to the new projects in renewable energies. Cordemais thermal power plant has two production units from coal and two production units from oil fuel. This assumes that the two production units working with coal are going to be closed since their impact on air is higher.

Table 7. Summary of Energy Sector Strategies

Pollutant	Base Case	Strategy #1		Strategy #2	
	ktons	ktons	Difference (%)	ktons	Difference (%)

CO_2*	1010.032	221.486	-78.07%	599.598	-40.64%
NO_X	1.568	0.276	-82.14%	0.621	-60.40%
PM_{Total}	0.154	0.082	-48.05%	0.104	-32.47%
NMVOC	0.014	0.004	-69.93%	0.009	-42.86%
SOx	3.984	0.02	-99.50%	0.267	93.30%
CO	1.175	0.05	-71.43%	0.136	-22.29%
Total	**1015.927**	**221.918**	**-78.16%**	**600.735**	**-40.87%**

*The EF of CO2 was taken from EPA (2014) since in EMEP EEA (2016) is not considered as an air pollutant.

4.3. BUILDINGS

Residential Sector

In 2009, Pays de la Loire counted 1 835 950 accommodations including 1 529 786 main residences. The dwellings could be divided into 3 categories according to their occupancy: main residences, secondary residences and vacant housing. Note that the following analysis was limited to main residences as in terms of energy there are the ones that have the higher impact (SRCAE, 2014).

The annual flux of new construction is in the order of 28 000 accommodations per year, representing approximately 1.5% of the existing housing stock. Figure xx shows that the majority of housings were constructed before 1975; therefore, before the first thermal regulations for buildings. For newer buildings the overall tendency is on increasing the housings size (surface area).

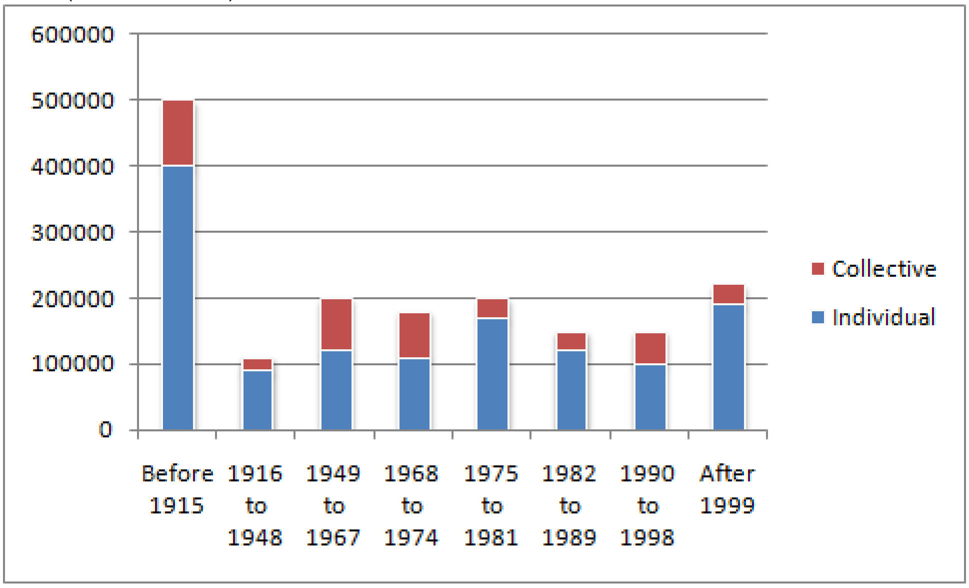

Figure 7. Distribution of Pays de la Loire housing based on the year of construction (SRCAE,2014)

Additionally, a diagnostic on energetic performance (DPE) prepared by Union Sociale de l'Habitat (USH) has shown that 38% of the collective housings had a consumption level equivalent to C (91 to 150 kWh/m2.year) and 28% were in level D (151 to 200 kwh/m2.year). The diagnostic was performed in 2010 and was based the investigation of 115 360 housing.

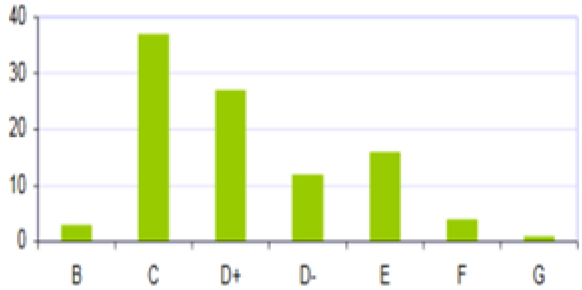

Figure 8. Ranking of social housing based on DPE

Figure 9. DPE ranking

Regarding the emitted pollutants, the greenhouse gas emissions from the residential sector are mostly energy-related and mainly concerning carbon dioxide. The distribution by use in Pays de la Loire shows a higher weight of CO2 emissions for heating compared to energy consumption (69% related to heating). This trend is particularly due to the greater penetration of electricity into cooking or hot water usage rather than petroleum products usually used for heating (Figure 3,4).

Additionally to such a high CO2 emissions, a relatively high CO, non-methane volatile organic compound along with particulate matter could also be noticed. Through a deeper analysis, it could be concluded that those pollutants are mainly due to the combustion of wood. Indeed, as it can be seen in figure 8, the combustion of wood is a particularly important emitter as it emits almost all the fine particles, NMVOCs and CO of heat combustion. These emissions come mainly from individual installations, in particular from open fireplaces (domestic fireplaces).

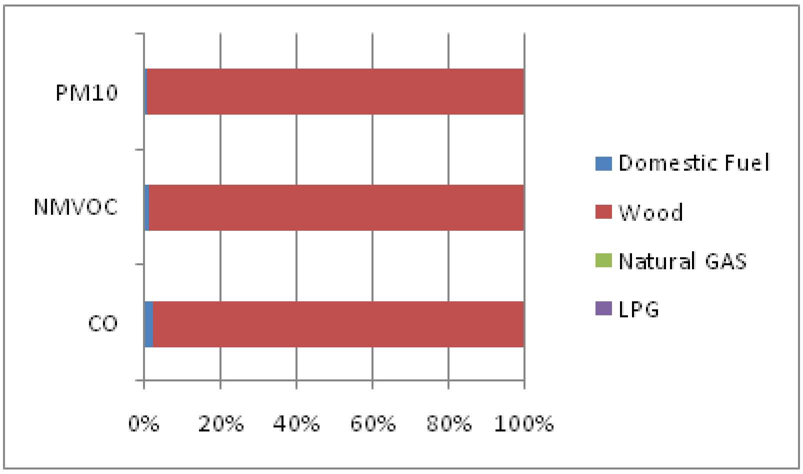

Figure 10. Fuel distribution of pollutants emission for heat

Tertiary Sector

Regarding heat consumption, the highest energy consumption in the tertiary sector is heating. Figure 9 shows that heating along account for 55% of the total energy consumption. Focusing on the heating consumption per branch, it could be noticed that the most energy consuming branches in term of heating are the cafes-hotels-restaurants and sport-leisure and healthcare buildings. Note that it is difficult to rank the types of tertiary buildings in terms of energy efficiency since the usage could be highly different from one building to another.

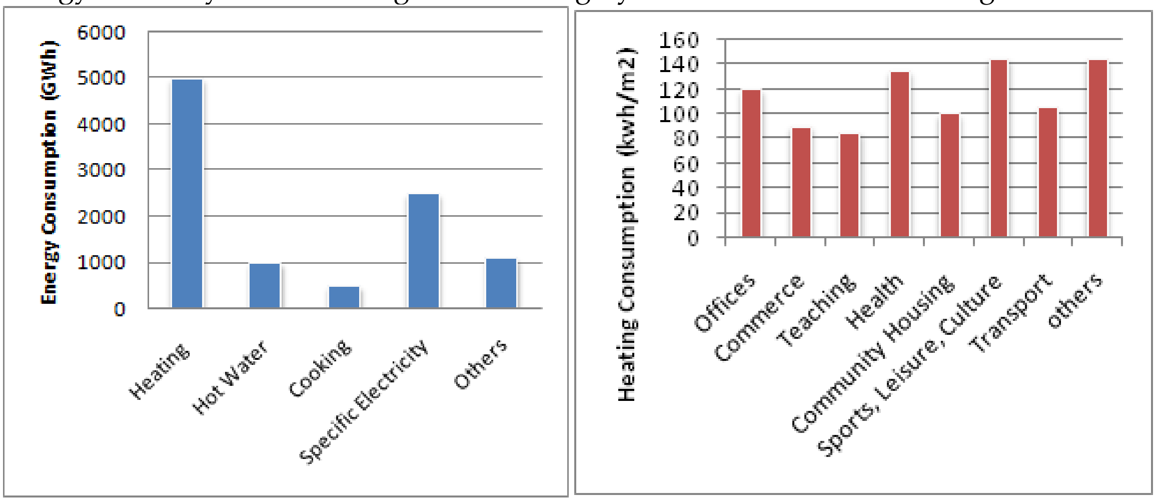

Figure 11. Energy and heating consumption (BASEMIS,2008)

Strategies

It can be deduced that heat consumption is a major concern for both residential and the tertiary sectors. Indeed, as said previously the DPE ranking for residential buildings are very low; in other words the current residential buildings in Pays de la Loire have high energy consumption. Therefore one strategy to remediate to the present issue is to improve the energy efficiency of the current buildings; residential as well as non-residential (with a particular focus on cafes-hotels-restaurants and sport-leisure and healthcare buildings for the tertiary sector) .

Table 8. Energy savings per new installation

New Installation	Energy Saving (GWh)
Global Renovation of 174 304 houses (120m2) (thermal insulation walls, double ventilation, combined solar system)	4 184,00
20 480 Heat pump installation	214,80
41 760 Installation of a VMC for 120m2 houses	108,00
12 800 Installations of Individual condensing boiler	9,60
Exterior insulation for 2 588 buildings (2500 m2)	550,00
Exterior insulation for 27 888 buildings (500m2)	1 000,00
Thermal Insulation of Roof for 27 888 buildings (500m2)	600,00
Insulation of 200 km hydraulic network	40,00

TOTAL	6 706,40

Energy efficiency could be achieved through thermal insulation, installation of heat pumps or VMCs. The following "sub-strategies" were defined based PDMDEE report as well as the housing distribution of Pays de la Loire.

Taking into consideration a total heat consumption of 19 409 Gwh, a first strategy could be formulated as follows:

Buildings - Strategy #1: Improve buildings energy efficiency by 35%

Regarding the second strategy, it formulation will be based on the fuel sources used for heating. Indeed, both residential and tertiary sector involve non-negligible polluters; such as natural gas or domestic fuel. Additionally, the residential buildings involve also wood which generates a high amount of air pollutants (CO, NMVOC) and particulate matter (Figure 8). Therefore, regulation to decrease the impact of such heat sources ought to be taken.

The focus of the following strategy would be on the development of renewable energies. Indeed, reducing consumption alone is not sufficient to achieve optimum air quality standards, meeting heat demand through clean energy is also necessary.

Buildings - Strategy #2: 15% of the heat consumption should be connected to a renewable heating network

Table 9. Emitted Pollutants (ktons)

Pollutant	Base Case	Strategy #1	Strategy #2
	ktons	ktons	ktons
CO_2	2 100	1 325	1 785
CO	31.6	20.6	26.9
NO_X	1.59	1.04	1.35
SOx	12.3	7.97	10
PM_{Total}	5.07	3.3	4.31
NMVOC	3.94	2.56	3.34
Total	2 154.5	1 400.3	1 831

4.4. TRANSPORT

The figure below shows the result of the air pollutant emission inventory derived from the emission factors and activity data collected.

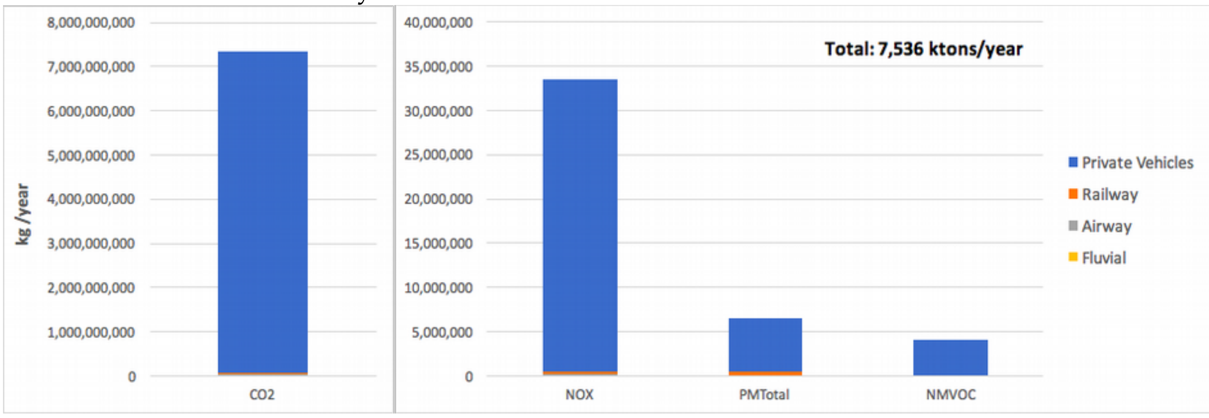

Figure 12. Air Pollutant Emission Inventory for Pays de la Loire (2012)

From here, it can be seen that an overwhelming majority of all emissions come from private vehicles. The following chart further breaks down the emissions from this sub-sector.

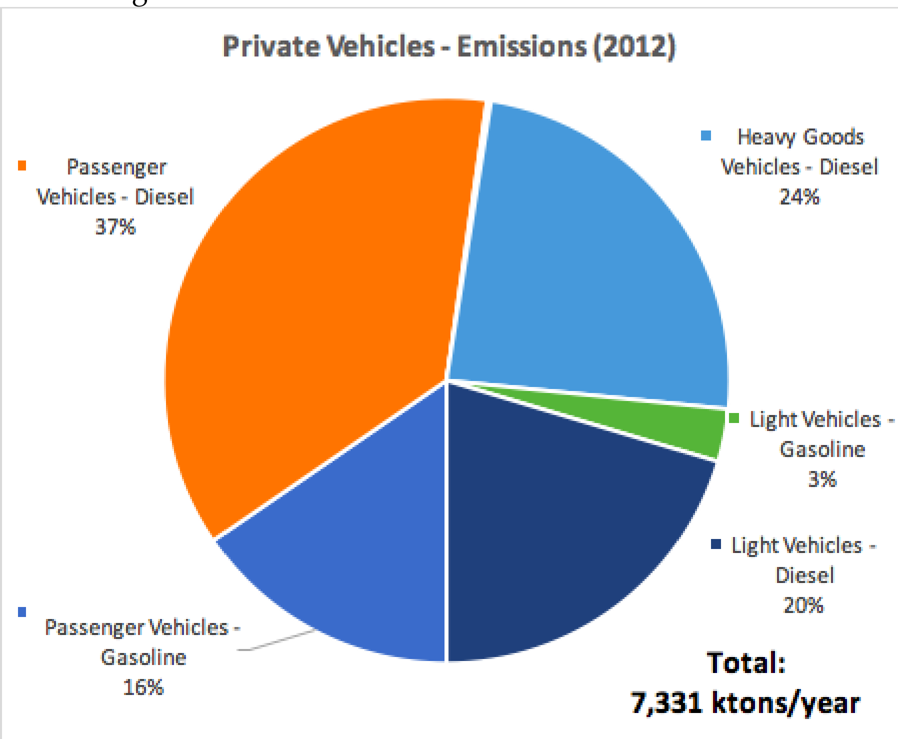

Figure 13. Breakdown of air pollutant emissions from private vehicles

It can be deduced that majority of the emissions come from passenger vehicles. According to DREAL's Report: *The Challenges of Reducing Daily Car Usage* (2012), 81% of the 1,497,000 active employees and students in Pays de la Loire travel by car, 11% by walking or biking, and only 8% use public transport. The following strategy is hereby proposed:

Transport - Strategy #1: Switch 10% of the active population from travelling by car to walking/biking

According to ICCT European Vehicle Statistics Pocketbook (2014), majority of Europe's new cars are still powered by diesel. In fact, 53% of all new registrations in 2014 are diesel cars. In France, hybrid electric vehicles only had 2.3% of the total market share. According to the Regional Council of Pays de la Loire (2016), one of the main pillars of its energy plan is the installation of infrastructure for the charging of electric vehicles. This shows the region's initiative in promoting electric vehicles. In line with this, the following strategy is hereby proposed:

Transport - Strategy #2: Switch 10% of the active population who travel via gasoline/diesel cars to electric cars

The table below shows the summary of the emission reductions attained by employing the two strategies. Detailed calculations can be found in the Appendix.

Table 10. Summary of Transport Sector Strategies

Pollutant	Base Case	Strategy #1		Strategy #2	
	ktons	**ktons**	**Difference (%)**	**ktons**	**Difference (%)**
CO_2	7,356.31	6,675.96	-9%	6,823.18	-7%
NO_X	33.45	30.36	-9%	30.75	-8%
PM_{Total}	6.48	5.92	-9%	5.93	-8%
NMVOC	4.04	3.67	-9%	3.67	-9%
Total	**7,400,286**	**6,715,897**	**-9%**	6,863.54	-7%

4.5. AGRICULTURE

Agriculture: Present state

According to the BASEMIS Inventory (2014), the Pays de la Loire region emitted a total of 11.2 Mtoeq CO_2 of greenhouse gases, making it the largest polluter in the inventory. It also consumed in the same year 0.3 Million Tonnes of Oil Equivalent (Mtoe). However, the importance of this sector lies not in emissions associated to energy use, but in methane from cattle and the application of nitrogen fertilizers, which together represent 94% of the greenhouse gases in the sector, while particulates from non-energy activities account for 85% of total pollutant emissions.

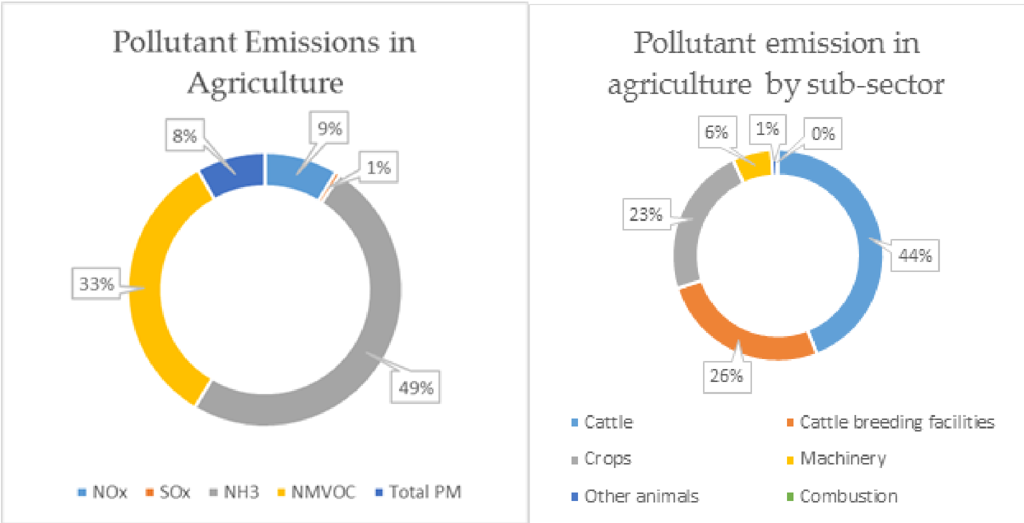

Figure 14. Pollutant emissions in agriculture by pollutant and by subsector. Source: Air Pays de la Loire (2013)

Emissions of agricultural pollutants account for 20% of regional emissions for NOX, 40% for regional PM10 emissions and 98% for NH3 emissions. It is therefore an important sector in terms of air quality, especially since NH3 combines with nitrogen oxides to form so-called secondary particles, mainly composed of ammonium nitrates. At the national level, these figures are 10%, 20% and 98%.
Regardless of the pollutant considered among the three species mentioned, it is observed that the emission is strongly, or even predominantly, of non-energy source, distributed between the breeding installations and the cultural practices. As regards nitrogen oxides, agricultural machinery traffic accounts for almost 55% of emissions.

Strategies

As it is evident from the previous section, the most important sectors to be addressed in terms of are emissions from bovines and crops. Therefore, strategies were developed to reduce the impact of this sector. The impact of these strategies has been calculated using the information in Appendices 1, 2 and 3. A summary chart of emissions in the baseline, low and high case can be found in the chart at the end of this section.

Strategy #1: Reduce mineral nitrogen fertilizer use

Less than half of fertilizer (mineral or manure) is absorbed by the crops (Reay et al., 2012). This low efficiency is due in particular to the fact that the nitrogen supplied is subjected to a number of biological and physical processes which intervene very early after nitrogen input and which are in strong competition with the plant population (gas losses, microbial activity, transport and leaching). Yet, the more the availability of nitrogen is synchronized with the potential nitrogen demand of the crop, the greater the recovery of this nitrogen brought by the crop (Recous and Machet, 1999). This knowledge has gradually gone into practice, which has resulted in an increase in the fractionation of inputs (increase in the number of applications), but this did not lead to reducing the total doses of nitrogen supplied (Agreste, 2010).Therefore some reductions in fertilizer use are suggested based in this conclusion. The strategy is also summarized in the following table, and the details of the technique are explained in the following subsections.

Table 11. Strategies for reduction of mineral nitrogen fertilizer. Source: INRA (2013)

Scenario	Strategy	Reduction (Kg-N/ha)
High	a)Reduction in the dose of mineral N-fertilizers	25
High	b)Improving seasonal application of fertilizers	15
Low	a)Reduction in the dose of mineral N-fertilizers	15
Low	b)Improving seasonal application of fertilizers	10

a) Reduction in the dose of mineral N-fertilizers

France is in a situation of strong surplus for mineral nitrogen. In 2010, agricultural activities generated an average of 32 kg per hectare of nitrogen surplus, ie a quarter of total nitrogen fertilization and 23% of the average amount of nitrogen contributed by mineral fertilization. Nevertheless, there is a high regional variability due to differences in availability of N in the soil (Commissariat général pour la développement durable, n ° 448, September 2013).

However there have been efforts by the French Government to formulate a method to calculate the optimal amount of fertilizer per hectare to be applied on agricultural lands, it was found in a study by INRA (2013) that the results of these calculations yield still a high dose of application, since the method is based in the expected yield of the crop, which is often overestimated. In turn, they suggest that the provisional dose of fertilizer be reduced by 20 kgN/ha (around 25% of the total) for large crops. This will be used as the baseline scenario for the strategies here presented. An optimistic case of 35 kg N/ha has been used.

b) Improving seasonal application of fertilizers

The purpose of this sub-action is to seek a better adjustment of nitrogen inputs to crop needs. It assumes that in a number of situations the first dose of the year can be suppressed because the nitrogen balance at the end of winter is greater than the crop requirements at that time. Removal of this first contribution leads to an improvement in the efficiency of the nitrogen supplied to the crop (the absorption by the crops of nitrogen brought in at later dates is greater) and then allows the dose to be reduced total.

This measure has been applied to winter cereals (common wheat, durum wheat and barley). We have reduced total fertilization by taking into account a criterion for improving nitrogen efficiency by considering an average apparent use coefficient of 30% on a first supply and 60% on a second supply (Machet et al., 1987, Recous et al., 1997). Taking into account the improvement in the efficiency of the later inputs, and according to the study by INRA (2013) the deferral of a nitrogen supply of 50 kgN saves an average of 15 kgN / ha in these situations (which represents a part of the first contribution, not the entirety). This average saving in fertilizer represents a deduction of 9% to the fertilization of the concerned crop areas. This will be used as the baseline scenario. A reduction of 25 kg-N/ha has been used.

Strategy #2: Reduction of NH3 emissions by improving manure application

Manure application as fertilizer to crops also shows the same problems highlighted in the previous strategy, where not all of the nutrients in the fertilizer are so easily absorbed by plants. In order to address this problem, Oenema, Velthof, Klimont & Winiwarter (2012) suggest low-emission manure application techniques involve machinery that (i) decreases the exposed surface area of slurries applied to surface soil, and/or (ii) buries slurry or solid manures through injection or incorporation into the soil.

To develop the scenarios for this strategy, a technique with low cost and low emissions reduction potential was selected (trailing hose), and for the high scenario, a technique with high emissions reduction potential but higher price was selected.

Table 12. Techniques for reduction of NH3 emissions from manure application. Source: Oenema, Velthof, Klimont & Winiwarter (2012)

Scenario	Technique	Definition	NH3 reduction potential
High	Trailing hose	Slurry is discharged at ground level to grass or arable land through a series of flexible hoses	30%
Low	Soil injection	manure is injected beneath the soil surface, thus decreasing the manure surface area exposed to the air and increasing infiltration into the soil.	90%

Summary of results

The following table and graph illustrate the kton emissions avoided by each one of the strategies in the high and low scenarios.

Table 13. Summary of results for agriculture in kton of pollutant per strategy and scenario

Scenario	Pollutant	NOx (kton)	NH_3 (kton)
H	Strategy 1	0.032	0.041
L	Strategy 1	0.035	0.043
H	Strategy 2	0	18.531
L	Strategy 2	0	6.177

The following table and graph show the overall reduction in kton and in percent for emissions of NOx and NH3 when combining strategy 1 and strategy 2.

Table 14. Summary of total emission reduction in kton and percentage

Scenario	Pollutant	NOx	NH_3
H	Total reduction (kton)	0.032	18.571
L	Total reduction (kton)	0.035	6.220
H	% Reduction	0.312	29.112
L	% Reduction	0.312	9.751

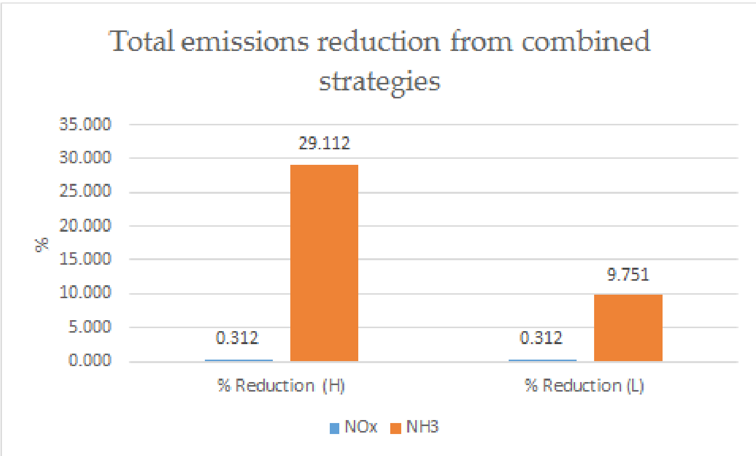

Figure 15. Total emissions reduction for combined strategies (%)

5. DISCUSSION

The energy, buildings, and transport sector had several common emissions (carbon dioxide, NOx, PM, and NMVOC). This made sense because these sectors use the same fuels, and can somehow be tied together by the energy sector. Special pollutants were carbon monoxide for the energy sector and sulfur oxides for the buildings sector. Meanwhile, the main pollutants of interest for agriculture are ammonia and NOx. Not much CO_2 is produced from this sector. Also, although the pollution is predominantly carbon dioxide, the other pollutants present in trace amounts can have severe health effects. Each sector is discussed in detail below.

In the energy sector, the calculation of Municipal Solid Waste incineration pollution was calculated with the emissions factors from "EMEP EEA air pollutant emission inventory guidebook 2016 Introduction", which are based on measurements carried out in Denmark. The different eating habits, the different industrial and weather conditions, between other factors, could change greatly the characteristics like moisture content, inert content, specific heat, etc. of MSW of Nantes in comparison with the MSW of Denmark, which means the energy produced and the pollutants emitted could vary. For that reason, this measure is made to have a rough idea of the impact. A characterization of the MSW of nantes and some tests would have to be done in order to know the actual values (EF).

Regarding the building sector, heating is a major concern as it emits a non-negligible amount of air pollutants and particulate matter. A specific concern should be on using wood as a fuel since it produces the large majority of carbon monoxide, particulate matter or NMVOC. Indeed, the second strategy should mainly emphasize on switching wood to renewable energy.

In the transportation sector, the higher impact from Strategy #1 is because the switch is made to walking/biking, where there are zero emissions. Meanwhile, when the switch is made from gasoline/diesel/LPG cars to electric cars, the emissions prevented are replaced by the emissions produced from generating the electricity needed to power the cars. The electricity mix assumed for this calculation is 83% wind:17% lignite coal - consistent with the strategy proposed for the energy sector. It is also notable that the reduction in NOx, PM_{Total}, and NMVOC for this case is higher compared to the reduction in CO_2. This is because for coal, the CO_2 emission factor is relatively higher compared to the other pollutants'.

In the agriculture sector, the contemplated strategies are useful to reduce the NH_3 emissions, but do not present a big impact on the NOx emissions. Through the application of strategies 1 and 2 to reduce the mineral fertilizer doses and improve manure application, 0.31%of NOx emissions can be reduced, while 9.751 to 29.11 % of emissions NH_3 can be avoided. From this it can be concluded that the strategies are more effective to reduce NH3, and this has a more significative impact in the overall emissions for all sectors, since agriculture is the greatest polluter for this compound. However, in order to determine the most likely scenario to be applied to the Pays de la Loire region, it is necessary to take other factors into account, such as expected crop yields, economic and policy factors.

6. CONCLUSION

The total emissions for Pays de la Loire were calculated to be 11,506.09 ktons. The major pollutants were carbon dioxide, nitrogen oxides, sulfur oxides, ammonia, particulate matter, and non-methanolic volatile organic carbons. Among the four sectors studied, Transport sector had the highest emissions (7,400.28 ktons). Two scenarios for pollution mitigation (high and low), were developed per sector, and had a resulting reduction of 22% and 13% , respectively. The energy sector's strategies were the most effective within the industry, at 78.16% (high) and 40.87% (low) - mainly due to the zero emissions when the switch to renewable energy is made. The pollutant which is most effectively mitigated is carbon monoxide, at 44.05% (high) and 21.96% (low) which is one of the energy sector's main products. In addition, the building sector also reduced its CO production by 50%.

At the energy production level, it is clear that the use of coal as energy source harm greatly the air, even suppressing only the coal units of Cordemais thermal plant, which counts for around 25% of the total energy produced in Pay de la Loire, it will reduced by 41% the total pollution generated by this sector, the second most polluting after the transport sector.

Heating of buildings contributes mainly to carbon monoxide, carbon dioxide, particulate matter or SOx pollutions. Those pollutants are mainly due to the combustion of domestic fuel or wood. Adding to that a bad insulation of Pays de la Loire current buildings; developing approppropriate measures is required. Therefore a first strategy aims at improving the energy efficiency of the current and future buildings of the region while a second one focuses on meeting the heat demand with a clean energy source. Such strategies combined were able to decrease the overall emissions of the building sector by 50%.

The major contributor for air pollution in the transport sector were passenger vehicles. The two strategies developed thus address this issue, by diverting people from traditional cars to walking/biking and electric cars. This is in line with Pays de la Loire's actual energy plan. The total reduction in emissions brought about by these strategies were 9% and 7%, respectively. It is important to clarify that the switch from gasoline/diesel cars to electric cars is effective only because it was assumed that 83% of the region's energy will come from renewable energies,. This is in line with the energy sector's Strategy #1.

The main polluters in the agriculture sector are the bovine cattle and fertilization of soils. The focus of the strategies was given to the improvement of manure application and reduction of mineral fertilization of large crops (wheat, barley, sunflower, etc.). Through the application of the strategies a total of 9.7 to 29.1% of NH3 and 0.31% of NOx emissions can be avoided. Further studies on economic, political and technical aspects are needed to implement this strategies fully.

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8. APPENDIXES

Please find attached Microsoft Excel files:

Appendix 1. Emission Factors

Appendix 2. Activity Data

Appendix 3. Emission Inventory

Appendix 4. Strategy Calculations