FLUENCE and FLUENCE Z.E.
LIFE CYCLE ASSESSMENT
OCTOBER 2011

DRIVE THE CHANGE

SUMMARY

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I

INTRODUCTION CONTEXT

I INTRODUCTION/CONTEXT

The current report presents details of the Life Cycle Assessment of a Renault vehicle, Fluence, in its two motorizations: Internal Combustion Engines and Battery-electric.

Based on ISO 14040-44 standards, Life Cycle Assessment assesses in a scientific and objective way, all potential impacts on environment of a product, considering its whole life cycle: from cradle to grave.

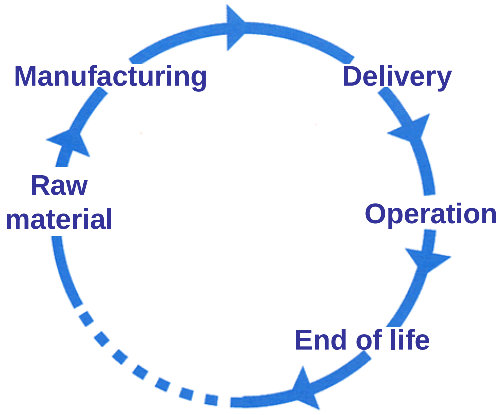

Figure 1 : Life Cycle of a product

The study respects the ISO 14040 and 14044 standards [ISO 2006], and the following points (fig.2) are considered. Note that several iterations, of this proceeding, are necessary to achieve a full LCA study, starting from a screening work, completed with complementary investigation for key specific data.

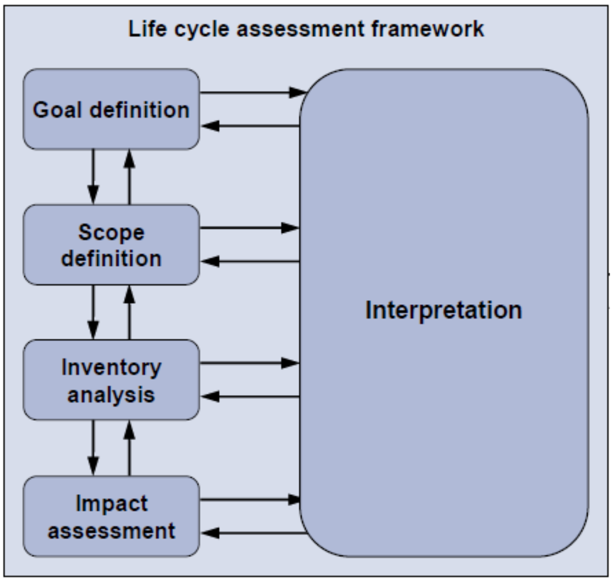

Figure 2 : Schematic table of LCA steps [EC 2010a]

Context: Why, who?

Goal and scope definition: What is considered for the study and its context (temporal, geographic and technological)

Inventory analysis: Identify and quantify the system's incoming and outgoing flows. Quantify errors from this step.

Impacts assessment: Transcription of flows in potential environmental impact.

Interpretation: Summary of environmental records and their use to achieve considered goals

II

GOALS AND SCOPE OF THE STUDY

II GOAL AND SCOPE OF THE STUDY

II.1 GOAL OF THE STUDY

II.1.1 LIFE CYCLE ASSESSMENT OF THE RENAULT GROUP

Since 1995, Renault has led an ambitious environmental policy aimed at protecting ecosystems natural balance. Internationally, the Group is working to reduce the ecological impact of its activities. Renault strategy takes into account the complete vehicle life cycle, from its design to its end of life treatment.

For Renault, protecting the environment means creating a range of vehicles and services that will respect the ecological balance, regarding the local ecosystem in one hand and on a global level as well, while considering economical and social aspects. Therefore, the Renault group is providing a unique range of eco-designed product at affordable price for all.

For a number of years Renault has been making precise measurements of environmental flows during vehicle production and use phases. We obtained gradually a clearer picture of impacts on other life-cycle phases such as supplier chain and end-of-life treatment of end of life vehicles (ELVs). Started in 2005, comparisons are now systematically performed between different generations of vehicles in the same segment.

Since 2007, Renault eco^2 and Dacia eco^2 signatures were efficient opportunities to introduce a life-cycle approach in the dialogue with our customers.

In 2011, Renault confirmed its life cycle commitment with the setting of a new Key Performance Indicator: Reduce the average world product carbon footprint of average Renault Group vehicle by 10% between 2010 and 2013 and 10% more between 2013 and 2016. This is a worldwide premiere in the automotive sector. [Morel&al 2011]

Our aim nowdays is to provide our expert stakeholders, inside and outside the company, some detailed information on our new technology toward a sustainable mobility for all the electric vehicle range.

The precise goal of the study is detailed bellow through six aspects:

- Intended application(s)
- Limitations
- Reasons for carrying out the study and decision-context
- Target audience
- Comparative studies to be disclosed to the public
- Commissioner of the study and other influential actors

II.1.2 INTENDED OPPORTUNITIES

LCA brings some opportunities, from defining the group's strategy to some dialogues with stakeholders.

The first one will be to complete our range of LCA studies in order to be able to integrate electric vehicles in our group KPI to reduce our worldwide average product carbon footprint by 10% between 2010 and 2013 and 10% more between 2013 and 2016.

Then this study will set up new unit process and Life Cycle Inventory data sets for use in a new calculation model, which will be a reference for all future electric vehicles studies.

- These Electric Vehicles embed a brand new technology, and a weak point analysis will guide the ecodesign work in order to reduce identified environmental burdens.

- Finaly this study will also provide quantitative life cycle data, scientifically based, in order to build a comprehensive dialogue with expert stakeholders inside and outside of the company.

II.1.3 LIMITATIONS

This report will present LCA results for two thermal engine vehicles and one electric vehicle. If the results are compared, the reader shall keep in mind that on the one hand we have a brand new technology (new batteries, electric engine, power electronics, etc) and on the other hand a well-known and developed one. Therefore, environmental progresses are expected in a short term thanks to key process improvement and massification of the production.

This LCA is an attributional LCA and do not take into account marginal or rebound effects. For an effective decision-making, a mix of the long-term marginal processes and/or systems shall be implemented. This study will set the basis and allow Renault to do so in the next studies.

This study is a picture of the products as they will be launched in 2011 and operated for 150 000km. The potential progress in the battery system or electricity production at grid will not be taken into account in a time dynamic perspective.

Since the battery is a new component, it was necessary to carry a full new study on this topic. For this reason some data where collected from various sources and aggregated. Some consistency question could occur while reintegrating this battery LCA in the overall product model. Nevertheless, a tremendous work has been done on this topic.

Concerning the use of the product, we consider that all vehicles are operated during the same lifetime and kilometers. Nevertheless, since the electric vehicle will have a shorter autonomy, the manner this amount of kilometers are made could differ.

The compared products are all from the Renault group and we recommend not comparing them with any other car manufacturer product LCA without a detailed knowledge of both studies.

Regarding the battery recycling processes, they are newly adapted to the Lithium-ion battery, data collection of this phase will continue during new experimentations. Several uncertainties remain to evaluate precisely the environmental impacts of the recycling processes for EV batteries.

In general for this study, benefits from the recycling processes are considered as potential credit not allocated to our product in this study. Result will be provided for information on the potential benefit for the society.

II.1.4 REASONS FOR CARRYING OUT THE STUDY AND DECISION-CONTEXT

This study will benchmark the environmental burdens of three passenger cars of different technologies.

Given the limited share of electric vehicles in the total production of the automotive sector, its production, use and end-of-life can be reasonably expected to cause none or only small changes in the background system or other systems of the economy that would not directly or indirectly structurally change it.

The life cycle is modelled by depicting the existing supply-chain attributionally. Primary physical data will be collected and associated to generic processes, which represent the average market consumption mix. One exception is the battery where primary data are collected from the supply chain and specific processes generated from existing companies.

II.1.5 TARGETED AUDIENCE

This LCA is firstly dedicated to Renault internal audience. It will be a reference for the Renault management to define future environmental objectives for Renault products by identifying strengths and weaknesses of the actual product.

This study will also provide a clear picture of the burdens linked to the battery and specific parts production, and point out for the engineers the main items to ecodesign.

Finally, this study will identify the gaps to cover, critical data to improve and allow the LCA practitioners to achieve an evaluation of the best level.

This report will be accessible for expert stakeholders in order to continue our dialogue on life cycle management and an executive summary will be prepared for non-expert readers.

From April to September 2011, a panel of international experts, in environment and life cycle assessment, has reviewed this report in order to fully comply with the ISO 14 040 norms related to Life Cycle Assessemnt.

II.1.6 COMPARATIVE STUDIES TO BE DISCLOSED TO THE PUBLIC

The study includes a comparative assertion and is planned to be disclosed to the public. Nevertheless, the compared products are all from the Renault group and we recommend, as stated in the limitations, not comparing them with any other car manufacturer LCA without a detailed knowledge of both studies.

II.1.7 COMMISSIONER OF THE STUDY AND OTHER INFLUENTIAL ACTORS

LCA actors :

Commissioner: RENAULT SAS., A de BRAUER, T KOSKAS.
Practitionners: A. BARAT, V. DANG, F. QUERINI, S. MOREL
Critical Review:
- Chair panel: P. OSSET
- Panel: H-J ALTHAUS, W KLÖPFFER, A RICHTERS, P GAUDILLAT
- Observers: S. VALDIVIA, S. ERTEL, J AURIAC

II.2 SCOPE DEFINITION

This report details and analyses the environmental potential impacts on the environment of selected Fluence models. Three models were selected: one diesel, one petrol and one electric. For this last model, several countries for the product operation are also compared.

The results are calculated in respect with the ISO 14040 [ISO 2006] and 14044 norms. All the detailed perimeter of the study and data collection are presented below.

II.2.1 PRODUCT'S DEFINITION : RENAULT FLUENCE MODELS

GENERAL DESCRIPTION	
Constructor	Renault
Denomination	Fluence
Production start	November 2009
Category	M1 (Vehicle used for the carriage of passengers and comprising no more than eight seats in addition to the driver's seat)
Body	4-doors sedan, 5 seats

MECHANICAL SPECIFICATION			
TECHNOLOGY	**Diesel – Fluence dCi**	**Petrol – Fluence 16V**	**Electric – Fluence Z.E***
Engines (fig. 3).	1.5l dCi (66kW) (K9KH8)	1.6l 16v (81kW) (K4MV8)	2460 cm3 (70 kW) (5AM400)
Gearbox	5-speed	5-speed	no-gear
Manual			-
Automatic / Robotized	- / -	- / -	•
Max speed	175 km/h (109mph)	185 km/h (115mph)	135 km/h (84mph)
Emission standard for type approval (70/220/CEE)	EURO V	EURO V	EURO V
Consumption (NEDC)	4.4 l/100km (53.46mpg)	6.7l/100km (35.11mpg)	140 Wh/km
Drivetrain battery energy content			22kWh

TAILPIPE EMISSIONS DURING THE VEHICLE OPERATION			
CO_2 (NEDC)	115 g/km	155 g/km	-
NOx	0.163 g/km	0.036 g/km	-
CO	0.309 g/km	0.339 g/km	-
HC+Nox (diesel)	0.191 g/km	-	-
HC (essence)	-	0.048 g/km	-
SO_2	0.001g/km	0.00118g/km	-
Particles PM10	0.001 g/km	-	-

DIMENSIONS			
Length	4613mm	4613mm	4748mm
Width	1813mm	1813mm	1813mm
Height	1501mm	1501mm	1477mm
Unladen mass	1205kg	1190kg	1530kg

EQUIPEMENT			
Level	Dynamique	Dynamique	Expression
Particle filter (FAP)	yes	no	-
EGR	yes	-	-
Air conditioning	yes	yes	Yes
Aluminum rims	yes	yes	Yes
Low consummation tires	no	no	Yes
Opening roof / panoramic	No / No	No / no	No / no
Systems' compare: As they are from the same generation, vehicles are up to be compared because the difference is the element of comparison: comparison of 3 different technologies: Petrol, diesel and electric			

Table 1: Specifications of analyzed vehicles

REMARK: We will only list equipment that may have a significant impact on environment due to weight change or energy consumption
REMARK: This product definition does not include any driving performance like 0-100 km/h as it is not a homologation data
REMARK: The volume of the electric motor refers to the rotor's volume

REMARK: Fluence Z.E. is the given name to the electric vehicle in order to differentiate it from diesel and petrol. Even if Z.E. stands for Zero Emission, the author wants to emphasize that this is only true for tailpipe emission during operation of the car. Of course, even an electric vehicle produces environmental burdens. Fluence Z.E. shall be interpreted solely as a given commercial name and nothing else.

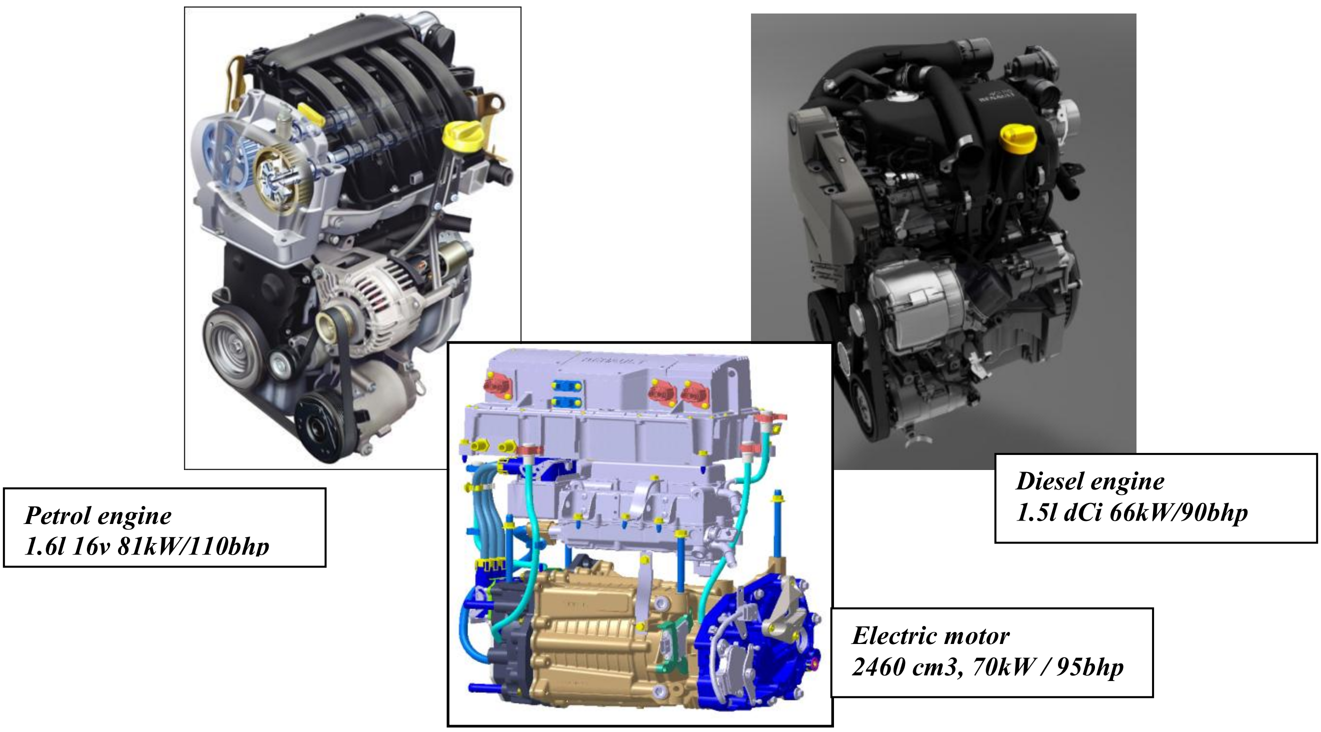

Figure 3: Renault 1.6l 16v petrol, 1.5l dCi diesel engines and 5AM 400 electric motor

II.2.2 FUNCTIONAL UNIT

The functional unit names and quantifies the qualitative and quantitative aspects of the function(s) along the questions "what", "how much", "how well", and "for how long". [EC 2010a]

This is a critical point since the rest of the study will relate to this reference. [Reap,2008]

An analysis of available studies show that fuctional unit should be completed and that most of passenger vehicle studies chose a duration of 150 000 km as lifetime. [Morel&al 2010]

Functional unit

Description of key items of the functional unit :

- What: Transportation of persons in a passenger vehicle
- How much: 150 000 km (Europe geographic scope)
- How long: 10 years
- In what way: Respect of the norms, type approval M1, and short day trips (school drive, commuting…)

Definition of the functional unit:

Transportation of persons in a passenger vehicle for short trips, for a lifetime of 150 000 kms (~93 000 miles), during 10 years, respecting M1 type approval norms (e.g. NEDC driving cycle)

The reference flow is the flow to which all other input and output flows quantitatively relate.

Reference flow

The definition of the reference flow is Fluence (SMMT C-category), a 4-doors sedan, 5 seats, as described in table 1.

II.2.3 SYSTEM'S BOUNDARIES

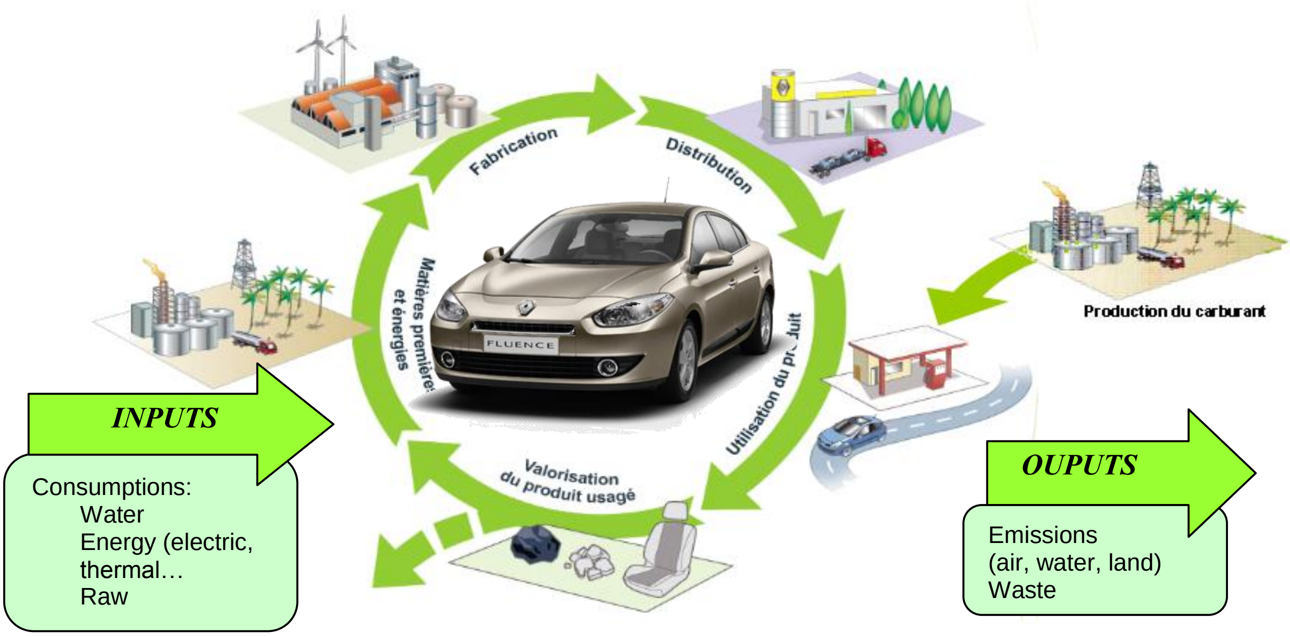

Figure 4: Renault vehicle LCA pattern

This study analyzes all the necessary data to cover 7 main contributions: materials production, part production and delivery to the factory, vehicle's production, vehicle's distribution to dealers, fuel or electricity production, vehicle's operation and end of life treatment.

II.2.3.1 Cutoff criteria for initial inclusion of incoming (consumption) or outgoing (emissions)

A cutoff criteria will be fixed at 99% of mass for the vehicle's production and 95% for all incoming flows (see fig. 5). So:

- On a 1.5-ton vehicle production, a maximum of 15 kg can be neglected

NB: Omitted flows will not include toxic substances and rare resources like platinum or gold (i.e. electronic components)

- Use of the vehicle (thermal): consumption 4.4L/100km*150 000kms ≈ 6 600 L of diesel, no more than 330 L can be neglected (≈280kg)

- For various emissions (air, water, land), calculated flows are approximated to µg and the ones given in database kept without approximation.

REMARK: For more information about cutoff criteria applied to the different elements of LCA software databases used: GaBi 4.4, report to documentation available at: http://database-documentation.gabi-software.com/

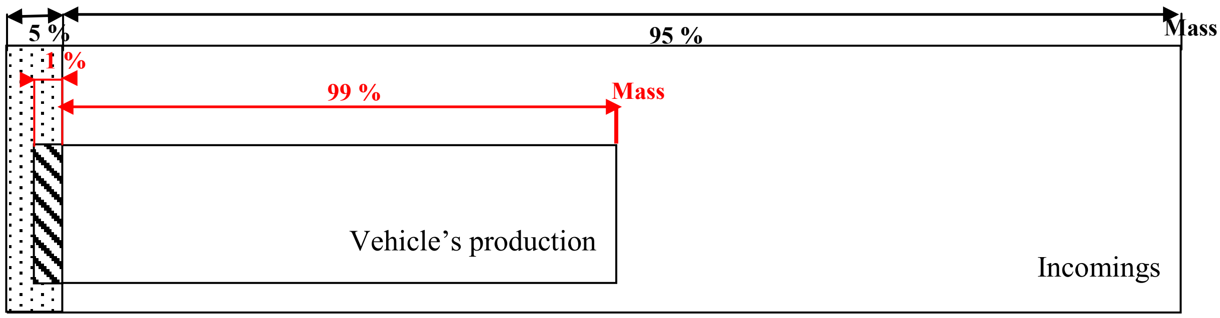

Figure 5: Cutoff criteria representation

II.2.3.2 System modeling

We exclude the construction of infrastructures like trucks, roads or other buildings as they are the same for all vehicles under estimation.

In case of decision making and consequential approach, the electricity infrastructure shall be analysed. [Frischknecht &al 2010]. Nevertheless, a study carried by the CIRED state that even with the highest expectation of sales, the electric vehicle fleet will represent a very small share of the grid electricity consumption. [CIRED 2009]

We will not consider factories because their impacts are negligible. Considering their construction, it is equivalent to 4kg of steel and 45kg of concrete, considered as negligible.

Moreover, concrete is mostly composed of aggregate; it is produced with a low quantity of energy. We will develop these hypotheses in the sensitivity analysis.

Figure 6 represents steps and elements constituting the system:

1) Dark green blocks represent extraction of raw materials and energy production
2) Green blocks the supply chain part production
3)Light Green blocks represent renault engine, gearbox, battery and vehicle production line
4) Blue blocks represent the use phase including driving and maintenance
5) Orange blocks represent diesel, petrol or electricity production
6) Brown blocks represent the end of life of the vehicle with different scenarii.
7) Grey blocks are necessary for almost all processes

The main blue dots zone represents the perimeter included in the study while the orange one represents the excluded steps such as material second life benefit.

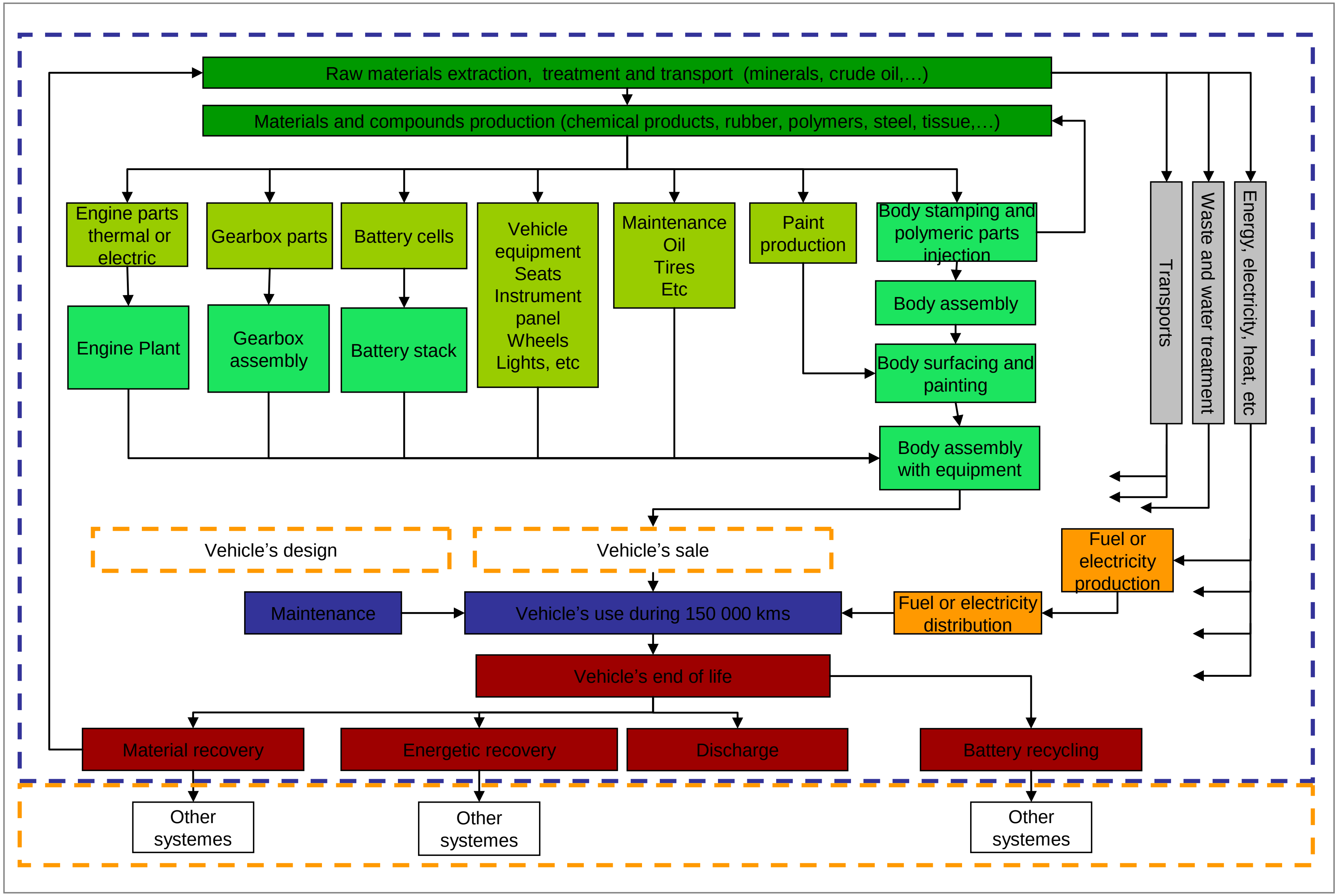

Figure 6: Systems modeling

II.2.3.3 Production

II.2.3.3.1 Supply chain

The supply chain represents the production of equipment assembled in the vehicle and maintenance's one. It corresponds to 80% of the total mass of parts and components and 45-50% of the mass of the vehicle. The knowledge on the material content of the vehicles allows us to estimate the full supply chain impact on the material production and processing stages.

The supply chain is modeled as European wide. Further work will be carried in order to precise the geographical location of our suppliers. A first study was made to compare Europe and Korea [MAKISHI 2008] and material flow analysis (MFA) tools are currently under test in Renault . A work on Input-Ouput Tables coupled with MFA will start in 2012 in order to check the necessity for more precise geographic inventories.

In this study, we pay a particular attention to the battery production. It will be describe below.

II.2.3.3.2 Lithium-ion battery materials production

The boundaries of the battery system include the production of specific materials for main components of li-ion cells: cathode, anode, electrolyte and separator… It considers the raw materials extraction and transformation stages, as well as data related to materials transportation (approximative distance, mode of transport and materials mass).[1]

Production of other components, the materials of which are more common in LCA database (Gabi, Ecoinvent), such as: battery case, battery management system, components ensuring battery assembly and electrical connection…

Transportation of these components to battery assembly factory

The raw materials extraction and transformation is detailed here:

lithium carbonate: average process from "lithium carbonate from brine (Chile)" and "lithium carbonate from spodumene (Australia)"

Manganese: Worldwide

Other active materials: worldwide extraction (modeled by PE International.)

Common materials (aluminum, copper, plastics…): Ecoinvent v 2.1, Gabi

- Components production (electrode rolls, separator rolls, electrolyte): Japan
- Assembly (cells, modules and pack): Bursa factory (Turkey) on a specific assembly line.

[1] In order to be coherent with the current context (first generation of electric vehicles), the baseline case of this report considers that active materials of electrodes are produced from raw materials and not from recycling process. However, a sensitivity analysis on this point is necessary, especially when first batteries are going to be recycled in the coming years.

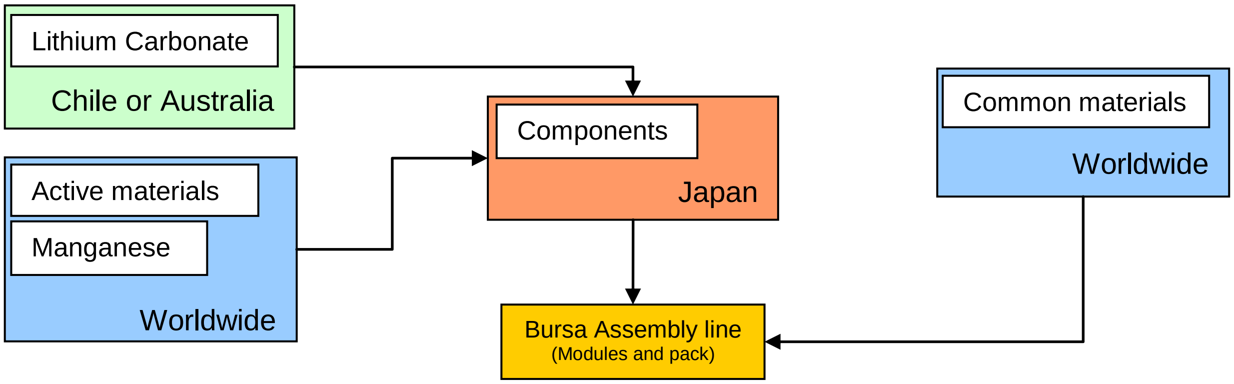

Figure 7: Drivetrain battery production's process tree

II.2.3.3.3 Renault's assembly lines

This life cycle stage includes:

- Engine production and assembly (ICE)
- Gearbox production and assembly (ICE)
- Body production and assembly
- Body treatment and painting
- Final assembly to functional vehicle

Factories are changing depending of the Drivetrain technology:

Drivetrain	Diesel	Petrol	Electric
Engine factory	Bursa (Turkey)	Bursa (Turkey)	Supply (Continental DE)
Gearbox factory	Bursa (Turkey)	Bursa (Turkey)	Supply (Continental DE)
Battery final assembly	-	-	Bursa (Turkey)
Assembly factory	Bursa (Turkey)	Bursa (Turkey)	Bursa (Turkey)

Table 2: Fluence production plants localization

II.2.3.4 Fuel production

This step includes the whole production of fuel from extraction until vehicle's tank filling. This step is also named « well to tank (WTT) ».

Data used on model is 2008 PE-GaBi EU-27 Petrol or Diesel

The allocation method applied within the refinery model is based on a staged approach, i.e. the more process steps a product passes from the crude oil distillation until the finalization of the product (refinery gate), the higher the emissions are allocated to these products. The energy demand of the corresponding steps is the decisive factor.

In the end, gasoline seems more difficult to produce in Europe since it is passing more and also very intensive energy processes. Hence, the environmental impact is higher.

This is the allocation rule choosen by the database provider. Since this is an important share of the life cycle, Renault is also implicated in the French EPA study on electric vehicles in order to improve these datas while keeping the consistency in the flows and perimeters.

II.2.3.5 Electricity production

For power supply in the use phase, we will consider power grid mixes based on PE-GaBi dataset. As the product is sold in several countries, a sales prediction weighted grid country mix is made in order to calculate the average electric vehicle. Predicted sales volumes are for 2012, which is the first full year after launch. Nevertheless, this is not sufficient and this value willl be challenged by two specific electricity mixes, France (the most sold country) and Great Britain (globally worse grid mix available in our database), where the vehicle is also sold.

Data used is 2008 power grid mixes from PE International to consolidate this sensible data.

II.2.3.6 Logistics

First rank suppliers and delivery of assembled vehicles from Bursa to final customer are considered.

II.2.3.7 Use

Total distance covered is fixed to 150 000 kms. This step includes on this distance:

- Fuel or electric consumption
- Atmospheric emissions from thermal engine operation and electricity production: CO_2, CO, NOx, HC, SO_2, Particles PM10 (from diesel engines)
- Maintenance elements:
  - Oil (drain), oil filters (thermal engines), tires, windscreen washer liquid, air conditioning
  - Wash

II.2.3.8 End of life

European Commission regulated the treatment of vehicles at their end of life. Directive 2000/53/CE (through Decree n°2003-727) defines following regulations for January 1, 2015:
85% of re-use and recycling,
95% of re-use, recycling and recovery,

Four steps constitute the vehicle's end of life (fig 8)

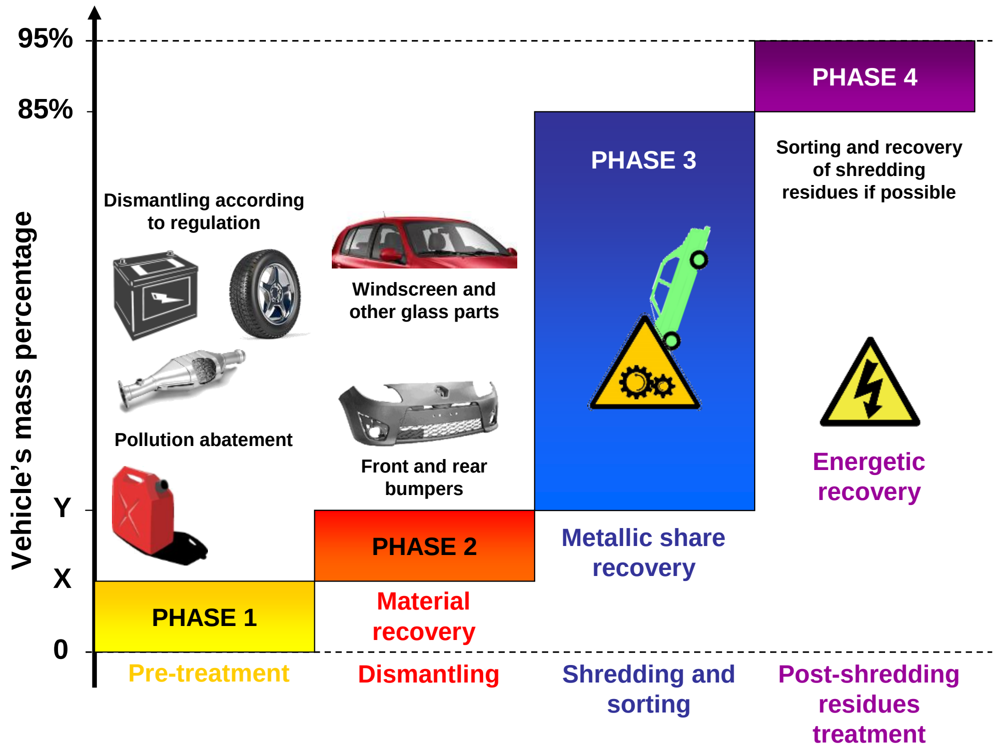

Figure 8: Treatment of a vehicle at its end of life

Phase 1: pre-treatment. This phase allows to secure the vehicle in order to proceed to the next steps. It includes airbags disarmament, fluids extraction, catalytic and battery disassembly. It represents about 7% of the total mass of the vehicle. In the EV, drivetrain battery is also disassembled from the vehicle at this step, representing a global 21.5% of the global mass of the vehicle.

Phase 2: disassembly. Also about 7% of the total mass of the vehicle. Disassembly of major parts that will be re-used (standard change) or recycled like bumpers, glass or seat foams.

Phase 3: The vehicle is crushed and then separated: ferrous metals, non-ferrous metals, crush residue (heavy and light). Metals are recycled*.

Phase 4 represents the 10% of the car energetically recovered, including materials sorted after crush and recycling. All vehicles from Renault include recycled polymer parts. Renault is currently using 25 000 tons of recycled polypropylene per year.

Recycled steel represents 10% of the high elastic limit steel composition used to build a new vehicle.

II.2.3.9 Li-ion battery End of life

EU Directive 2006/66/CE requires a recycling rate of 50% for EV Li-Ion batteries.

At the end of life of the vehicle, the drivetrain battery is removed from the vehicle during "phase 1 – pretreatment" and is treated separately by a dedicated process.

Due to its high voltage, the battery is neutralized before recycling. Then it is dismantled into smaller parts: pack case, electronic parts, electrochemical units (cells or modules)… All parts excepting cells and modules are recycled with current technique, as they contained well-known materials such as steel, aluminium and plastics.

Concerning the recycling of cells-modules, there are currently two main processes: pyrometallurgy and hydrometallurgy. These processes have been developed mainly for the recycling of cell phone or laptop Li-ion cells. They are taking place in specifics structures, which gaseous emissions are treated by a high-performance system. The following picture depicts an overview of this EoL:

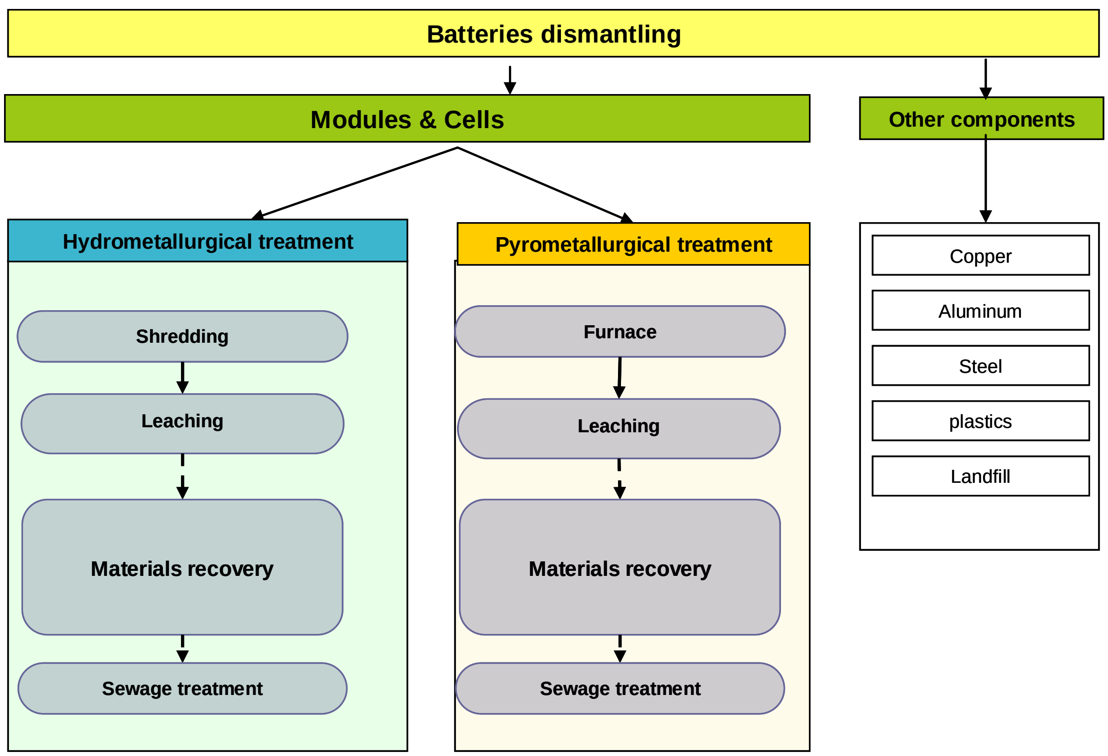

Figure 9: Treatment of drivetrain batteries at their end of life

Since these processes are newly adapted to the battery, data collection of this phase will continue during new experimentations. Several uncertainties remain to evaluate precisely the environmental impacts of the recycling processes for EV batteries.

In order to reduce the energy consumption of the battery recycling process, the remaining energy of the drivetrain batteries before their neutralization is use to contribute to the cumulative energy demand for battery recycling (thermal, electric…)

As the recycling treatment has not been chosen yet, it is difficult to calculate accurate and definitive impacts. However, considering recent literature and progress in battery recycling like Umicore activities, we can assume a credit hypothesis of 90% and also calculate treatment impacts, average of hydro and pyrometallurgic treatments.

Environmental impacts for recycle 1 pack of EV battery	Recycling process	Credit from recycled materials (90%)
Abiotic Depletion (ADP) [kg Sb-Equiv.]	0.98	-2.5
Acidification Potential (AP) [kg SO2-Equiv.]	0.89	-8.06
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	0.04	-0.25
Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	297	-541
Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	0.06	-0.41
Primary energy from resources (net cal. value) [MJ]	2876	-5623

Table 3: Environmental impacts for recycling 1 pack of EV battery

Modules and cells treatment

Data:

Data for the furnace is obtained from the literature [Umicore patent (2005) and Dewulf (2010)]

Reactant consumption and gas emissions are estimated by our own calculations, based on chemical reactions.

REMARK: The results are extremely sensitive to this chosen value for EoL credit, due to the fact that impacts linked to the primary materials production of Ni, Co… are quite consequent

II.2.3.10 System context

II.2.3.10.1 Temporal context

Fluence was launched on November 2009. The first year of production was 2010.
Fluence Z.E. will be launched on September 2011. The first year of production will be 2012.

Following hypotheses are considered:

- Design and development of the product: 3 years before launch
- Raw materials extraction: 2 years
- Supply chain and Renault production: 1 year
- Fuel production: 1 year before launch
- Electricity production: At launch
- End of life: 10 years after launch

REMARK: End of life will last until end of 2020 (resp. 2022) to prevent lack of data or knowledge about waste treatment or recovery.

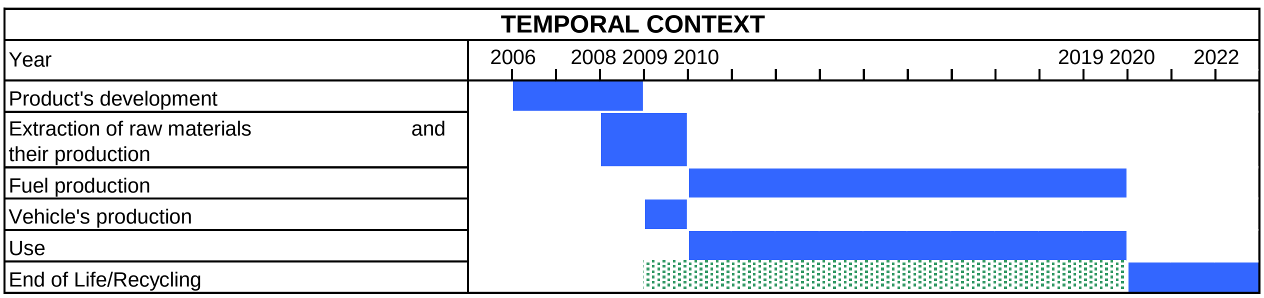

Table 4: Temporal context of the system (Internal Combustion Engine vehicle)

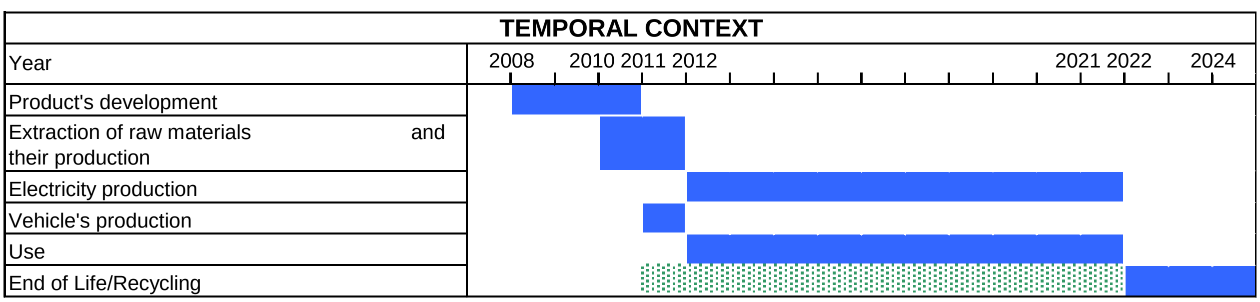

Table 5: Temporal context of the system (Electric vehicle)

Waste elimination phase starts at production of materials to build the car. This is when waste starts to be produced and then need to be treated.

II.2.3.10.2 Geographic and technologic context

	RAW MATERIALS EXTRACTION AND PRODUCTION OF MATERIALS	VEHICLE'S PRODUCTION SUPPLY CHAIN AND RENAULT	FUEL PRODUCTION	USE	END OF LIFE TREATMENT
GEOGRAPHIC CONTEXT	World (5 regions)	Assembly : Bursa (Turkey) Engine : Diesel, petrol : Bursa (Turkey) Electric : Continental (Gifhorn DE) Gearbox : Diesel, petrol Bursa Electric: Supply Parts (equipment) : Europe Battery : Active materials : Worldwide Electrolyte : Japan Final assembly : Bursa	Extraction: Russia, Middle-East et Africa (Algeria, Libya, Nigeria) Refining: Europe (France, Euro med, Asia-Africa)	Europe	Europe
TECHNOLOGIC CONTEXT	From low-cost technology for raw material extraction in emerging countries to best technologies like for petrol refining in Europe.	Better production technology on production because process and machines are well known and efficient The battery is a new technology in development.	From low-cost technology for petrol extraction in Nigeria to best technologies like for petrol refining in Europe.	Current technology in 2008 in Europe (Euro V regulation)	Better technology expected in 2023. Development respects current recycling and re-use regulations (2015) with current technology. Therefore, in 2023, elimination would be in progress.
SOURCE : PARTS LISTS FROM RENAULT DATABASES AND SYSTEMS INCLUDE GEOGRAPHIC ORIGIN OF THOSE PARTS (FIRST RANK SUPPLY)					

Table 6: Geographic and technologic context of the system (electric vehicle)

III

LIFE CYCLE INVENTORY ANALYSIS

III LIFE CYCLE INVENTORY ANALYSIS

III.1 DATA COLLECTION : METHODS AND PROCEDURES

Data collection phase consists in gathering all info about any part or process of the vehicle. Once collected, this data is used in a LCA software (GaBi 4.4), specifically dedicated to Renault's needs. The result obtained will be the life cycle pattern of the vehicle, describing processes and flows.

Following schema describes the data collection procedure:

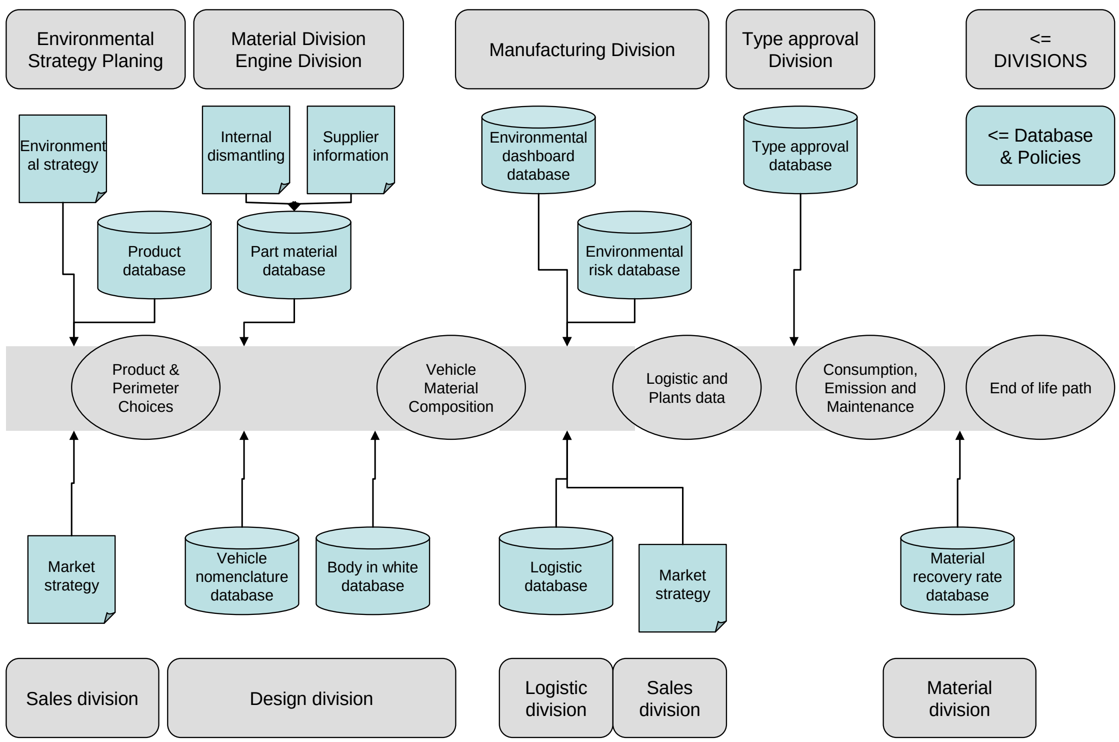

Figure 10: Data collection procedure done in Renault for LCA

As seen in this figure, collecting all data to perform an LCA is quite long. It requires a network of employees across all departments, as we do not need only technical data but also marketing data, environmental reports or sales predictions.

III.2 VEHICLE'S DESCRIPTION

Our study focuses on electric technology on Fluence. The electric version of Fluence is Fluence Z.E. available on sale in September 2011. It will be compared to its Internal Combustion Engine (ICE) version with vehicles chosen on sales department's reports defining the most sold model in both diesel and petrol engines. These vehicles are documented in the product database with drivetrain technology, gearbox type and equipment level corresponding. This database gives, from the VIN, access to data from homologation, data necessary for calculating use-phase.

III.3 VEHICLES' COMPOSITION

III.3.1 SIMPLIFIED PATTERN

For eco-design purpose, it is necessary to know environmental strengths and weaknesses of each part, organ or function of the vehicle in order to target future actions.

The vehicle can be splitted in 40 modules corresponding to the engineering organization. Then, each part is referenced with its mass/material data in a module.

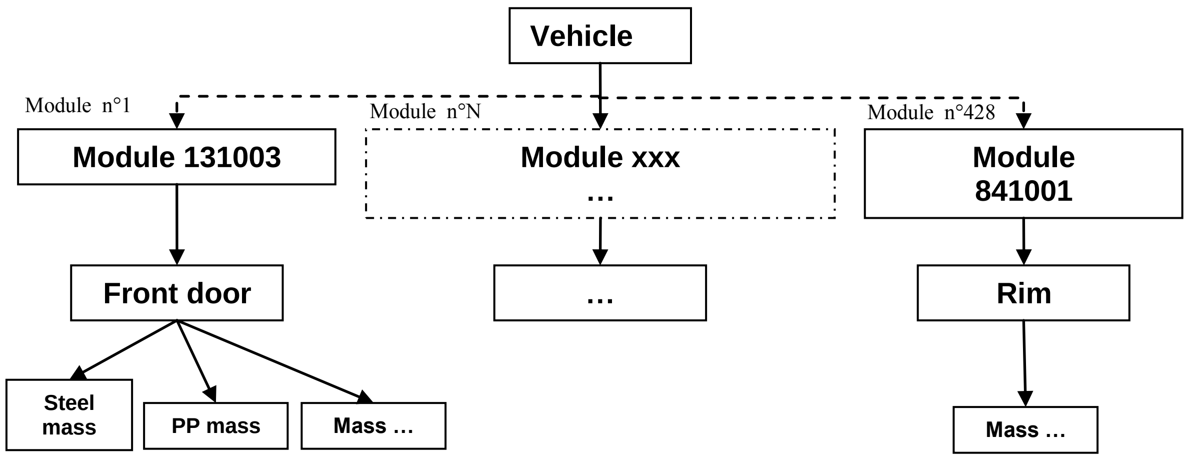

Figure 11: Vehicle material decomposition in a simplified model (5 boxes)

In order to simplify the simulation and realization of the LCA, a simplified pattern composed of five representative modules has been developed (fig 11):

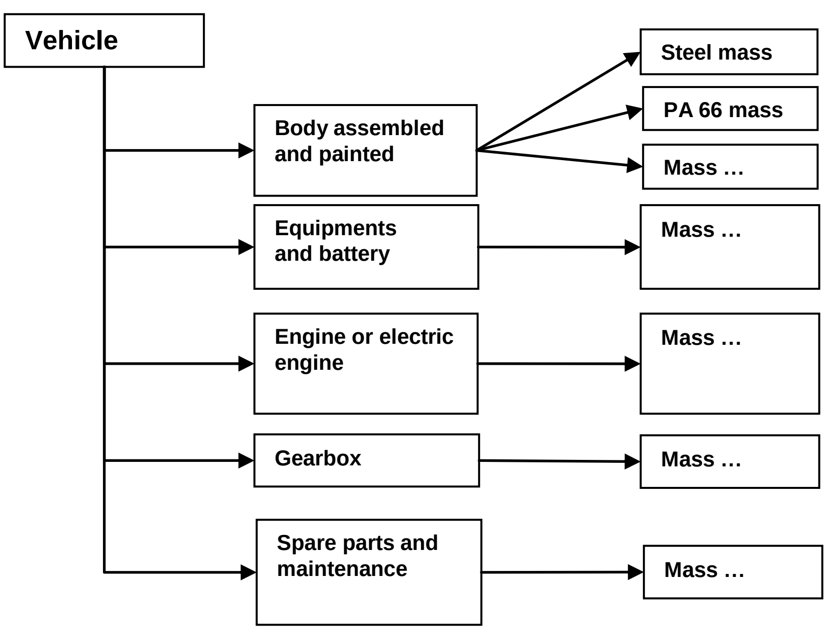

Figure 12: Vehicle decomposition in modules and materials according a simplified model

III.3.2 REFERENCE VEHICLE MATERIAL COMPOSITION

III.3.2.1 Material composition from disassembly source

Collecting data from different departments is long and tedious. A faster way to collect this data is to disassemble a vehicle and to make it as a reference for the rest of the study. In gathering info from disassembly and from departments, the pattern can be adjusted to a precise definition of the vehicle.

The vehicle, Fluence, is disassembled in mono-material parts at the recycling workshop
Each part is weighed (± 1 g) and identified with two notes:

- Material note to inquire part's composition (compulsory if mass is superior to 100g)
- Renault note (number) to identify each part in design database.

A specific tool has been developed in line with engineering organization and results are included in a standard file "Life Cycle Material Inventory"

This file cuts the vehicle in seven families of materials (metals, polymers, elastomers, glass, fluids, natural materials, and others). Data from design databases is a file support and covers the whole project. The file has been designed for mass/material data to be directly identified to a specified module (through a Renault reference or description from the recycling workshop) and then to part of the vehicle (engine, gearbox, equipment...)

This method is quick (data under 6-8 weeks), quite precise about the mass/material composition of the vehicle, and centralize data. Standardize this file gives homogeneous results in Renault databases, directly workable to synthesize mass and materials data.

This analyze also include data from design departments' databases:

DIMat (Materials Design) for materials composition

DICAP (Body assembled and painted Design) for info about mastic, paint, solvent and insulator quantities used.

In addition to material composition of our vehicle, the model includes the losses from its production. For example with steel sheets for body naked production's, we considered that producing 1 ton of final parts for assembly generates 500 kg of scrap. Therefore, production of 1 ton of steel sheet parts needs a 1.5 ton of steel sheet supply.

III.3.2.2 Modelling choices

Some elements or assemblies like ECU, DC motors or glass are not disassembled but automatically detailed from a standard composition.

It may be:

- Either a composition based on suppliers reports (components like motors, lighters, antenna…)

- Or with elements a bit more complex like ECU or cables, a composition based on a study made during a previous disassembly (SCENIC 1,9ldCi 88kw/120bhp in 2004).

Considering our cutoff criteria, we can admit that composition of those elements is the same (considering dangerous substances and rare materials, considering that it has not changed a lot since 2004).

Most of the materials exist in the software database, some approximations are possible when necessary. They are available in appendix.

III.3.2.3 Studied models' composition.

The composition of studied models is based on mass/materials composition of the disassembled vehicle. Design departments study and evaluate differences, similarities, and modify the database if needed.

III.3.2.3.1 Similitude

The equipment level is the same: « dynamique ». We consider the equipment module is the same than the reference one. We make the same hypothesis for maintenance components because differences respect our cutoff criteria (here inferior to 0.5kg)

Tires are the same: 205/55R16 (Product database source), except for Fluence Z.E. which is equipped with low-resistance tires. They have the same lifetime, are lighter and offer a lower resistance to rotation in order to maximize autonomy.

The assembled and painted body is the same for thermal models: a 5-doors sedan. (DICAP Body assembled and painted Design source). For the Z.E. model, the body in longer by about 135 mm in order to host the battery pack and to keep some trunk space. Renault tries to standardize the bodies' construction (except for 4WD, roadsters and sunroofs models)

III.3.2.3.2 Differences

The engine's composition and related electronic (especially for EV engine),

The gearbox's composition (especially for the EV, which only includes a reducer built in the electric engine block)

Presence of the battery pack or not

III.3.2.3.3 Modifications done

The petrol and diesel engine's composition come from a previous disassembly. Like majority of Renault engines, they are composed of more than 17% of aluminum.

Gearbox model is obtained from previously disassembly and their composition is the same (some parts change but not their composition)

Electric motor and reducer composition comes from Renault datasheets.

Engines and gearbox material composition used for all three models of this study are available in appendix V.3.

Modifications due to engine suspension and exhaust line are neglected. They are inferior to our cutoff criteria.

The presence of rare materials (platinum, rhodium, and palladium) in the catalyst forbids us to neglect any variation on patterns.

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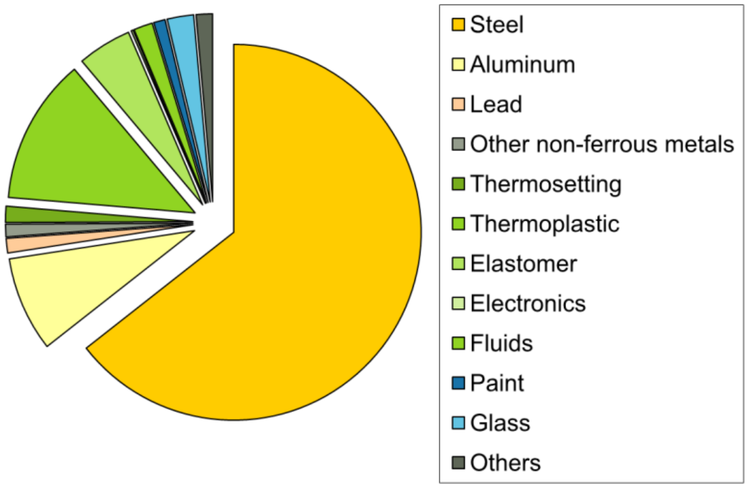
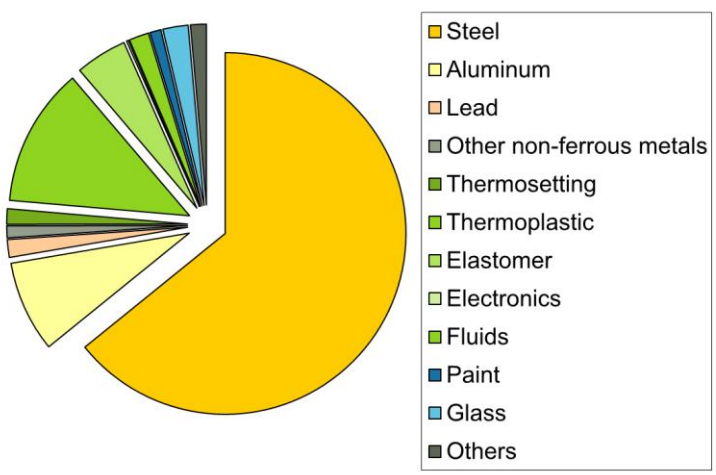
III.3.2.4 Materials overview

Figures 13, 14 and 15 give material compositions of our three models, respectively petrol, diesel, and electric.



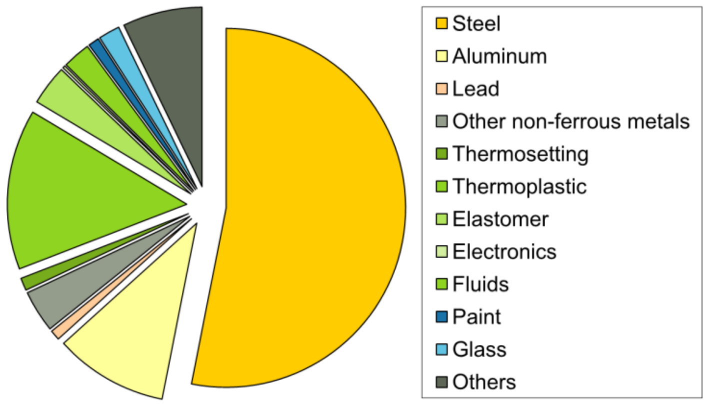
Material	Mass (Kg)	%
Steel	802,34	64,42%
Aluminum	101,69	8,17%
Lead	15,56	1,25%
Other non-ferrous metals	13,49	1,08%
Thermosetting	17,40	1,40%
Thermoplastic	156,13	12,54%
Elastomer	58,08	4,66%
Electronics	2,10	0,17%
Fluids	20,27	1,63%
Paint	12,38	0,99%
Glass	28,37	2,28%
Others	17,61	1,41%
TOTAL	1245,42	100,00%

Figure 13: Material composition of Fluence, 1,6l 16v petrol engine



Material	Mass (Kg)	%
Steel	807,26	64,17%
Aluminum	102,56	8,15%
Lead	19,95	1,59%
Other non-ferrous metals	13,41	1,07%
Thermosetting	17,40	1,38%
Thermoplastic	156,21	12,42%
Elastomer	58,14	4,62%
Electronics	2,10	0,17%
Fluids	22,32	1,77%
Paint	12,38	0,98%
Glass	28,37	2,26%
Others	17,85	1,42%
TOTAL	1 257,95	100,00%

Figure 14: Material composition of Fluence, 1,5l dCi diesel engine



Material	Mass (Kg)	%
Steel	820,86	53,10%
Aluminum	157,81	10,21%
Lead	14,00	0,91%
Other non-ferrous metals	58,47	3,78%
Thermosetting	17,52	1,13%
Thermoplastic	223,28	14,44%
Elastomer	55,74	3,61%
Electronics	3,66	0,24%
Fluids	38,56	2,49%
Paint	15,30	0,99%
Glass	29,63	1,92%
Others	110,98	7,18%
TOTAL	1 545,81	100,00%

Figure 15: Material composition of Fluence Z.E, 5AGen1 motor

We remark that compositions are quite the same (in proportion) in both ICE models:

- Steel and aluminum mass are around ¾ of the vehicle's total mass (about 72% for both engines).

Polymer part is around 19% of the vehicle's total mass with a major part composed by thermosetting materials (around 76-77% of polymer mass) favoring material recovery possibilities.

Only steel and aluminum mass are changing due to drivetrain technology's change (fuel and gearbox change):

+ 4 kg of steel and 1 kg of aluminium for the diesel model

This small difference of mass between those engines comes from their difference of power and generation. As the petrol engine has more power and is an older design generation, it is lighter than the diesel one but only by about 5.5 kg.

As a major progress, the electric engine is far lighter than the thermal engines.

	Petrol	Diesel	Electric
Drivetrain mass	183.86 kg	189.38 kg	113.73 kg

Table 7: Comparison of Fluence drivetrain masses for all technologies

Where electric technology is disadvantaged towards thermal engines is the need of the 282kg battery. The small mass of the engine allows limiting this mass increase. Appendix V.3 gives details of the electric engine's composition.

III.4 FACTORIES AND LOGISTIC

III.4.1 FACTORIES

III.4.1.1 Supply chain

As seen in § II.2.3.3.1, equipment manufacturing is subcontracted by suppliers. As we do not have any information about each process (forming, water consumption, energy consumption, emissions…) specific to each part, PE International developed specific material data by applying an additional emission factor on materials used for supply chain parts. It includes then emissions generated by the forming of the part. The emission factor is then superior to materials considered before forming like the ones used for the body naked calculation.

III.4.1.2 Renault's factories

III.4.1.2.1 Impacts

Every plant participating in Fluence and Fluence Z.E. production is ISO14001 certified. They control consumptions and emissions to improve their environmental performances. Controlled values are:

Energy consumption (electric, thermic),
Water consumption (industrial, domestic, dismineralized),
Atmospheric emissions (CO, CO_2, CH_4, N_2O, NOx, SO_2, VOC…),
Water emissions (organic substances, heavy metals, particles in suspension, chemical and biological oxygen demand, associating emissions)
Waste quantities (standard, specials)

Those values are gathered in Renault plants' environmental dashboards established each year on December 31.

III.4.1.2.2 Allocations

Problem of impacts' allocation occurs when a factory produces different engines and gearbox. We need to determinate the contribution of each module (engine or gearbox) we are working on, according to flows.

Bursa body and assembly plant also produces different cars: Fluence, Clio III, Symbol, and Megane Generation). We need to calculate the contribution of each model to every flow. Those contributions are calculated at different steps:

Stamping: number of stamping shots.
Sheet metal work : number of weld points for air emissions and energy
Painting : Quality of paint, surface (for energy and air emissions)
Equipment assembly: time for assembly for energy and waste

In our study, we equally split emissions and consumptions data of the factory between each vehicle (id. Gearbox and engines factories).

REMARK: We can improve this allocation by using an eco-risk tool (environmental management measure) but a sensitivity analysis previously performed has evaluated it as unnecessary.

All data necessary for the analysis and extracted from dashboards are compiled in tables potentially identifying interesting incoming and outgoing flows. These are available on appendix V.5.

III.4.2 LOGISTICS

Concerning first rank suppliers, an average value of 2000km is set as reference value, referring to a previous study. It sums up contribution of each transportation mode in a European context.

REMARK: All engines and gearbox of thermal engines are built at Bursa. Logistic for those heavy parts is then reduced to a factory perimeter distance, which is negligible. We will only consider electric engine logistic from Germany (first rank supplier)

The LCA study only includes logistic from factory to final customer and from first rank suppliers.

To determinate average distance done by a Fluence to its final customer, we will use data from sales' predictions giving distribution of vehicles around 15 countries. After considering distance to capitals, we will add a standard 230 kms distance for capital to final customer transport.

The average distance calculated (from viamichelin.com and Google maps) is quite random. Sales previsions are for 2012 (Fluence Z.E). Then, we have following mileages:

Models	Road mileage
Thermal engines	1788 kms
Electric engine	2276 kms

Table 8: Average mileage for assembly line to final customer travel done by each vehicle

III.5 USE

III.5.1 USE: FUEL AND ELECTRICITY PRODUCTION

Fuel production step starts with oil extraction and ends at sale to customer. This step is named “well to tank”.

Data necessary to achieve this step are:

- Mileage done by the vehicle during its total use phase: 150 000 kms fixed by the functional unit.
- Energy type (diesel, petrol or electricity) and its quality (sulfur…, electric production mix)
- Vehicle’s consumption, available on the homologation certificate:
  - 4.4l /100km for Fluence 1.5L DCi (diesel)
  - 6.7l /100km for Fluence 1.6L16v (petrol)
  - 0.14 kWh/km for Fluence Z.E.

The environmental flows associated to these consumptions (incoming or outgoing) are included in the software (automatic).

Considering Fluence Z.E., we tried to fit to the real electricity consumption of the car. As precised in II.2.3.5, we collected data from sales predictions department and we made a weighting with the 2008 power grid mixes. This data is based on 2008 IEA databases and we recently obtained them from PE International before their official release in 2012.

For Fluence Z.E., consumption includes charging losses. After the vehicle is fully charged, it is running two NEDC cycles and then charged. At this second charge, total energy consumption is mesasured and then divided per the total amount of kilometers traveled (2*11 kms), as presented in II.3.4.5.

III.5.2 USE : CAR USE PHASE

Impacts of this phase are calculated from a 150 000km mileage.
It requires collecting following data:
- CO, CO_2, HC, NOx, SO_2 and particles PM10 emissions
- Fuel and electricity consumption

Tailpipe emission data are included in conformity certificates, excluding SO2 emissions.
Those certificates contain official M1 vehicle type homologation data of Renault cars.

SO2 emissions depend on sulfur rate of fuel. They are calculated with the following formula:

$$\textbf{ppm of S} * 2*10^{-6} * \textbf{consumption (en g/km)} = \ldots\ gSO_2/km$$

With density:
Petrol = 747g/l
Diesel = 835g/l

In 2011, Fluence complies with Euro V tailpipe emission regulation: sulfur rate in petrol and diesel is 10 ppm. Of course, Fluence Z.E. is zero emission in use and then respects Euro V regulation.

III.5.3 NEDC CYCLE (NEW EUROPEAN DRIVING CYCLE)

Consumption and emissions values (CO_2 and SO_2) are calculated through mixed (urban and extra-urban) NEDC cycles. In those cycles, engines rounds at optimal rotation speeds. Air-conditioning (standard on Fluence) is off during the NEDC cycle. More data about the NEDC cycle in appendix V.7.

Following results are:

Models	5AGen1 electric	1.5l dCi diesel	1.6l 16v petrol
Consumption (mixed NEDC cycle)	0.14 kWh/km	4.4 l/100km	6.7 l/100km
CO_2 (mixed NEDC cycle)	0	115 g/km	155 g/km
NOx	0	0.163 g/km	0.036 g/km
CO	0	0.309 g/km	0.339 g/km
HC+NOx (diesel)	0	0.191 g/km	-
HC (petrol)	0	-	0.048 g/km
Particles PM10 (diesel)	0	0.001 g/km	-
SO_2	0	0.748 µg/km	1 µg/km

Table 9: Vehicles' emissions and fuel consumption during their using phase for NEDC cycle

As consumption is a quite critical data, a sensitivity analysis will be done on this criteria. Of course, the electric vehicle is zero emission (from engine's operation) during its use phase.

III.5.4 USE : MAINTENANCE

Maintenance operations (excepting crash) include (Table 10):

Operation	Life cycle frequency according to Renault recommendations (ICE)	Life cycle frequency according to Renault recommendations (EV)
Air-conditioning fluid change	1	1
Pb-battery change	1	1
Brake fluid change	1	1
Cooling fluid change	1	1
Windscreen washing liquid change	4	4
Drain	5	0
Oil filter change	3	0
Tire change	3	3

Table 10: Operation and frequency of maintenance operations

Concerning wash, we based on a study performed by "Elephant Bleu": http://www.commlc.com/presse/pdf_eb/dp_eb_conf141206.pdf, to evaluate the quantity of water used for washing purpose during the use phase of the vehicle.

Elephant Bleu data:
- Average number of washes per year in a dedicated center (poll result): 8.9
- Quantity of water used for a high-pressure wash (from French Ministry of Ecology): 50L

Therefore (8.9washes/year) x (10years) x (50l of water / wash) = 4450 liters of water is dedicated to wash during the use phase of the vehicle.

If the customer uses this system to wash his car, we can consider that all pollutants are collected and then treated in a waste water treatment facility. Water would go back to the ecosystem with a neutral impact.

As all washes are the same from one product to another, this water consumption is not considered to calculate impacts and then, <u>not considered in our study</u>.

III.5.5 USE: ELECTRIC CONSUMPTION AND REGENERATIVE BRAKES

Concerning electric vehicles, the consumption calculation is a new method recently created. This calculation is processed this way:

- We charge the vehicle to 100% of its energy capacity.
- Then, the vehicle runs two NEDC homologation cycles.
- Finally, we charge the vehicle to 100% like before the two cycles.

During this last phase, we measure the energy delivered to the vehicle and then divide it by the total mileage run by the vehicle. The 0.14 Wh/km includes then the global efficiency of the drivetrain: charge, motor controller and motor itself.

As we may understand, this consumption value includes regenerative brakes operation. On Fluence Z.E., regeneration operates on acceleration pedal release, and not on standard action on the brake pedal. That is why anticipation is important to get the best advantage of regenerative brakes. On an NEDC cycle, this regeneration offers about 20 kilometers more range (reaching 185 kms). Considering an urban conditions driving cycle, this contribution can reach 30 to 40 kilometers.

III.6 END OF LIFE

The end of life scenario is modelled in 4 phases and uses recovery rates from current technologies, preceding our vehicle's end of life temporal context (2020). In 2020, thanks to EU recovery regulations, the end of life model should be cleaner.

In order to respect the study's perimeter, the model split the end of life in two steps:

- Pre-treatment (equivalent to cleanup): tires treatment, fluids drain (oils, air-conditioning), catalyst and battery.
- Decomposition of the rest of the vehicle (including manual disassembly and crush) by materials (steel, aluminum, copper, polymers, special metals, electronics, glass…) that are linked to a specific energetic or material recovery structure.

We can consider two different allocations for recycling (fig. 13):

Car recovery to another application: no benefit or impact (linked to recycling process) is applyied to our vehicle; we consider they are applied to the life cycle of the secondary product.

Car to car recovery: part of materials reintegrates production. We consider that benefits go to the current vehicle (recycling process of environmental impacts).

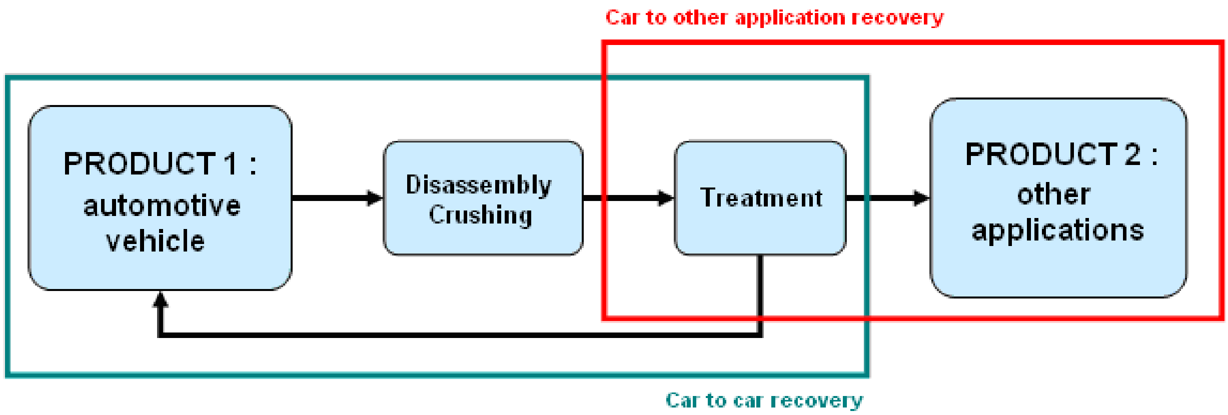


Figure 16: Possible recycling imputation scenarii

<u>In this study, we do not consider car to other application recovery. We will only focus on car-to-car recovery, which detailed process is explained (for steel) in following figure 13.</u>

Considering any vehicle, it is difficult to know the part of recycled materials coming from automotive industry. However, we can consider a closed-loop system because of two main facts: first, secondary materials mainly exist because of the automotive industry and automotive products; and because it is the constructor's responsibility to ensure the vehicle's recyclability. Secondary material produced with recycling operations substitute to new material at production.

We consider burdens from recycling for the LCA of our current vehicle.

In some cases like steel (fig 17) or aluminum, part of the material flow reintegrating the material manufacturing process. Die-casting is for example a process, which consume steel waste as input. Therefore, the amount needed in the production phase is oriented to the production and do not bring any credit in the end of life.

In general, for this study, benefits are considered as potential credit not allocated to our product in this study.

Then we consider following hypothesis:

Recovery:
- Metals (steel, aluminum, copper) recycled over 98%
- Tires:
    - Material recovery about 67 %
    - Energetic recovery about 33%
- Polymers and elastomers:
    - Material recovery about 60 %
    - Energetic recovery about 40%
- Discharge: Crushing residues:
    - 2% of metals
    - 75% of glass (laminate glass)

<u>REMARK</u>: Considering fluids, some rare metals or natural materials, we do not model this phase because of lacks of data about their recovery structure. Although those elements are not put in discharge or emitted in the nature, impacts or benefits are not calculated.

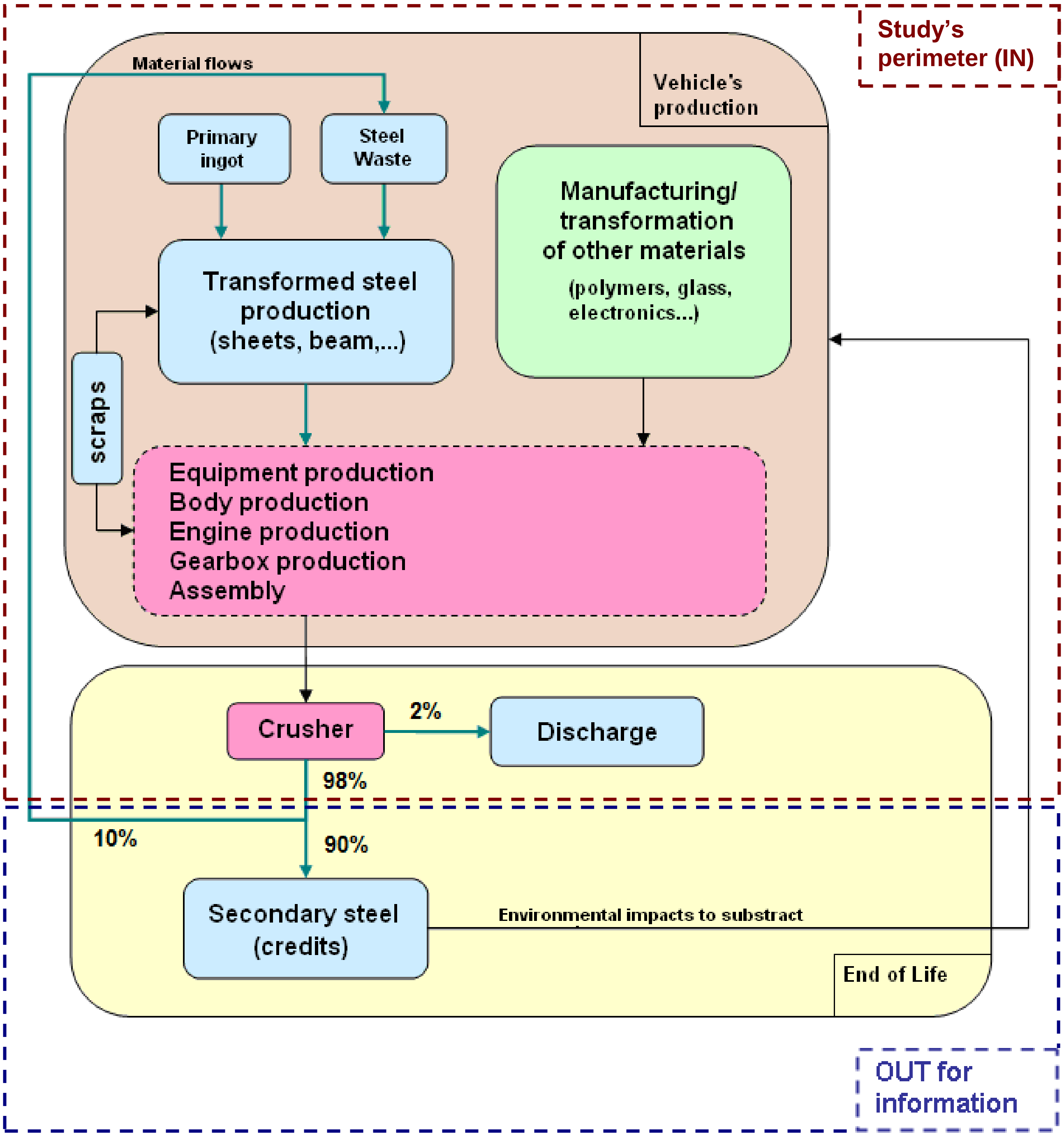


Figure 17: Steel recycling

III.7 QUALITY OF DATA

Process	Data specification			Data source					Comments
	Product specific	Specific to site	General	1	2	3	4	5	
Vehicle's production									
Crude oil and ores extraction			X		X				PE – GaBi data on demand, update 2011 reference year 2008
Steel production			X	X					PE – Average industrial data
Aluminum production			X	X					PE – Average industrial data
Polymers and plastics production			X			X			PE – Average industrial data / Literature
Other materials production (copper…)			X			X			PE – Average industrial data / Literature
Engine composition	X			X	X				RENAULT - Decomposition per category of material measured + hypothesis on metals decomposition
Engine production and assembly		X		X					RENAULT - EDB Bursa
Gearbox composition	X					X			RENAULT – Mass ratio compared to another model
Gearbox production and assembly		X		X					RENAULT - EDB Bursa
Body and equipment composition	X			X	X				RENAULT - Measure on reference model disassembly
Body production and assembly	X			X					RENAULT - EDB Bursa
Body treatment and paint	X			X					RENAULT - EDB Bursa + DICAP data
Equipment production	X					X			PE process database
Equipment assembly to body	X	X		X					RENAULT - EDB Bursa
Vehicle's transport to dealer		X						X	RENAULT – hypothesis delivery to final customer

Notes : PE stands for : PE International GMBH Life Cycle Engineering & LBP – GaBi, database update 4.131(year 2006) & GaBi version 4.4.123.1
1) Measures
2) Calculations from mass balances and/or incoming data for the defined process
3) Extrapolation of data from a defined process or similar technology
4) Extrapolation of a defined process or similar technology
5) Estimations

EDB : Environmental dashboard

Product specific data : refers to processes specifically referring to Fluence
Site specific data : concern data from sites included in Fluence's system but not specific to this model
General data : what is left

Board source: Adapted from « Environmental Assessment of Products » - Volume 1 – H. Wenzel

Table 11: Origin and specifications of data collected during analysis

Process	Data specification			Data source type					Comments
	Product specific	Specific to site	General	1	2	3	4	5	
Fuel production									
Crude oil extraction			X		X				PE – GaBi data on demand, update 2011 reference year 2008
Crude oil refining			X		X				PE – GaBi data on demand, update 2011 reference year 2008
Fuel production			X	X					PE – Average industrial data / PE – GaBi data on demand, update 2011 reference year 2008
Vehicle's use									
Life time	X				X				RENAULT – INRETS statistics
Fuel consumption	X			X					Renault – NEDC cycle homologation testing structure
Emissions	X			X	X				Renault – NEDC cycle homologation testing structure
Real cycle (fuel consumption)									
Vehicle's end of life									
Elimination structures (Recovery, treatment)			X			X			PE - Literature
Recovery rate	X				X				PE – Literature /Recycling centers
Vehicle's pre-treatment		X			X				PE – Literature / Recycling centers
Vehicle's dismantling		X			X				PE – Literature / Recycling centers
Transport									
Distance and modes		X			X	X			PE – Literature /Statistics
Emissions and energy consumption		X		X	X				PE – Literature /Statistics
Energies									
Energy production (including electricity)			X			X			PE – GaBi data on demand, update 2011 reference year 2008

Notes : PE stands for : PE International GMBH Life Cycle Engineering & LBP – GaBi, database update 4.131(year 2006) & GaBi version 4.4.123.11)
Measures
2) Calculations from mass balances and/or incoming data for the defined process
EDB : Environmental dashboard
3) Extrapolation of data from a defined process or similar technology
4) Extrapolation of a defined process or similar technology
5) Estimations

Product specific data : refers to processes specifically referring to Fluence
Site specific data : concern data from sites included in Fluence's system but not specific to this pattern
General data : what is left

Board source: Adapted from « Environmental Assessment of Products » - Volume 1 – H. Wenzel

Table 12: Origin and specifications of data collected during analysis (following and end)

III.8 OVERVIEW OF ASSUMPTIONS AND DEFINITIONS FOR THE LIFE CYCLE ASSESSMENT

The table below presents a summary of all the assumptions and definitions considered in this study.

Intended applications

- Complete our range of LCA studies in order to be able to integrate electric vehicles in our group KPI monitoring
- Set up new unit process and LCI data sets (eg battery) to be utilised use in a new calculation model
- Carry a weak point analysis in order to persue the ecodesign work on this new technology
- Benchmarking against the Renault European product group's average (2010 year)
- Build a comprehensive science based dialogue with expert stakeholders inside and outside of the company

Scope of assessment

- Function of systems:
Transport of passengers in a five-seater car
- Functional unit:
Transportation of persons in a passenger vehicle for short trips, for a lifetime of 150 000 kms (~93 000 miles), during 10 years, respecting M1 type approval norms (e.g. NEDC driving cycle)

Comparability

• Comparable performance figures
• Cars with standard equipment and fittings

System boundaries

• The system boundaries include the entire life cycle of the cars (manufacturing, service life and recycling phase) and according to the cut-off criteria.

Cut-off criteria

• The assessment includes maintenance but not repairs
• No environmental impact credits are awarded for secondary raw materials produced
• Cut-off criteria applied in GaBi data records, as described in the software documentation (www.gabi-software.com)
• Explicit cut-off criteria, such as mass or relevant emissions, is defined at 99% for the vehicle's definition and 95% for incoming flows.

Allocation

• Allocations used in GaBi data, as described in the software documentation (www.gabi-software.com)
• Allocations described in the end of life chapter, earlier in this report

Data basis

• Renault vehicle parts lists
• Material and mass information from the Renault Material Data
• Technical data sheets
• Emission limits (for regulated emissions) laid down in current EU legislation
• The data used comes from the GaBi database or collected in Renault plants, suppliers or industrial partners

Life Cycle Inventory results

• Life Cycle Inventory results include emissions of CO_2, CO, SO_2, NOX, NMVOC, CH_4, as well as consumption of energy resources
• The impact assessment includes the environmental impact categories

eutrophication potential, ozone depletion potential, photochemical ozone creation potential, global warming potential for a reference period of 100 years and acidification potential • Normalisation of the results to average impact per inhabitant values
Software
• Life Cycle Assessment software GaBi
Evaluation
• Evaluation of Life Cycle Inventory and impact assessment results, subdivided into life cycle phases and individual processes • Comparisons of impact assessment results of the vehicles compared • Interpretation of results

Table 13: Assumptions and definitions for the Life Cycle Assessment

IV

LIFE CYCLE IMPACT ASSESSMENT

IV LIFE CYCLE IMPACT ASSESSMENT

IV.1 INDICATORS CHOSEN FOR THIS STUDY

Environmental indicators were chosen in considering three criteria:
- Contributions known and supposed of automotive product.
- Diversity of ecosystems, local biodiversity, global resources depletion.
- Indicators positively considered by environmental experts and the European automotive industry.

The choice of indicators was validated by using the French matrix: adapted [ADEME 2011]

[ADEME 2011] Impact Assessment Proposals		EVALUATION			
		RELEVANCE	FEASABILITY	CONSISTENCY	FIABILITY
Global warming	✓	high	high	high	high
Abiotic depletion	✓	high	high	high	high
Water eutrophication	✓	medium	medium	medium	medium
Photochemical pollution	✓	medium	medium	medium	medium
Acidification	✓	medium	medium	medium	medium
Aquatic ecotoxicity	✘	medium	low	medium	low
Biodiversity	✘	low	low	medium	low
Land Use Change	✘	low	low	medium	low

Table 14: Impact assessment choice matrix

Another indicator is added to the study: Primary Energy Demand for renewable and non-renewable materials. This indicator is closely linked to abiotic depletion, nevertheless, the electric vehicle technology emphasizes this aspect and it will therefore be included in the further analysis.

Characterization factors chosen are CML 2001 ones, according to project LIRECAR and Renault. (More details at http://www.leidenuniv.nl/cml/ssp/databases/cmlia/cmlia.zip):

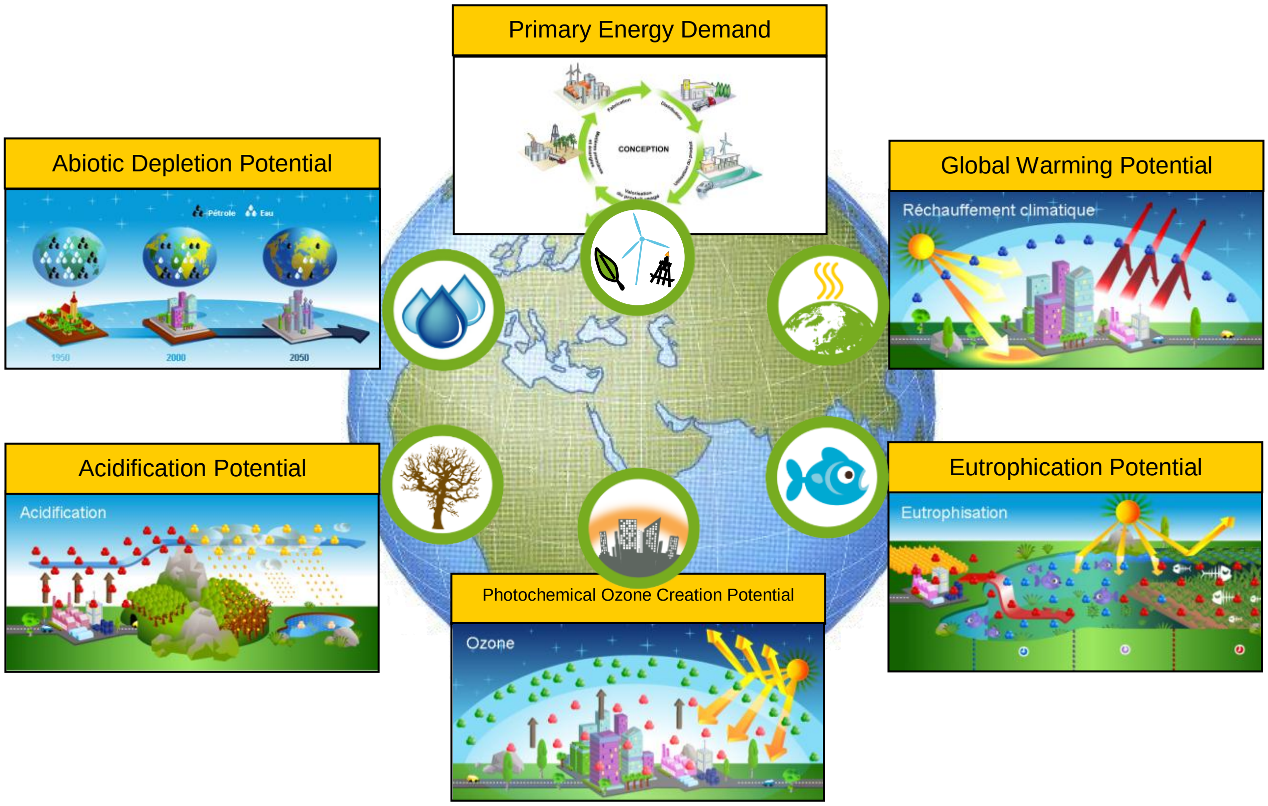


Figure 18: Impact categories chosen for the study

Indicators	Definition
Global Warming 100yr Potential (kg CO_2 equivalent)	Quantifies non-natural increase of greenhouse effect gas concentration (CO_2, N_2O, CH_4, refrigerants…) in the atmosphere and consequently of global warming potential.
Acidification Potential (kg SO_2 equivalent)	Characterize the acid substances increase (NOx, SO_2…) in lower atmosphere, source of acid rains and forests depletion.
Photochemical Ozone Creation Potential (kg Ethene equivalent)	Quantify the production of pollutant ozone (≠ to ozone layer), responsible of « ozone peaks », results of reaction of sunlight on NOx and volatile organic compounds. This ozone is irritating for respiratory system.
Eutrophication Potential (kg Phosphates equivalent)	Characterize introduction of nutrient (nitrogenous or phosphate compounds per example) providing proliferation of algae, which consequence is the asphyxia of the aquatic world
Abiotic Resource Depletion Potential (kg Sb equivalent)	Quantify ores (steel, aluminum, copper…), water, and non-renewable energies (crude oil, coal…) consumption leading to resources and abiotic depletion.
Primary Energy Demand (MJ) (renewable and non-renewable)	Quantify the quantity of energy (crude oil, coal…) consumption

Table 15: Environmental impacts categories selected and definition

The environmental impacts determined in the Life Cycle Assessments are representing a specific burden to the environment; therefore, they are measured in different units. For instance, the global warming potential is measured in CO2 equivalents and the acidification potential in SO2 equivalents. In order to make them comparable, a normalisation process is required. In this Life Cycle Assessment, the results were normalised with reference to the annual average environmental impact caused by Western Europe (EU15). For example, in the global warming category, the impact caused by Western Europe was about 4.7 billion metric tons of CO_2 equivalents.

Inidcators	Impact caused by Western Europe inhabitants (EU15) ($x10^6$)
Abiotic Resource Depletion Potential (kg Sb equivalent)	14 847
Acidification Potential (kg SO_2 equivalent)	27 354
Eutrophication Potential (kg Phosphates equivalent)	12 472
Global Warming 100yr Potential (kg CO_2 equivalent)	4 727 748
Photochemical Ozone Creation Potential (kg Ethene equivalent)	8 241

Table 16: EU 15 normalisation factors in accordance with CML 2001

IV.2 INDICATORS NOT CHOSEN

IV.2.1 HUMAN TOXICITY

It includes carcinogens and atmospheric pollution (PM10 particles principally). Because of lack of data and results disparities depending on the simulation method, we did not choose this indicator. The Environmental relevance and Scientific robustness & Certainty are quoted as compliant in some aspects only by [EC 2010b].

IV.2.1.1 Particles (PM10)

These are fine dust from incomplete diesel combustion. With a diameter inferior to 10µm, they can penetrate animal and human airway and cause asthma, inflammations or cancers.
That is why Renault pays a large attention into respecting Euro regulations to reduce PM10 quantity. Then, PM10 quantity was reduced of 82% from 1994 to 2005 and has reached a 96% reduction in 2008-2009.

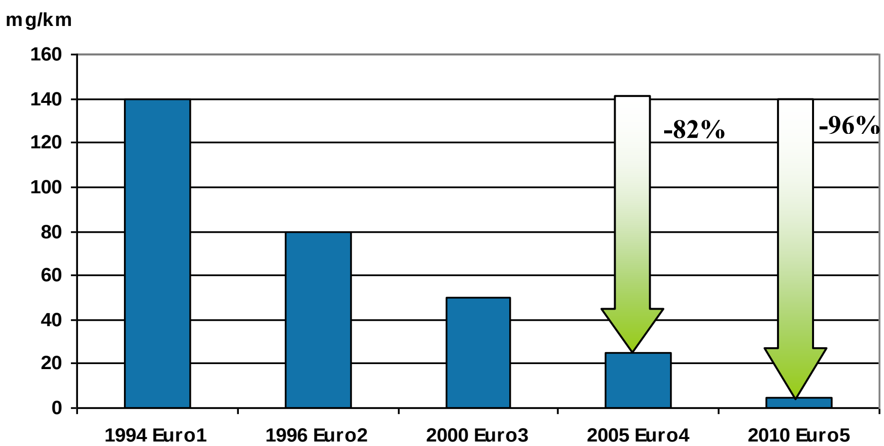


Figure 19: PM10 quantity reduction between 1994 and 2010

The best solution is using a particle filter, which stocks them in a first time and then burns them in a regeneration process. Renault developed a Fifth injector technology, which lets these operations unknown from the user and reduces PM10 emissions to less than 1µg/km. In order to answer Euro V regulations, diesel vehicles are now equipped with particle filters.

IV.2.1.2 Carcinogens substances

Benzene is a substance contained in a low quantity (< 1%) in HC (unburned hydrocarbons emitted in exhaust gas), which carcinogen factor is verified. However, there is not any limitation value, so it is difficult to evaluate its impact on human heath. In a prevention purpose, its concentration should be as low as possible.

REMARK: Some work is currently in progress on human toxicity evaluation method [Rosenbaum&al 2008]. Renault is observing the evolution of this work and made a first tryout in order to prepare its integration in our future LCAs. [Querini&al 2010]

IV.2.2 WATER CONSUMPTION

Water consumption integration in a LCA is a complex problem which methodology must be developed. (*source* RDC Environment). We need to identify:

Water used, treated and returned to natural environment (like washing water), from water consumed (demineralized water for paints)

Process water used in multiple cycles, paying attention in considering it once.

Water origin: groundwater cannot return there

Geographic context: Water consumption importance is not the same in Europe or in Africa (*water powerty* indicator needed?)

But, conscious of problems linked to water consumption and in an ISO 14001 approach, Renault works for reducing its use. In this way:

Group's water consumption decreased of up to 55% from 1998 to 2010, associated to a 22.7% increase of the production

Water consumption per vehicle produced decreased, from 11.3 m^3/veh, to a small 4.14 m^3/veh, representing a 63.3% decrease from 1998 to 2010.

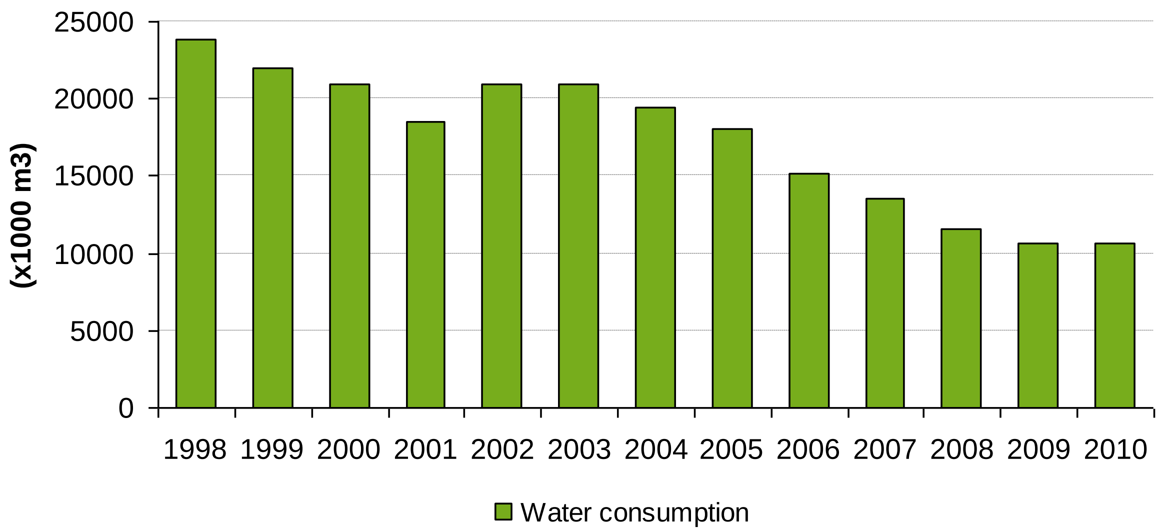


Figure 20: Water consumption reduction in Renault factories

IV.2.3 ROAD SAFETY

Although Renault dedicates a lot in this problematic, it is here out of the LCA context as it is non-environmental.

IV.2.4 WASTE QUANTITY

Renault can control waste production provided on major steps of the vehicle production (assembly line, engine and gearbox production), but no all along supply chain (implication in an ISO 14001 approach or use of an eco indicator tool). For these processes and raw materials extraction, waste quantities come from software databases.

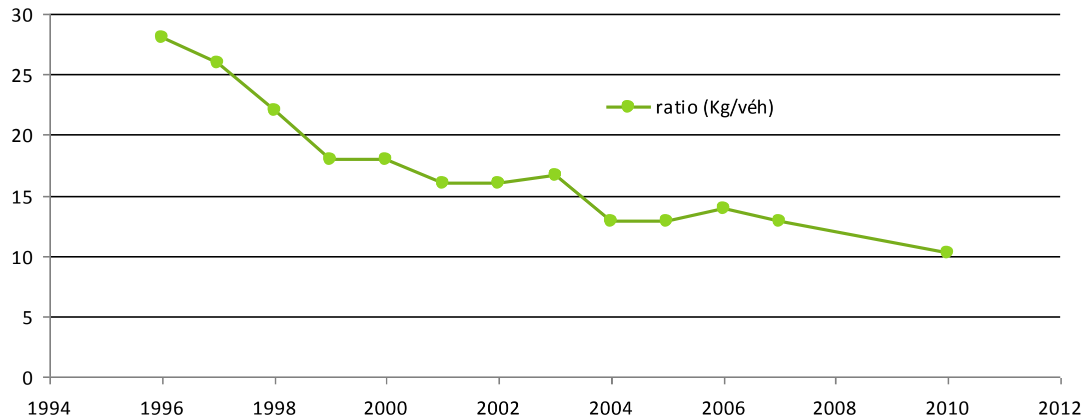


Figure 21: Evolution of packaging waste quantities at production. Quantity in kg per vehicle from 1996 to 2006

IV.2.5 NOISE

It is not precisely an environmental impact but considering the wish of reducing noise and according to European directive (70/157/CEE), Renault works on vehicles' noise reduction. Table 15 gives petrol, diesel and electric vehicles' noise. Electric technology brought some real progress, especially under 30 km/h (19mph). Over this speed, some noises appear:

- Mechanical
- Aerodynamic
- Tyres contact with the road
- Electronic whistling (speed controller)

Sound level, engine running, exterior passing	Petrol vehicle dB(A)	Diesel vehicle dB(A)	Electric vehicle dB(A)
Regulation	74	75	
Fluence	73.5	74.7	69

Table 17: Petrol and diesel sound level exterior to the vehicle

REMARK: The sound level measurement (ISO 362 type approval measurement) exists since 1981. The vehicle passes at 50km/h behind 2 microphones placed at 7.5m from the vehicle's passing lane. This measurement method is the same for every road vehicle. As the sound scale is logarithmic, a 5 dB(A) reduction is a major progress.

IV.2.6 NON-EXHAUST EMISSIONS

Non-exhaust emissions and especially particulate matter non exhaust emissions are of course part of the emissions while driving. National emission inventories include copper in their scope and the transport sector is responsible for 87% of the total emissions. Road traffic accounts for a little bit more than a half of this amount (CITEPA SECTEN report April 2011). Some publications also address vegetation contaminations near road network.

Nevertheless, there are very few data, to be used as a recognized emission factor database, to achieve reliable calculations for those emissions. As there exists no regulation addressing this scope, industry performs tests to evaluate functional properties but those measurements do not allow evaluating lifetime wear emissions.

Another difficulty is linked to the various origins of those wear particulates:

- Brakes seam to be the main source of emissions. But the composition of the particulate matter is very much dependent on the technology; disc brakes are much more emissive than drum brakes.
- Due to the geometry of clutches, the particulate emissions are virtually zero.
- The tire debris.

In addition, the composition of those wear particulates depends very much on the supplier and some of those parts do not stand for the lifetime of the car and can be changed without any control of the supply chain by the manufacturer.
Taking only account about the copper emission factor coming from COPERT methodology would probably be as restrictive as not considering this source of emissions at all.

Any way, ignoring non-exhaust particulate matter probably leads to underestimate the absolute result of the life cycle impact analyses, but this is not a problem for a wide comparative approach, tires and break wear being included in all cars whatever there are EV or fossil fuelled.

IV.3 IMPACTS ASSESSMENT

IV.3.1 REFERENCE CASE SCENARII RESULTS

Figure 19 presents repartition of selected impacts all along the life cycle, respectively for thermal engines and electric motor in EU geographic context and based on year 2012 sales predictions. Associated data is gathered in table 18 to 20.

In order to evaluate Fluence and Fluence Z.E. to the full range of vehicles built by Renault, we patterned an average car based on sales reports with associated data for its whole life cycle.

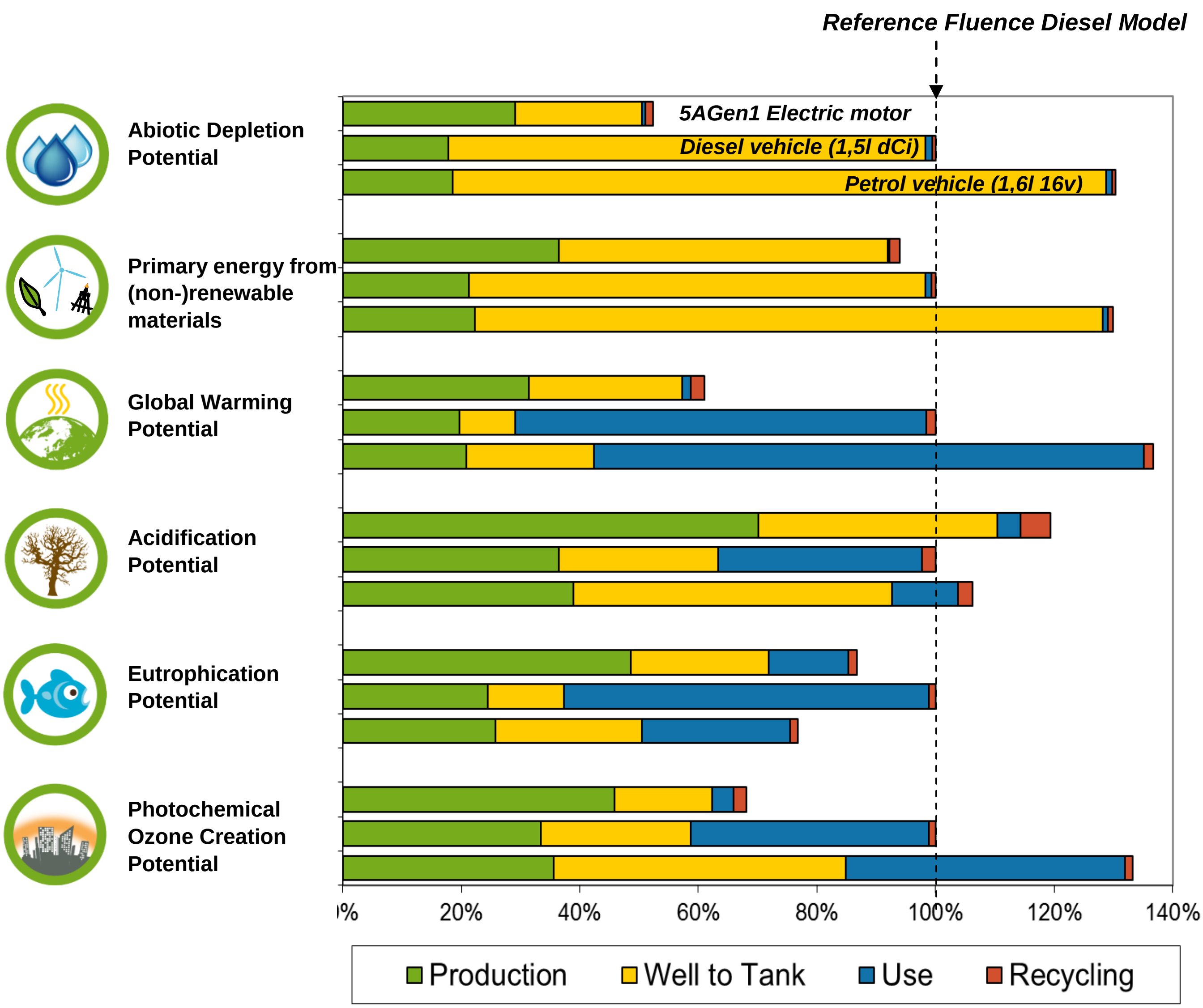


Figure 22: Environmental impacts of Fluence all along life cycle for diesel 1,5l dCi, petrol 1,6l 16v engines and 5AGen1 electric motor (EU geographic context for fuel and electricity production)

	1.5l DCi		1.6l 16v		Variation* (%)
	Quantity	Part in life cycle (%)	Quantity	Part in life cycle (%)	
ADP : Abiotic depletion potential (kg Sb-eq)					
Vehicle production	30,1	17,7%	31,4	14,2%	4,1%
Well to Tank	136,7	80,5%	187,2	84,5%	37,0%
Use	2,09	1,2%	1,80	0,8%	-14,0%
End of life	0,88	0,5%	1,10	0,5%	25,3%
PED : Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]					
Vehicle production	78668	21,2%	82346	17,1%	4,7%
Well to Tank	285521	77,1%	392734	81,6%	37,5%
Use	3659	1,0%	3041	0,6%	-16,9%
End of life	2633	0,7%	3284	0,7%	24,8%
GWP : Global warming potential (kg CO2-eq)					
Vehicle production	5034	19,7%	5338	15,3%	6,0%
Well to Tank	2411	9,4%	5491	15,7%	127,7%
Use	17712	69,3%	23691	67,8%	33,8%
End of life	389	1,5%	431	1,2%	10,7%
AP : Acidification potential (kg SO2-eq)					
Vehicle production	21,2	36,4%	22,6	36,7%	6,9%
Well to Tank	15,6	26,9%	31,2	50,6%	99,8%
Use	20,0	34,4%	6,5	10,5%	-67,6%
End of life	1,3	2,3%	1,4	2,3%	8,2%
EP : Eutrophisation potential (kg PO4-eq)					
Vehicle production	1,66	24,5%	1,74	33,5%	5,0%
Well to Tank	0,87	12,8%	1,68	32,2%	93,4%
Use	4,18	61,6%	1,70	32,6%	-59,4%
End of life	0,07	1,1%	0,09	1,6%	15,2%
POCP : Photochemical ozone creation potential (kg C2H4-eq)					
Vehicle production	3,23	33,49%	3,43	26,73%	6,38%
Well to Tank	2,43	25,22%	4,75	36,99%	95,52%
Use	3,87	40,18%	4,53	35,33%	17,18%
End of life	0,11	1,12%	0,12	0,95%	13,46%

Table 18: Comparison of environmental impacts all along life cycle of Fluence for diesel 1.5ldCi and petrol 1.6l 16v engines

* It is variation relative to diesel vehicle's impacts on this life cycle phase

	1.5l DCi		5AGen1		Variation* (%)
	Quantity	Part in life cycle (%)	Quantity	Part in life cycle (%)	
ADP : Abiotic depletion potential (kg Sb-eq)					
Vehicle production	30,1	17,75%	49,3	55,46%	63,5%
Well to Tank	136,7	80,50%	36,5	41,14%	-73,3%
Use	2,09	1,23%	0,91	1,02%	-56,6%
End of life	0,88	0,52%	2,11	2,38%	140,0%
PED : Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]					
Vehicle production	78668	21,2%	135300	38,9%	72,0%
Well to Tank	285521	77,1%	205289	59,0%	-28,1%
Use	3659	1,0%	1223	0,4%	-66,6%
End of life	2633	0,7%	6216	1,8%	136,1%
GWP : Global warming potential (kg CO2-eq)					
Vehicle production	5034	19,71%	8031	51,54%	59,5%
Well to Tank	2411	9,44%	6606	42,40%	173,9%
Use	17712	69,33%	376	2,41%	-97,9%
End of life	389	1,52%	568	3,65%	45,9%
AP : Acidification potential (kg SO2-eq)					
Vehicle production	21,2	36,43%	40,7	58,76%	92,5%
Well to Tank	15,6	26,88%	23,4	33,74%	49,8%
Use	20,0	34,42%	2,3	3,36%	-88,3%
End of life	1,3	2,26%	2,9	4,13%	118,1%
EP : Eutrophisation potential (kg PO4-eq)					
Vehicle production	1,66	24,49%	3,29	55,99%	98,4%
Well to Tank	0,87	12,79%	1,58	26,90%	82,5%
Use	4,18	61,63%	0,91	15,40%	-78,3%
End of life	0,07	1,09%	0,10	1,70%	35,5%
POCP : Photochemical ozone creation potential (kg C2H4-eq)					
Vehicle production	3,23	33,49%	4,41	67,38%	36,89%
Well to Tank	2,43	25,22%	1,59	24,24%	-34,61%
Use	3,87	40,18%	0,34	5,23%	-91,15%
End of life	0,11	1,12%	0,21	3,15%	91,69%

Table 19: Comparison of environmental impacts all along life cycle of Fluence for diesel 1.5ldCi engine & EV motor

* It is variation relative to diesel vehicle’s impacts on this life cycle phase

	1.6l 16v		5AGen1		Variation* (%)
	Quantity	Part in life cycle (%)	Quantity	Part in life cycle (%)	
ADP : Abiotic depletion potential (kg Sb-eq)					
Vehicle production	31,4	14,16%	49,3	55,46%	57,1%
Well to Tank	187,2	84,53%	36,5	41,14%	-80,5%
Use	1,80	0,81%	0,91	1,02%	-49,6%
End of life	1,10	0,50%	2,11	2,38%	91,6%
PED : Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]					
Vehicle production	82346	17,1%	135300	38,9%	64,3%
Well to Tank	392734	81,6%	205289	59,0%	-47,7%
Use	3041	0,6%	1223	0,4%	-59,8%
End of life	3284	0,7%	6216	1,8%	89,3%
GWP : Global warming potential (kg CO2-eq)					
Vehicle production	5338	15,27%	8031	51,54%	50,4%
Well to Tank	5491	15,71%	6606	42,40%	20,3%
Use	23691	67,78%	376	2,41%	-98,4%
End of life	431	1,23%	568	3,65%	31,8%
AP : Acidification potential (kg SO2-eq)					
Vehicle production	22,6	36,65%	40,7	58,76%	80,0%
Well to Tank	31,2	50,56%	23,4	33,74%	-25,0%
Use	6,5	10,49%	2,3	3,36%	-64,0%
End of life	1,4	2,30%	2,9	4,13%	101,6%
EP : Eutrophisation potential (kg PO4-eq)					
Vehicle production	1,74	33,50%	3,29	55,99%	89,0%
Well to Tank	1,68	32,24%	1,58	26,90%	-5,6%
Use	1,70	32,62%	0,91	15,40%	-46,6%
End of life	0,09	1,64%	0,10	1,70%	17,6%
POCP : Photochemical ozone creation potential (kg C2H4-eq)					
Vehicle production	3,43	26,73%	4,41	67,38%	28,67%
Well to Tank	4,75	36,99%	1,59	24,24%	-66,56%
Use	4,53	35,33%	0,34	5,23%	-92,45%
End of life	0,12	0,95%	0,21	3,15%	68,95%

Table 20: Comparison of environmental impacts all along life cycle of Fluence for petrol 1.6l 16v engine and EV motor

* It is variation relative to petrol vehicle's impacts on this life cycle phase

The table 21 presents the total results of the impact assessment over the whole life cycle.

Renault Fluence Z.E.	Global footprint	Footprint incl credits	Variation (%)
Abiotic depletion (kgSb-eq)	88.8	80.4	-9.4%
Global warming potential (kgCO_2-eq)	15580	13870	-11.0%
Acidification (kgSO_2-eq)	69.3	54.9	-20.8%
Eutrophisation (kgPO_4-eq)	5.88	5.33	-9.5%
Photochemical ozone potential (kgC_2H_4-eq)	6.55	5.45	-16.8%

Table 21: Comparison of environmental impacts all along life cycle of Fluence Z.E. with or without considering credit from recycling

From these results, Renault shows that the possible benefits from recycling are not neglectible. However, Renault will not consider those improved results as it cannot ensure the recycling rates of its car, or cannot assume that it would benefit from recycling credits. That's why credits will not be integrated to the global footprint of the vehicle.

The Figure 23 presents repartition of selected impacts all along the life cycle, for EV vehicles depending on the geographic context (for a clean power grid mix (France) and a quite poor one (Great Britain)), still in a European geographic context. Associated data is gathered in table 21.

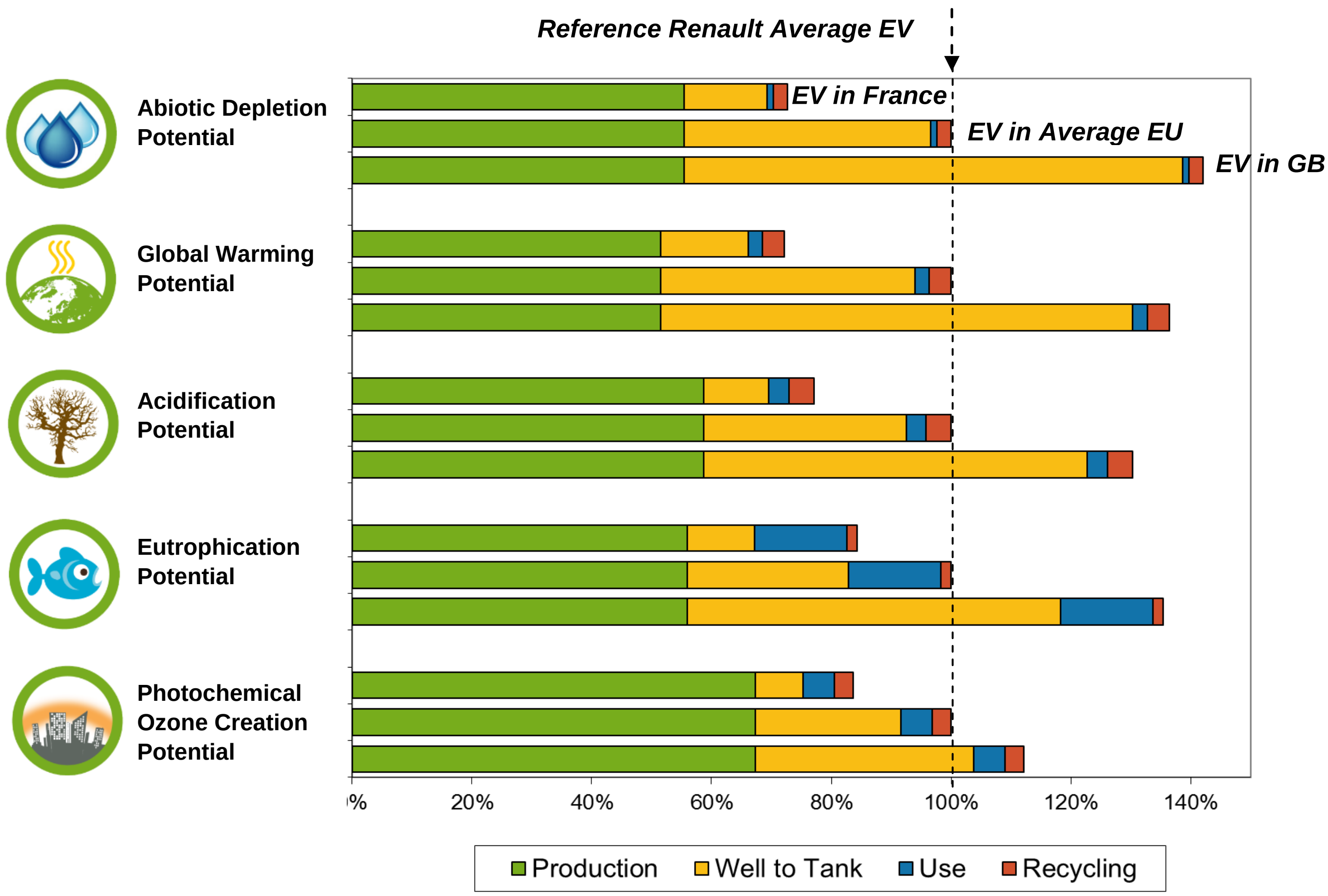


Figure 23: Environmental impacts of Fluence Z.E all along life cycle for different geographic contexts: France, Average Europe based on sales predictions, and Great Britain.

Variations on electricity production	EU-->FR	EU --> GB
Abiotic depletion (kgSb-eq)	-66%	+102%
Global warming potential (kgCO_2-eq)	-66%	+86%
Acidification (kgSO_2-eq)	-68%	+90%
Eutrophisation (kgPO_4-eq)	-58%	+132%
Photochemical ozone potential (kgC_2H_4-eq)	-67%	+50%

Impact on the global life cycle	EU-->FR	EU --> GB
Abiotic depletion (kgSb-eq)	-27%	+42%
Global warming potential (kgCO_2-eq)	-28%	+36%
Acidification (kgSO_2-eq)	-23%	+30%
Eutrophisation (kgPO_4-eq)	-16%	+35%
Photochemical ozone potential (kgC_2H_4-eq)	-16%	+12%

Table 22: Comparison of EU electricity production impacts (best and worst) and their consequence to the car global life cycle

Those results highlight the important contribution of the power grid mix on the vehicle's life cycle (detailed data on Appendix V.8). The use of renewable energies increases environment benefits of the electric vehicle. [EC 2009]

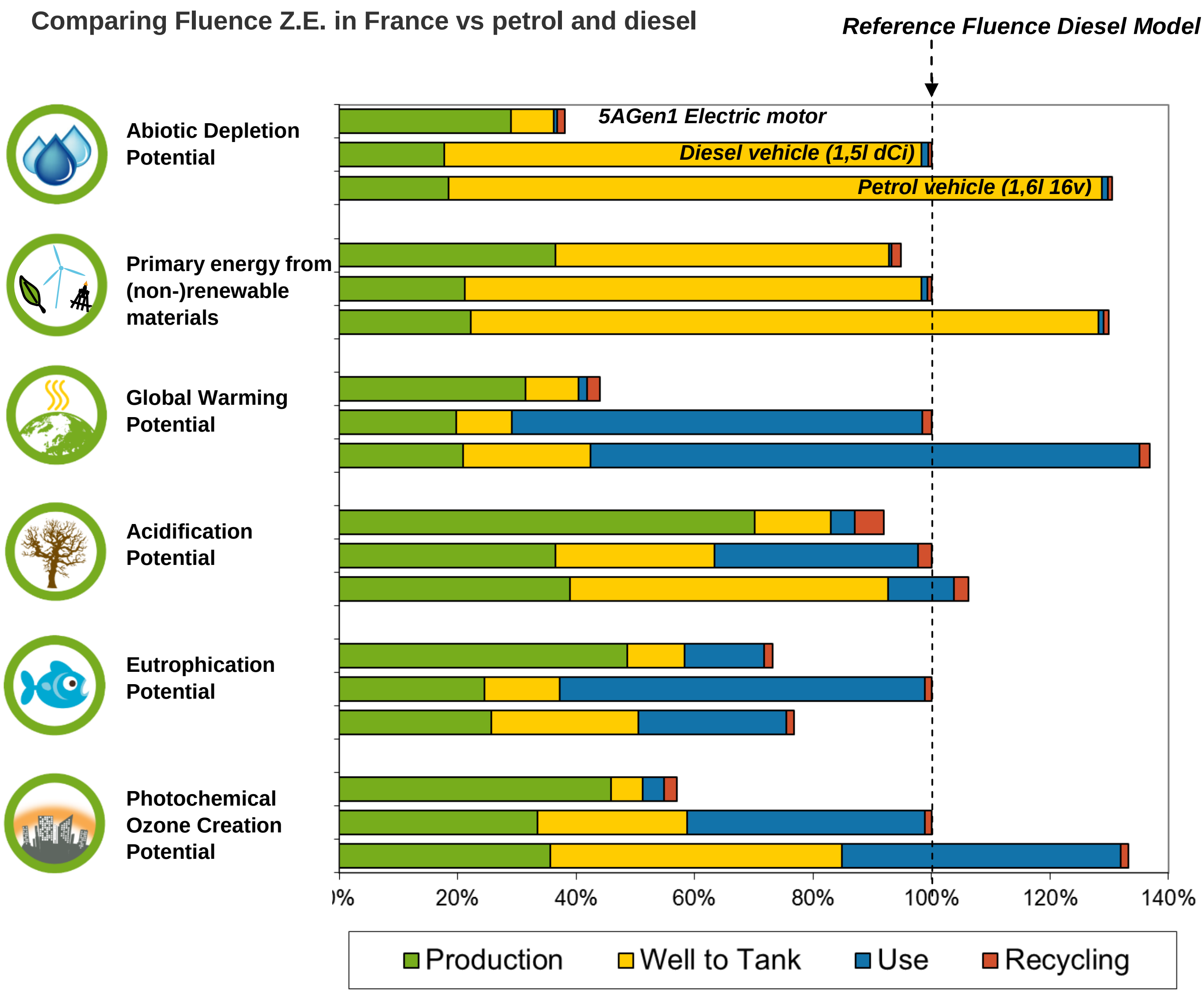


Figure 24: Environmental impacts of Fluence all along life cycle for diesel 1,5l dCi, petrol 1,6l 16v engines and 5AGen1 electric motor (France geographic context for electricity production)

Considering a France geographic context for the vehicle's use, we note that the sensitivity on acidification in an EU context is now developed and precised. Fluence Z.E. brings now a progress on all environmental impacts chosen considering both petrol and diesel versions. Moreover, eutrophication potential of the EV was superior to the petrol's one in an EU context and is now inferior.

Comparing Fluence Z.E. in Great Britain vs petrol and diesel

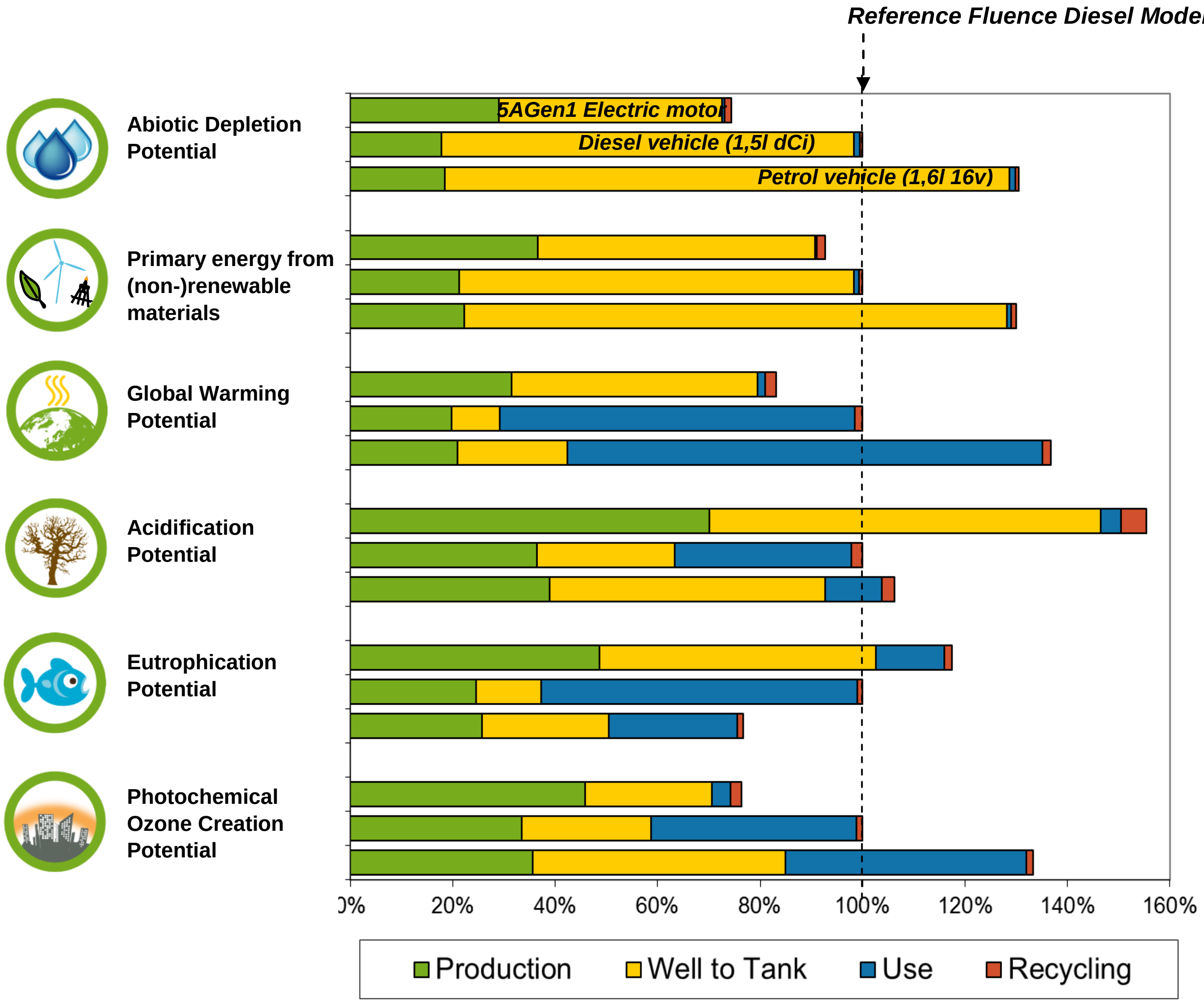


Figure 25: Environmental impacts of Fluence all along life cycle for diesel 1,5l dCi, petrol 1,6l 16v engines and 5AGen1 electric motor (GB geographic context for electricity production)

Considering a Great Britain geographic context for the vehicle's use, we note that the sensitivity on acidification in an EU context is now precised as a major challenge as well as eutrophication. It still brings a progress in the three main key issues which are ADP, PED and GWP, but the results on AP and EP are pointing the hard work needed on electricity production cleaning.

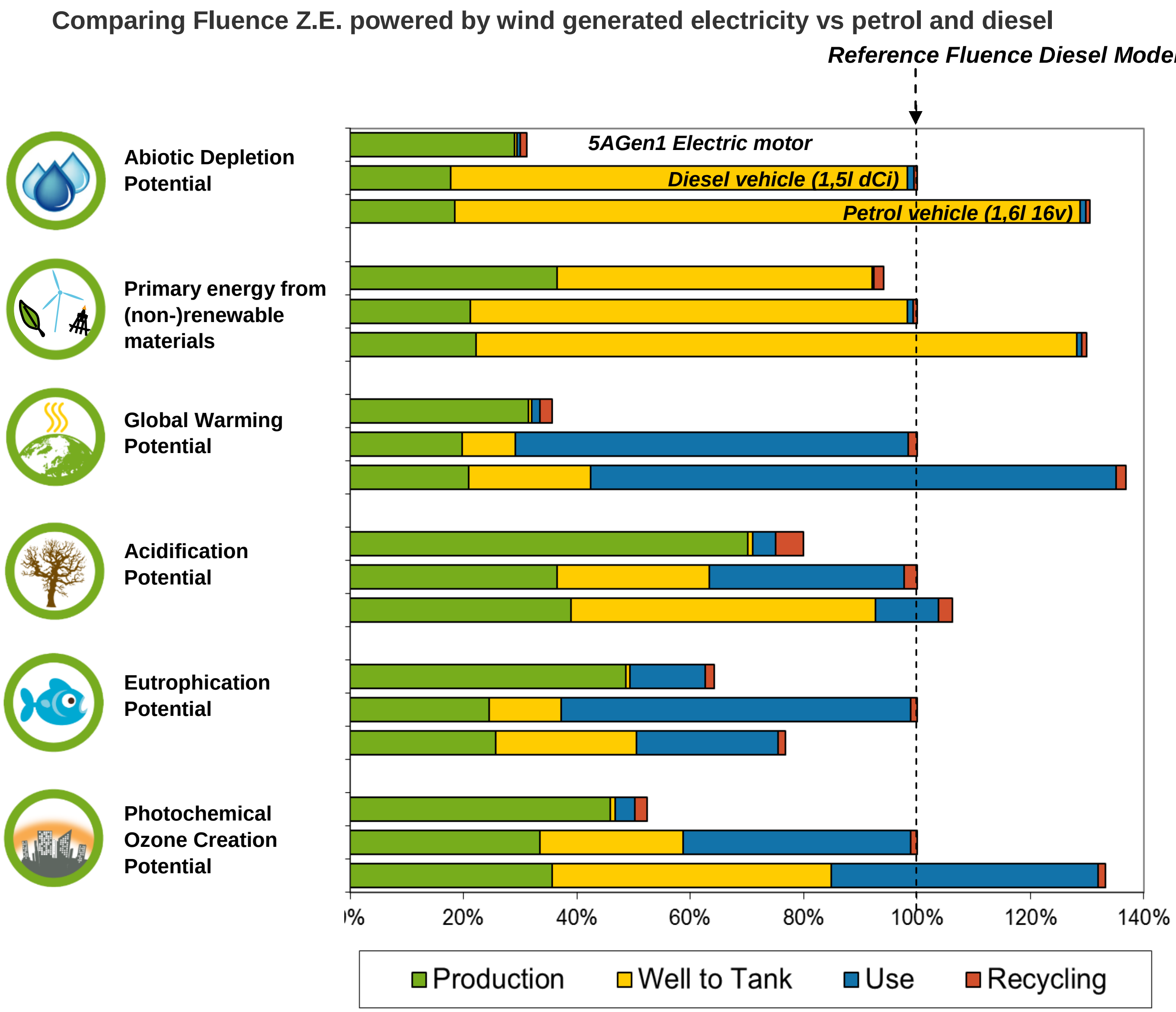


Figure 26: Environmental impacts of Fluence all along life cycle for diesel 1,5l dCi, petrol 1,6l 16v engines and 5AGen1 electric motor (wind power for electricity production)

Considering electricity produced by wind power for the vehicle's use, we note that renewable energy is the well to tank phase has nearly disappeared.

Those 3 case scenarii highlight the high impacts of the well to tank phase in the global footprint of Fluence Z.E. and of an electric vehicle in general. From a country to another of considering renewable energies, it can either bring EV as a progress for the environment comparing ICE vehicles, or be hardly dicussed considering what are the indicators on which it is necessary to focus on.

IV.3.2 NORMALISATION

The results are quite complex to interpret since in some cases, the electric vehicle could show a clear progress on global warming and resource depletion but the conventional vehicle can present, in certain cases, better results on acidification potential impact.

In this condition, it was decided to normalise the several potential impact presented in this study. The normalisation methodology is CML2001 Western Europe, which is in line with our scope. The results are presented below.

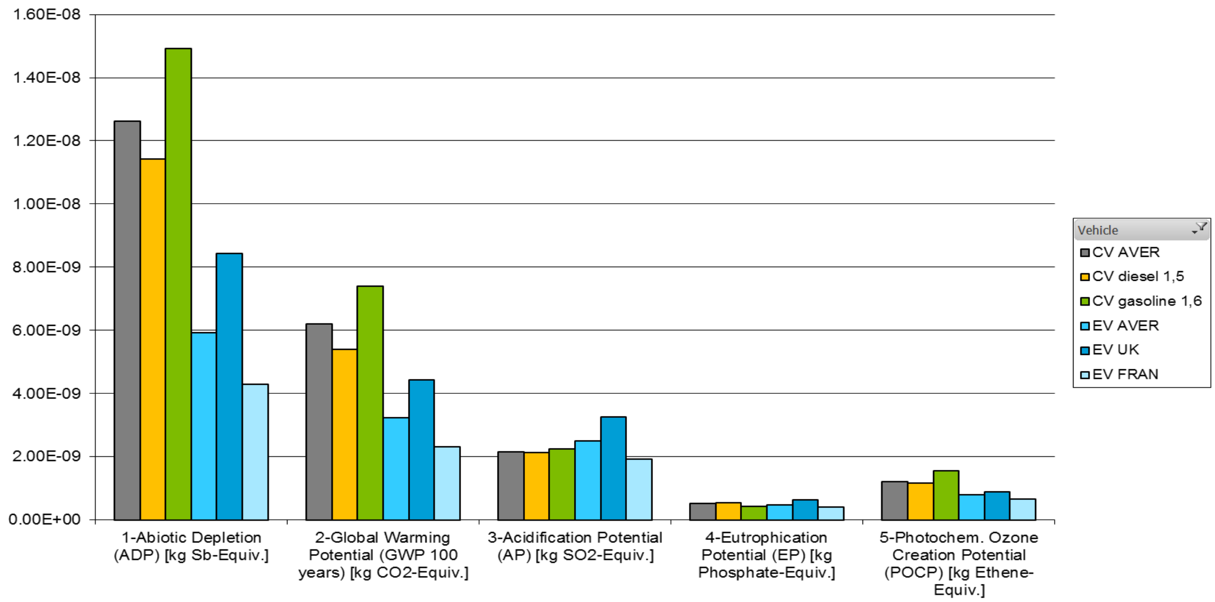


Figure 27 : Results presented with Western Europe normalized values

From this normalization, we have seen that eutrophication and ozone potential burdens are very low, below 1/10 (first line) of an annual average EU 15 inhabitant for all vehicles. Therefore, these results are not presented here.

Regarding Resource Depletion, the electric vehicle is providing an interesting progress. This is important because it underlines that this technology will be a long-term strategy for countries for the resource concern.

When speaking about Global Warming we can state than in all cases, the electric vehicle is better than petrol vehicles. It is also often the case when compared to diesel cars, but the electric vehicle in GB is not very far. It is therefore possible to conclude that electric vehicles will not create new burdens on climate. The electric vehicle is therefore a solution to fight climate change.

Finally, for the Acidification, emissions from the electric vehicle are nearly equal when considering the uncertainty on the results, even though it seems to be a few percent higher. Therefore, we can conclude that Acidification Potential is a new stake to tackle for electric vehicles, but on an overall perspective, this new technology brings a lot of benefice to the society. No grouping and weighting method are applied in this study to avoid misleading single score. [Schmidt & al 2010].

Power grid mixes improvement under EU regulation scheme could make Acidification Potential decrease.

IV.3.3 RESULTS ANALYSIS

Following table compares values of each impact on the whole life cycle for all technologies in a EU geographic scope. They highlight the benefits of the EV.

	1.5l dCi (Diesel)	1.6l 16v (Gasoline)	Variation (%)
Abiotic depletion (kgSb-eq)	169,8	221,4	30,4%
Primary Energy Demand (MJ)	370480	481406	29,9%
Global warming potential (kgCO_2-eq)	25547	34951	36,8%
Acidification (kgSO_2-eq)	58,1	61,7	6,3%
Eutrophisation (kgPO_4-eq)	6,78	5,20	-23,3%
Photochemical ozone potential (kgC_2H_4-eq)	9,6	12,8	33,3%

	1.5l dCi (Diesel)	5AGen1 (EL)	Variation (%)
Abiotic depletion (kgSb-eq)	169,8	88,8	-47,7%
Primary Energy Demand (MJ)	370480	348027	-6,1%
Global warming potential (kgCO_2-eq)	25547	15580	-39,0%
Acidification (kgSO_2-eq)	58,1	69,3	19,3%
Eutrophisation (kgPO_4-eq)	6,78	5,88	-13,2%
Photochemical ozone potential (kgC_2H_4-eq)	9,63	6,55	-32,0%

	1.6l 16v (Gasoline)	5AGen1 (EL)	Variation (%)
Abiotic depletion (kgSb-eq)	221,4	88,8	-59,9%
Primary Energy Demand (MJ)	481406	348027	-27,7%
Global warming potential (kgCO_2-eq)	34951	15580	-55,4%
Acidification (kgSO_2-eq)	61,7	69,3	12,3%
Eutrophisation (kgPO_4-eq)	5,20	5,88	13,1%
Photochemical ozone potential (kgC_2H_4-eq)	12,84	6,55	-49,0%

Table 23 : Comparison of global environmental impacts on all technologies studied in an EU geographic scope

Fluence Z.E. brings a major progress with its electric technology on about all impacts. There is sensitivity on acidification potential and eutrophication potential impacts due to the use of primary materials for battery production. It will be developed in the sensitivity analysis

IV.3.3.1 Abiotic depletion (ADP)

Following figure shows the distribution of abiotic depletion on different phases of the life cycle. Production phase is discomposed in multiple steps in order to identify which is the most impacting. So we identify:

- Material and parts production for supply chain
- Supply chain transport for rank-1 suppliers
- Material production for Renault's factories (aluminum and steel for body's construction only)
- Parts production in Renault factories

Moreover, benefit of recycling, as defined in § I.3.5, is not subtracted for previous values and is then considered separately.

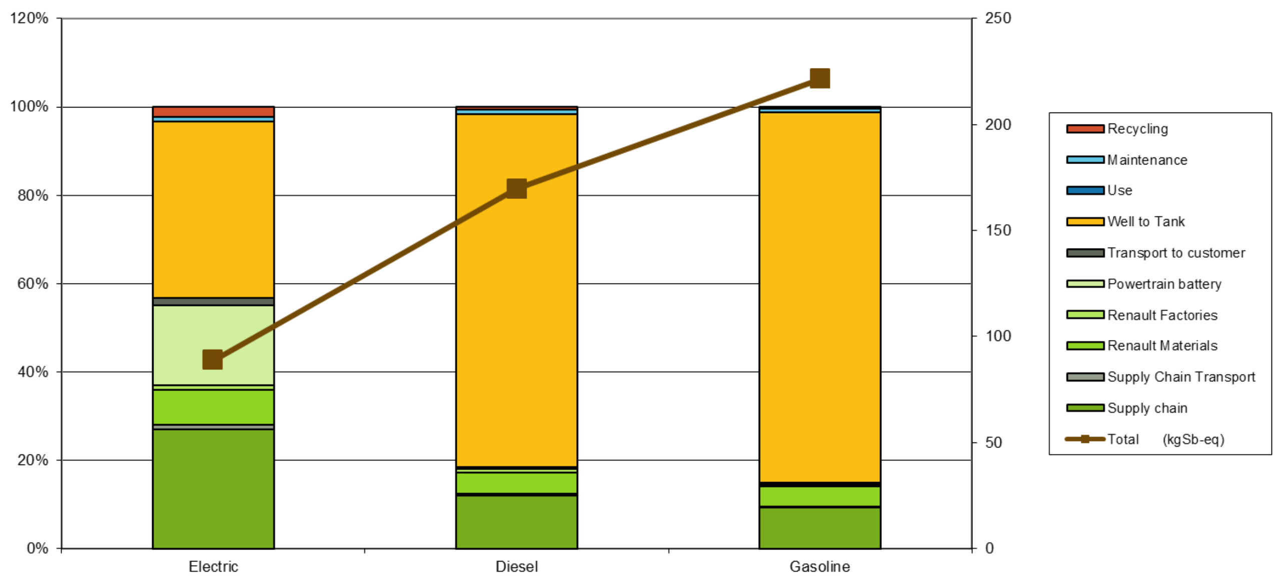


Figure 28 : Distribution of abiotic depletion from each actor or phase of life cycle

ADP	Supply chain	Supply Chain Transport	Renault Materials	Renault Factories	Powertrain battery	Transport to customer	Well to Tank	Use	Maintenance	Recycling	Recycling benefit	Total (kgSb-eq)	Total with recycling benefit
Electric	26,9%	1,0%	8,0%	0,9%	18,1%	1,7%	40,0%	0,0%	1,0%	2,3%	-9,4%	88,8	80,4
Diesel	12,0%	0,3%	4,9%	0,7%	0,0%	0,6%	79,8%	0,0%	1,2%	0,5%	-3,8%	169,8	163,4
Gasoline	9,3%	0,3%	4,4%	0,5%	0,0%	0,4%	83,7%	0,0%	0,8%	0,5%	-3,6%	221,4	213,5

Table 24 : Distribution of abiotic depletion from each actor or phase of life cycle

The most impacting phase is crude oil extraction in order to produce 6600L of diesel or 10050L of petrol to run all 150 000 km corresponding its lifetime (80% for 1.5l dCi and 84% for 1.6l 16v).

In table 18, the major difference of consumption (≈34.3% in mass) between diesel and petrol vehicles brings to an abiotic depletion difference approaching 37%. Use of electrical technology divides per 4 the abiotic depletion of the well to tank production (cf table 19 and 20).

Production phase represent respectively 55, 17.9 and 14.5% of this impact. It is mainly due to steel sheet production needed to build the body and all steel equipment (subframe, undercarriage, exhaust…)

This material's production is responsible of 35% of abiotic depletion of production phase (cf. next figure, 24% for the EV), not because of iron ores consumption but from fossil resources extraction to produce the necessary energy for this production.

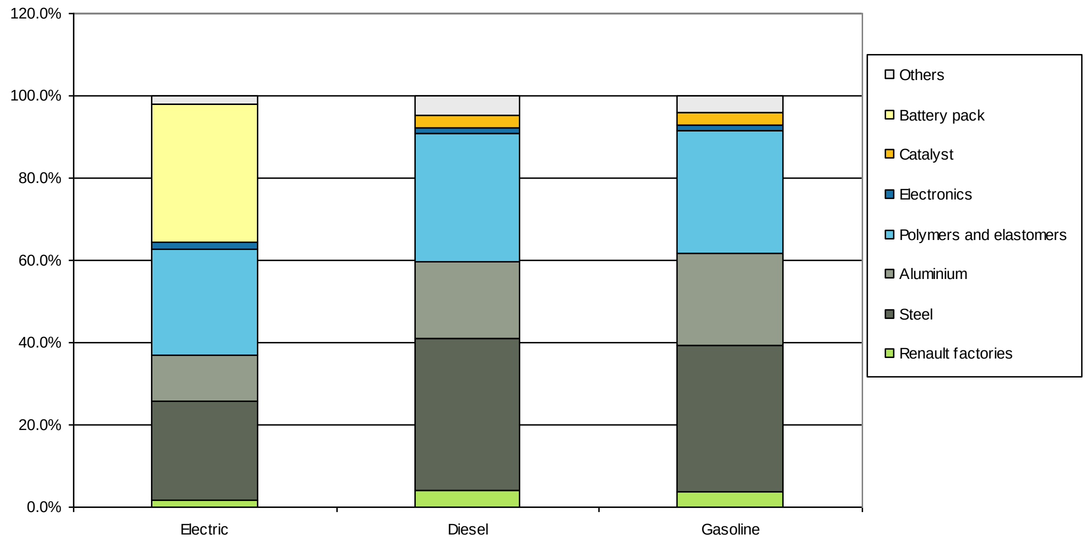


Figure 29 : Part of some elements production on abiotic depletion in production phase

ADP	Renault factories	Steel	Aluminium	Polymers and elastomers	Electronics	Catalyst	Battery pack	Others	TOTAL
Electric	1.6%	24.0%	11.4%	25.6%	1.8%	0.0%	33.6%	1.9%	49.3
Diesel	3.9%	37.1%	18.6%	31.2%	1.3%	3.2%	0.0%	4.7%	30.1
Gasoline	3.8%	35.6%	22.3%	30.0%	1.2%	3.0%	0.0%	4.1%	31.4

Table 25 : Part of some elements production on abiotic depletion in production phase

Almost all of this impact comes from fossil resources extraction (cf. following figure).

Then, part of aluminum reaches respectively 18 and 21% for thermal engines and 11% for the EV. We may note the importance of polymer fraction participating respectively to 30, 29 and 20.4%. Then come electronics (1-2%) and catalyst (3%) from rare metals extraction energy. Battery pack of the EV is the main element affecting abiotic depletion potential reaching 37%.

Part from Renault factories is small (6% for thermal vehicles and 3% for EV) due to major work on energy consumption reduction, but still negatively affected by the Turkish energetic mix.

ADP (kgSb-eq)

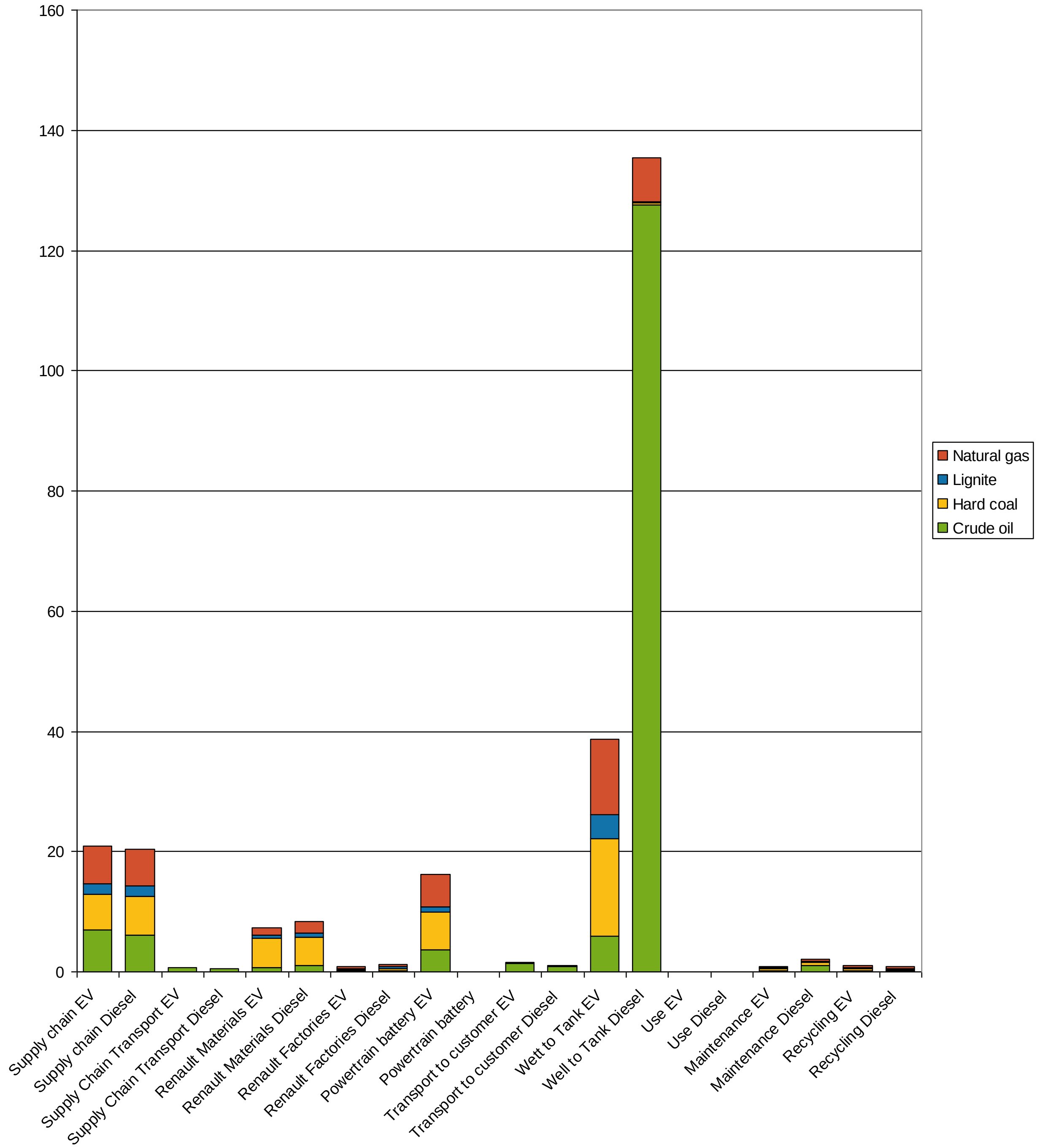


Figure 30 : Proportion of main flows affecting abiotic depletion on diesel and electric vehicles all along the life cycle

REMARK: Petrol vehicle's distribution in almost the same.

Steel recycling, and in lower contribution aluminum, can bring to a 3.5 to 9.5% reduction on this impact.

Bringing electric technology provide many benefits, principally on well to tank production despite drivetrain battery's needs. This progress can be even more interesting with a greener electric mix.

IV.3.3.2 Acidification potential(AP)

This impact is distributed between vehicle and fuel production and vehicle use.

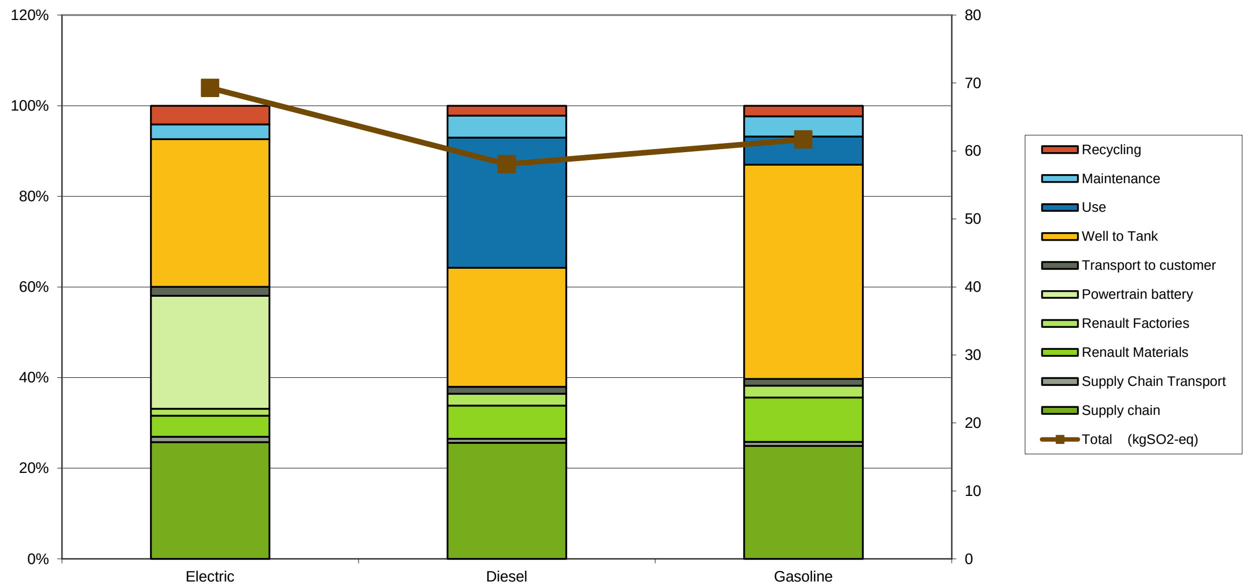


Figure 31 : Distribution of acidification from each actor or phase of life cycle

AP	Supply chain	Supply Chain Transport	Renault Materials	Renault Factories	Powertrain battery	Transport to customer	Well to Tank	Use	Maintenance	Recycling	Recycling benefit	Total (kgSO2-eq)	Total with recycling benefit
Electric	25,7%	1,2%	4,6%	1,5%	24,9%	2,0%	32,6%	0,0%	3,3%	4,1%	-20,8%	69,3	54,9
Diesel	25,6%	0,9%	7,3%	2,6%	0,0%	1,5%	26,2%	28,8%	4,8%	2,2%	-16,5%	58,1	48,5
Gasoline	24,9%	0,9%	9,8%	2,6%	0,0%	1,5%	47,3%	6,2%	4,4%	2,3%	-18,7%	61,7	50,1

Table 26 : Distribution of acidification from each actor or phase of life cycle

As shown in figure 30, it depends of two parameters:
SO_2
NOx

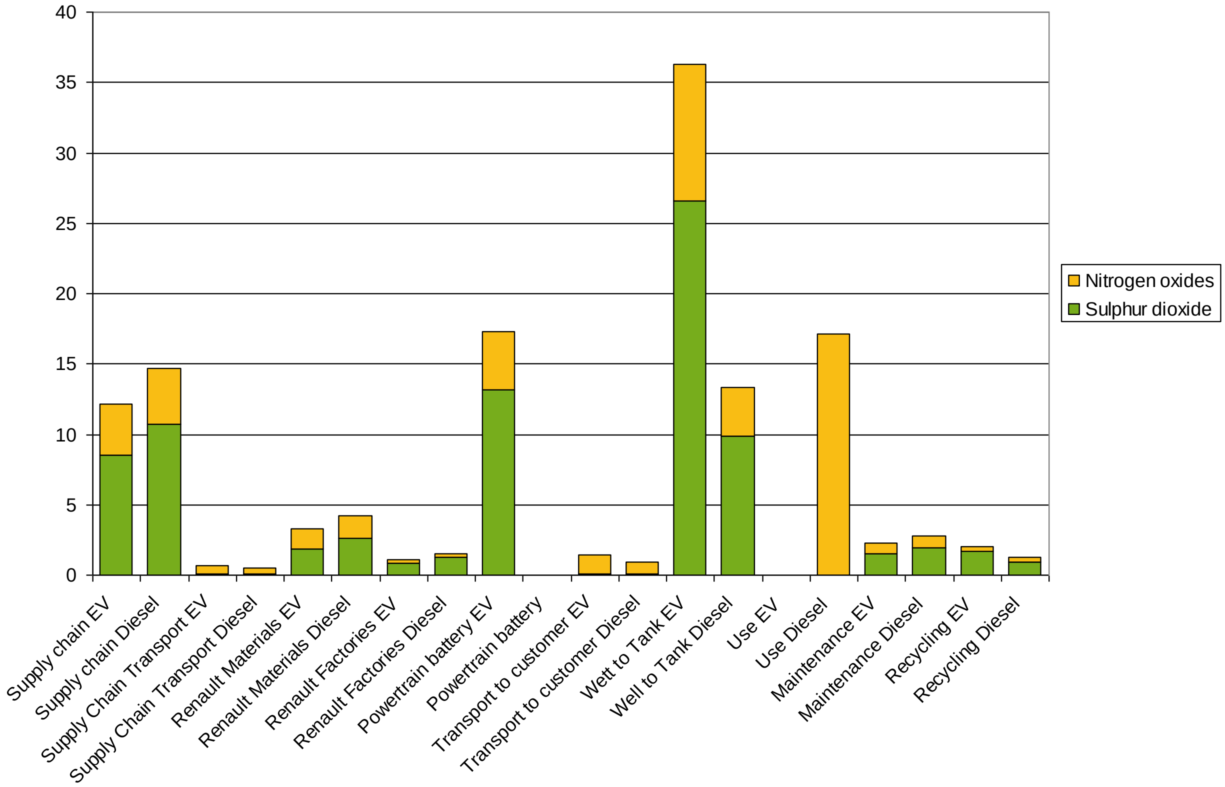


Figure 32: Proportion of main flows affecting acidification on diesel and electric vehicles all along the life cycle

Vehicle's production represents about 40% of the impact (supply and its transport, Renault materials and factories). It reaches 58% on the EV with the drivetrain battery. As we can see, acidification potential with an electric vehicle is mainly due electric mix. Its 24 kg SO_2-Equiv. increase approaches the global acidification potential increase. Acidification potential produced by the drivetrain battery comes from raw materials used (Cobalt and Nickel), production countries electric mixes and electrolyte production. Considering recycled cobalt and nickel would make environmental score of the battery decrease.
We notice the same behavior between petrol and diesel vehicle as for abiotic depletion due to vehicle's composition difference.

Contribution of Renault factories remains low representing about 3% due to body construction factory low SO_2 emissions and the high environmental performance of Bursa's factory.

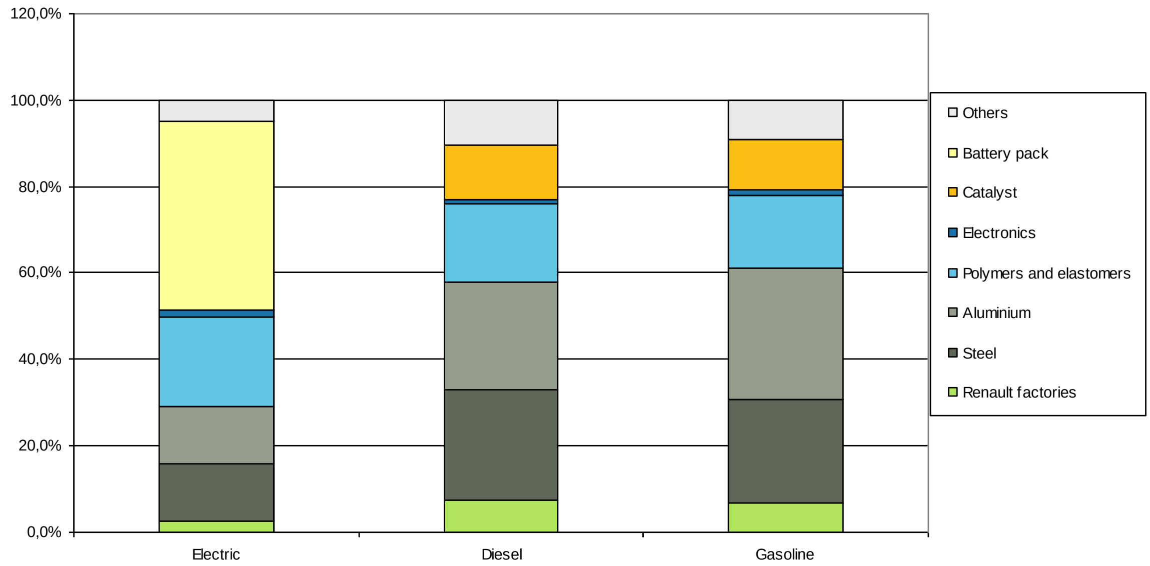


Figure 33 : Part of some elements production on acidification in production phase

AP	Renault factories	Steel	Aluminium	Polymers and elastomers	Electronics	Catalyst	Battery pack	Others	TOTAL
Electric	2.7%	13.2%	13.2%	20.8%	1.5%	0.0%	43.8%	4.8%	40.7
Diesel	7.4%	25.4%	25.1%	18.0%	1.2%	12.4%	0.0%	10.5%	21.2
Gasoline	6.9%	23.7%	30.6%	16.8%	1.2%	11.6%	0.0%	9.2%	22.6

Table 27 : Part of some elements production on acidification in production phase

We notice major differences during fuel production phase (table 26). It represents:

- 42% for electric vehicle;
- 23% for diesel vehicle;
- 46 % for petrol vehicle;

with a global acidification potential approaching 59% higher for petrol production. Those results are mainly due to SO_2 emissions, more important on petrol production, associated to 52% superior consumption of the vehicle on use. Due to a poor electric mix, EV has a negative impact on acidification. Nevertheless, as detailed considering a France geographic context for the use phase, this indicator can fluctuate and this negative contribution can disappear.

For using, it is the opposite behavior. This phase represents:

- 29% for diesel vehicle
- 6 % for petrol vehicle;

with a 83% lower value of the acidification potential during petrol vehicle use. This is due to important emissions of NOx during the engine's run. This quantity is about five times more important on diesel engines!

Steel recycling, and in lower contribution aluminum, can bring to a 10 to 19% reduction of this impact! (17% for diesel,19% for petrol and 21% for the EV)

IV.3.3.3 Eutrophication potential (EP)

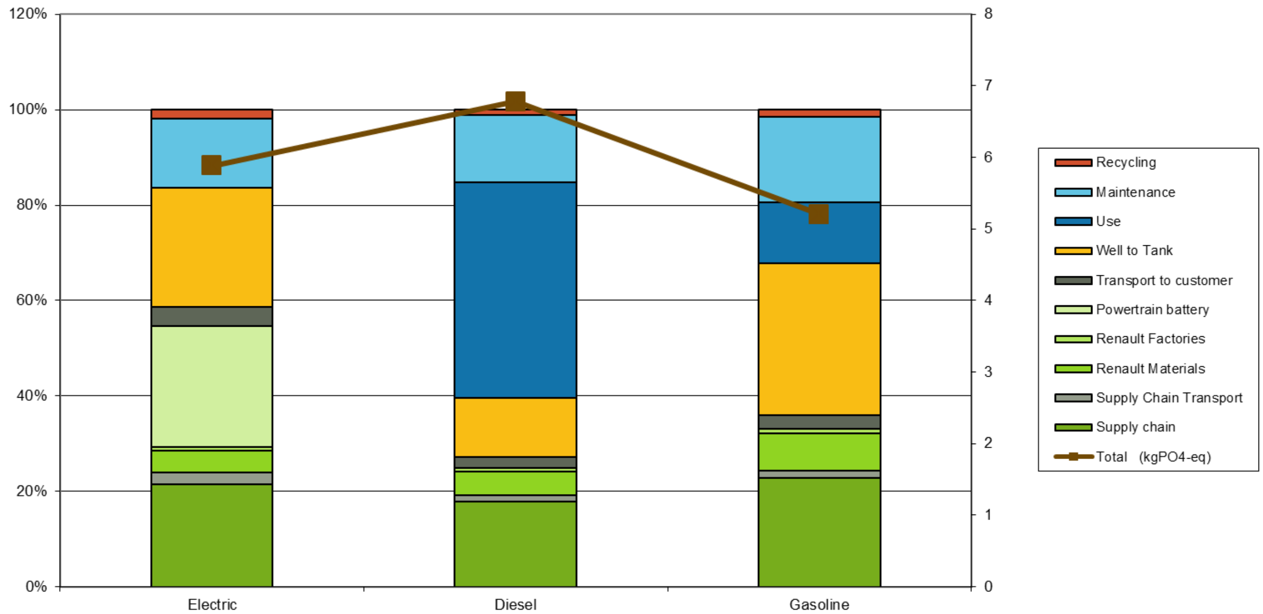


Figure 34 : Distribution of eutrophication potential from each actor or phase of life cycle

EP	Supply chain	Supply Chain Transport	Renault Materials	Renault Factories	Powertrain battery	Transport to customer	Well to Tank	Use	Maintenance	Recycling	Recycling benefit	Total (kgPO4-eq)	Total with recycling benefit
Electric	21,5%	2,4%	4,7%	0,6%	25,5%	3,9%	25,1%	0,0%	14,4%	1,9%	-9,5%	5,9	5,3
Diesel	17,9%	1,3%	4,9%	0,8%	0,0%	2,2%	12,3%	45,2%	14,2%	1,1%	-6,3%	6,8	6,4
Gasoline	22,7%	1,7%	7,7%	1,1%	0,0%	2,8%	31,8%	12,7%	18,0%	1,5%	-9,6%	5,2	4,7

Table 28 : Distribution of eutrophication potential from each actor or phase of life cycle

This impact principally depends on NOx emissions and is quite close to the acidification potential behavior for well to tank and vehicle use phases.

In fuel and electricity production, additional chemical oxygen demand of petrol production (+36%) associated to its superior consumption bring to an increased eutrophication potential (+38%) for the petrol vehicle.

For a petrol vehicle’s use phase, NOx emissions are about 5 times lower than a diesel vehicle, which brings to an eutrophication potential reduction approaching 83%.

We must note the importance of maintenance (between 14 and 18% along life cycle) due from over 98% to production of replacement tires (3 sets). Quantity of organic material emitted onto water also comes from production of tire (origin set) in production phase.

In this phase, steel and polymer production are principally responsible of this phenomenon. In third place comes catalyst, which production (extraction and forming) emits a lot of NOx.
Aluminum and electronics remains important elements in this impact’s creation.

Renault factories and materials contributions remain low for the diesel vehicle (6.5%) but approaches 10% for a petrol one (previous table). The difference on the impact's proportionality due to Renault factories is due to the large difference of NOx emissions of use phase, despite of the lower consumption of the diesel model. It is interesting to note that the petrol vehicle production generates the same impact as fuel production or use phase (use+maintenance), about 30-31%)
Like with the acidification potential, eutrophication potential of the EV is mainly penalized by the high emissions of NOx for the drivetrain battery production.

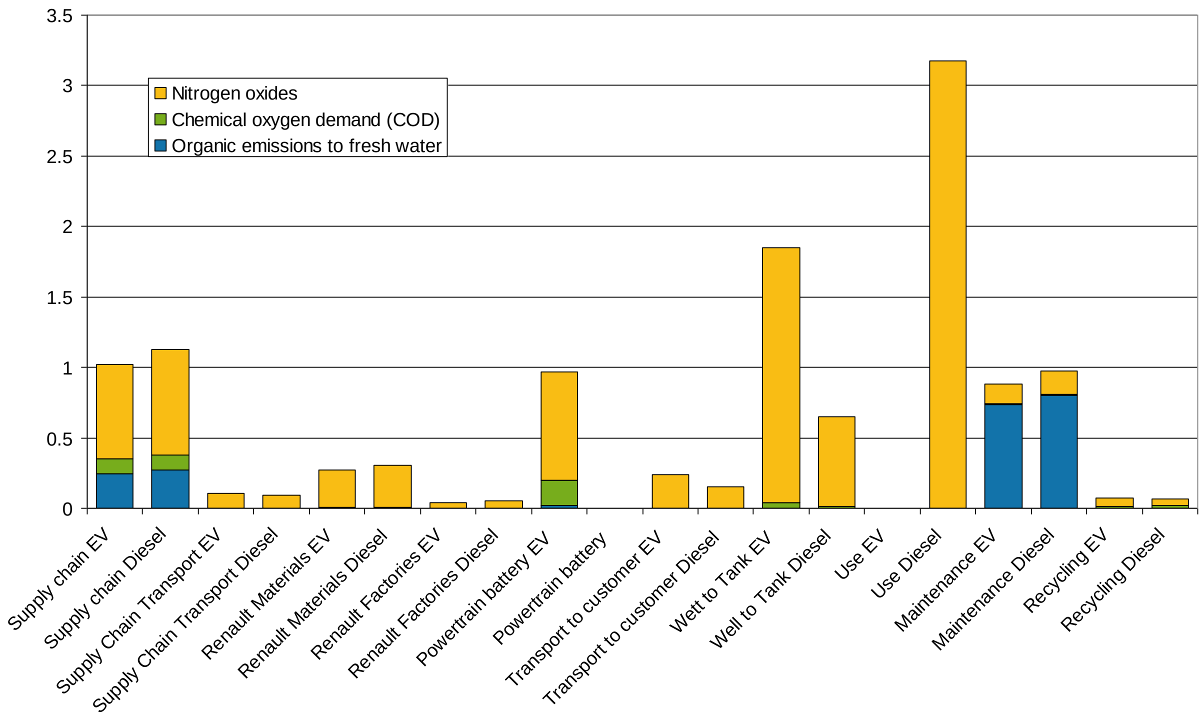


Figure 35 : Proportion of main flows affecting eutrophication on diesel and electric vehicles all along the life cycle

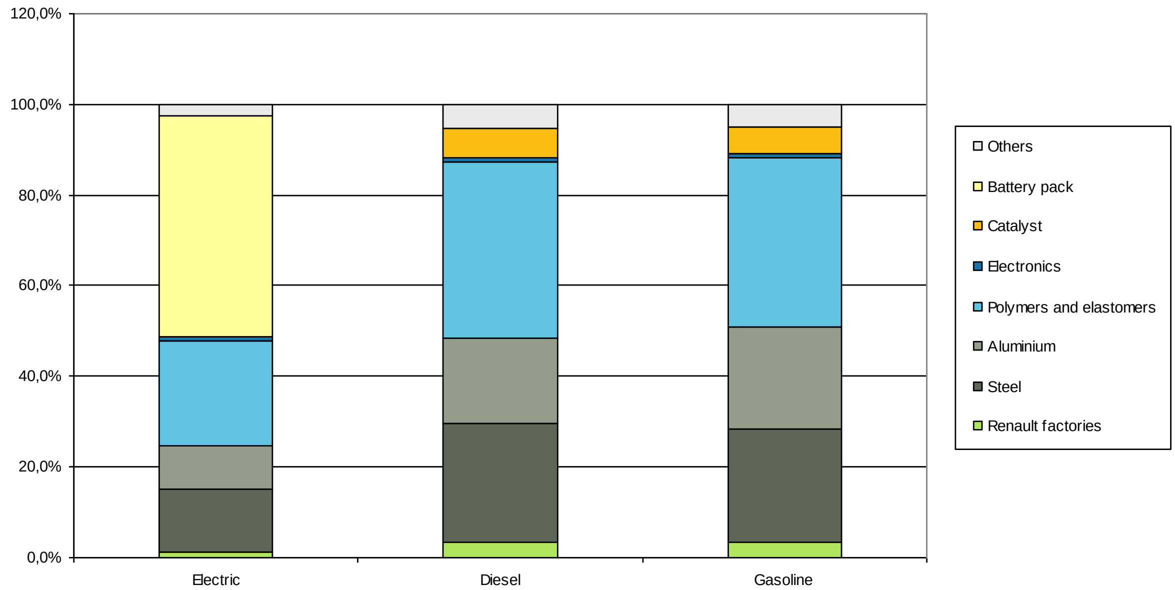


Figure 36 : Part of some elements production on eutrophication in production phase

EP	Renault factories	Steel	Aluminium	Polymers and elastomers	Electronics	Catalyst	Battery pack	Others	TOTAL
Electric	1.2%	14.0%	9.5%	23.0%	1.2%	0.0%	48.7%	2.4%	3.29
Diesel	3.5%	26.2%	18.7%	39.0%	1.0%	6.3%	0.0%	5.4%	1.66
Gasoline	3.3%	24.9%	22.8%	37.1%	0.9%	6.0%	0.0%	4.9%	1.74

Table 29 : Part of some elements production on eutrophication in production phase

Steel recycling, and in lower contribution aluminum, can bring to a 5 to 10% reduction of this impact! (6.3% for diesel, 9.6% for petrol and 9.5% for the EV)

IV.3.3.4 Global warming potential (GWP)

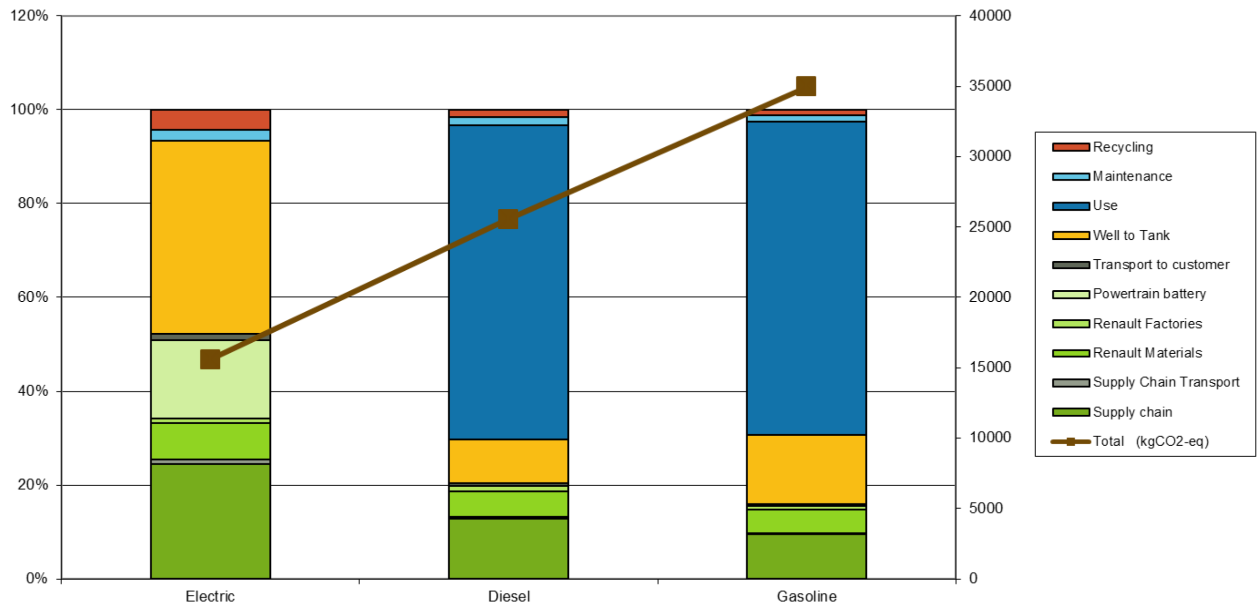


Figure 37 : Distribution of global warming potential from each actor or phase of life cycle

GWP	Supply chain	Supply Chain Transport	Renault Materials	Renault Factories	Powertrain battery	Transport to customer	Well to Tank	Use	Maintenance	Recycling	Recycling benefit	Total (kgCO2-eq)	Total with recycling benefit
Electric	24,5%	0,9%	7,8%	1,0%	16,6%	1,4%	41,1%	0,0%	2,3%	4,4%	-11,0%	15580	13870
Diesel	12,8%	0,3%	5,6%	1,2%	0,0%	0,6%	9,4%	66,9%	1,8%	1,5%	-5,2%	25547	24208
Gasoline	9,4%	0,2%	5,0%	0,9%	0,0%	0,4%	14,8%	66,7%	1,3%	1,2%	-4,8%	34951	33262

Table 30 : Distribution of global warming potential from each contribution or phase of life cycle

This impact is mainly due to CO_2 atmospheric emissions (96% of the global life cycle), principally in use phase of the car: 67% for both vehicles.

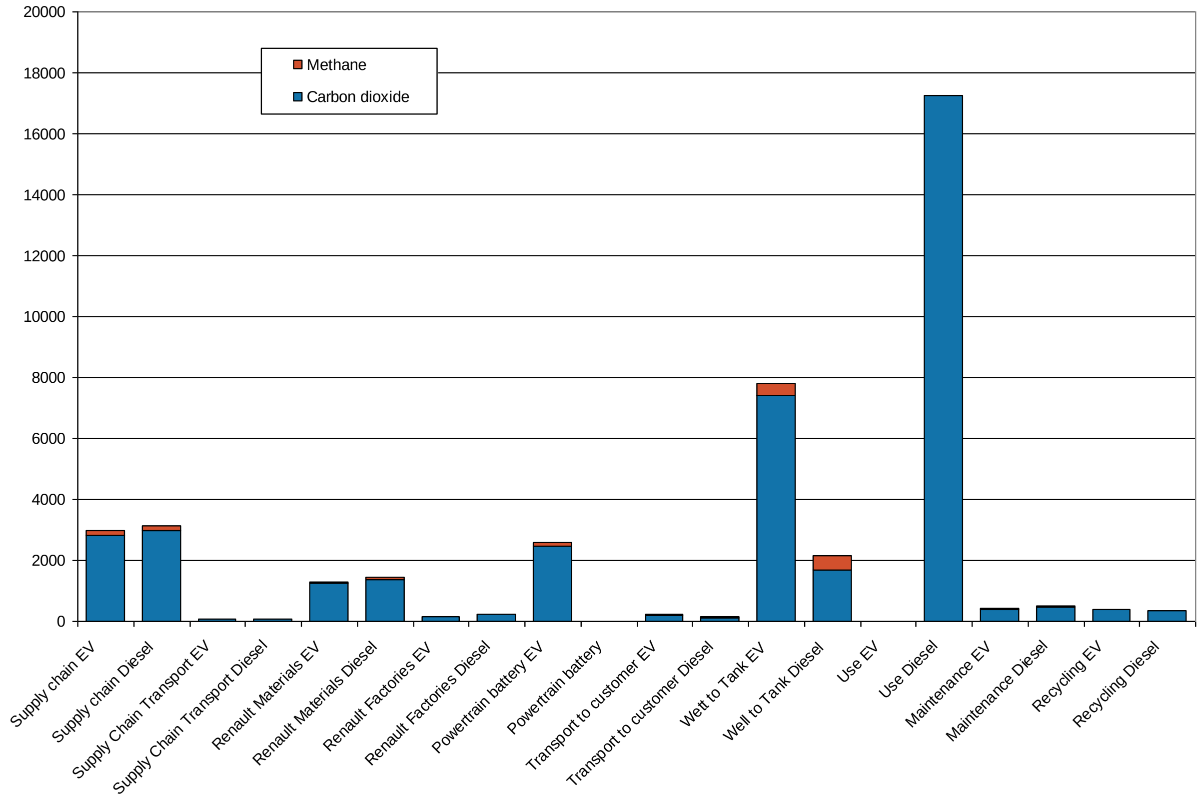


Figure 38 : Proportion of main flows affecting global warming potential on diesel and electric vehicles all along the life cycle

An EV emits over 38% less CO_2 during its global life cycle than a diesel engine. Although it is a zero emission vehicle during its use phase, construction of the drivetrain battery and electricity production are quite sensible and make its environmental benefit decrease.

Unlike standard thermal vehicle, production represents about 50% of total emissions for the electric vehicle (50.8% for electric, 19.9% for diesel and 15.5% for petrol). This is due to drivetrain battery production, emitting 2.7 tons of CO_2.

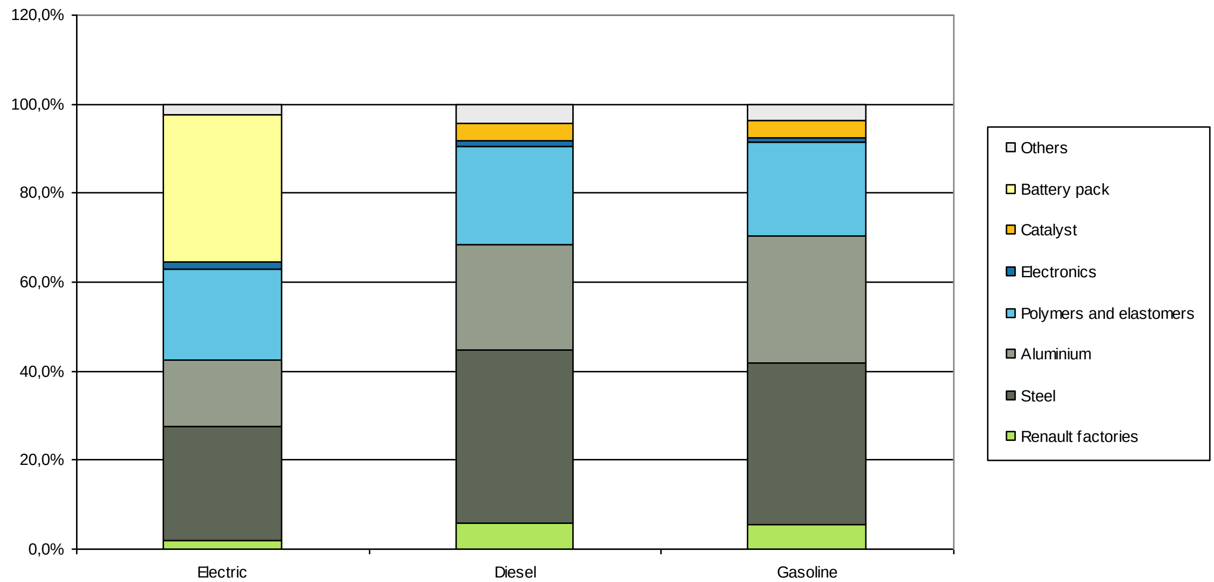
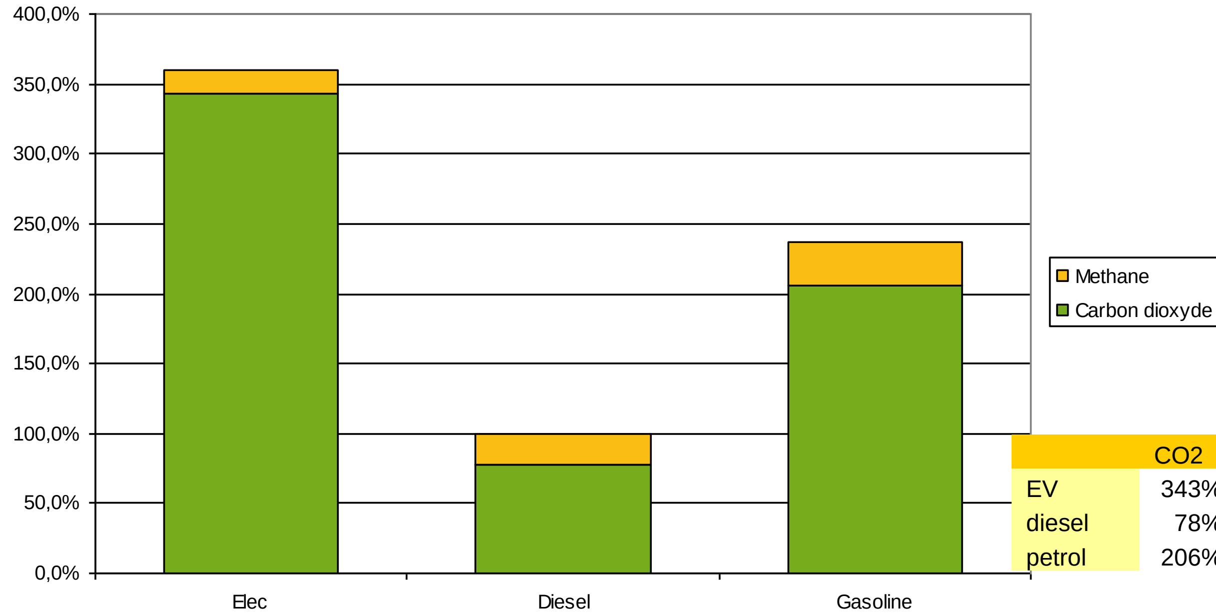


Figure 39 : Part of some elements production on GWP in production phase

GWP	Renault factories	Steel	Aluminium	Polymers and elastomers	Electronics	Catalyst	Battery pack	Others	TOTAL
Electric	2.0%	25.5%	15.1%	20.4%	1.5%	0.0%	33.3%	2.2%	8031
Diesel	5.9%	38.7%	23.9%	22.1%	1.0%	4.1%	0.0%	4.3%	5034
Gasoline	5.6%	36.4%	28.5%	20.9%	1.0%	3.9%	0.0%	3.8%	5338

Table 31 : Part of some elements production on GWP in production phase

Fuel production phase is very important considering electricity production. There is an important difference between production of diesel and petrol: 136% of GWP more with petrol (163% more CO_2 and 42% more methane (GWP 25 times superior to CO_2) to produce all 10050L of petrol), referring previous figure.
This is not only due to additional consumption of the petrol vehicle, but also superior energetic need of petrol production (refining, treatment, additives…). Due to a high CO_2 power grid mix in Turkey, GWP of the EV for the production phase is negative for the overall EV‘s environmental score. There is here a clear source of progress by ensuring for example renewable electricity supply to Bursa plant.



	CO2	Methane
EV	343%	17%
diesel	78%	22%
petrol	206%	31%

Figure 40 : Proportion of methane and CO_2 flows of petrol, diesel and electric vehicles towards GWP of the diesel vehicle, for the fuel or electricity production.

Steel recycling, and in lower contribution aluminum, can bring to an 11% reduction of this impact! (5.2% for diesel, 4.8% for petrol and 11% for electric)

IV.3.3.5 Photochemical ozone creation potential

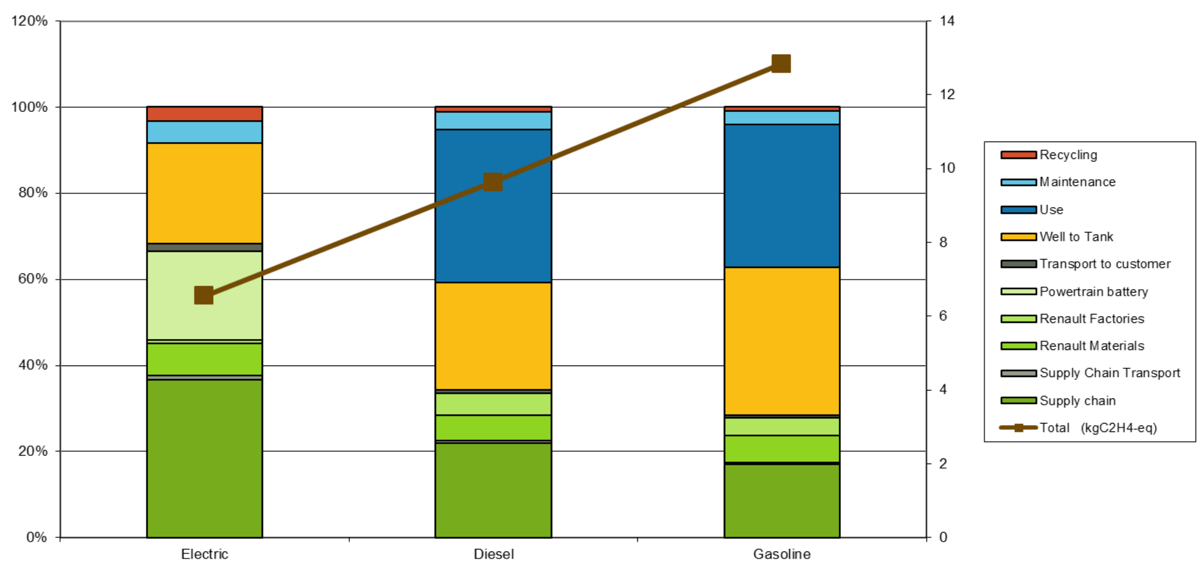


Figure 41 : Distribution of photochemical ozone creation potential from each actor or phase of life cycle

POCP	Supply chain	Supply Chain Transport	Renault Materials	Renault Factories	Powertrain battery	Transport to customer	Well to Tank	Use	Maintenance	Recycling	Recycling benefit	Total (kgC2H4-eq)	Total with recycling benefit
Electric	36,61%	1,05%	7,38%	0,90%	20,55%	1,71%	23,53%	0,00%	5,08%	3,20%	-16,82%	6,55	5,45
Diesel	22,00%	0,45%	5,89%	5,20%	0,00%	0,75%	24,91%	35,55%	4,15%	1,11%	-8,73%	9,63	8,79
Gasoline	17,08%	0,34%	6,32%	4,05%	0,00%	0,58%	34,36%	33,17%	3,11%	0,98%	-8,53%	12,84	11,74

Table 32 : Distribution of photochemical ozone creation potential from each actor or phase of life cycle

This impact is quite equally split between production and use phases of the vehicle (including fuel production phase)

As shown in the three following figures, there are more significant flows affecting this impact than on previously studied impacts. Moreover, distribution varies a lot depending on the life cycle considered step.

During use phase, sulphur dioxide and NOx mostly contributes to photochemical ozone creation. For the electric vehicle, the production of the drivetrain battery is at the same level of emissions as supply chain.

Industrial processes are mostly characterized by SO_2 emissions (few emissions for automotive vehicles).

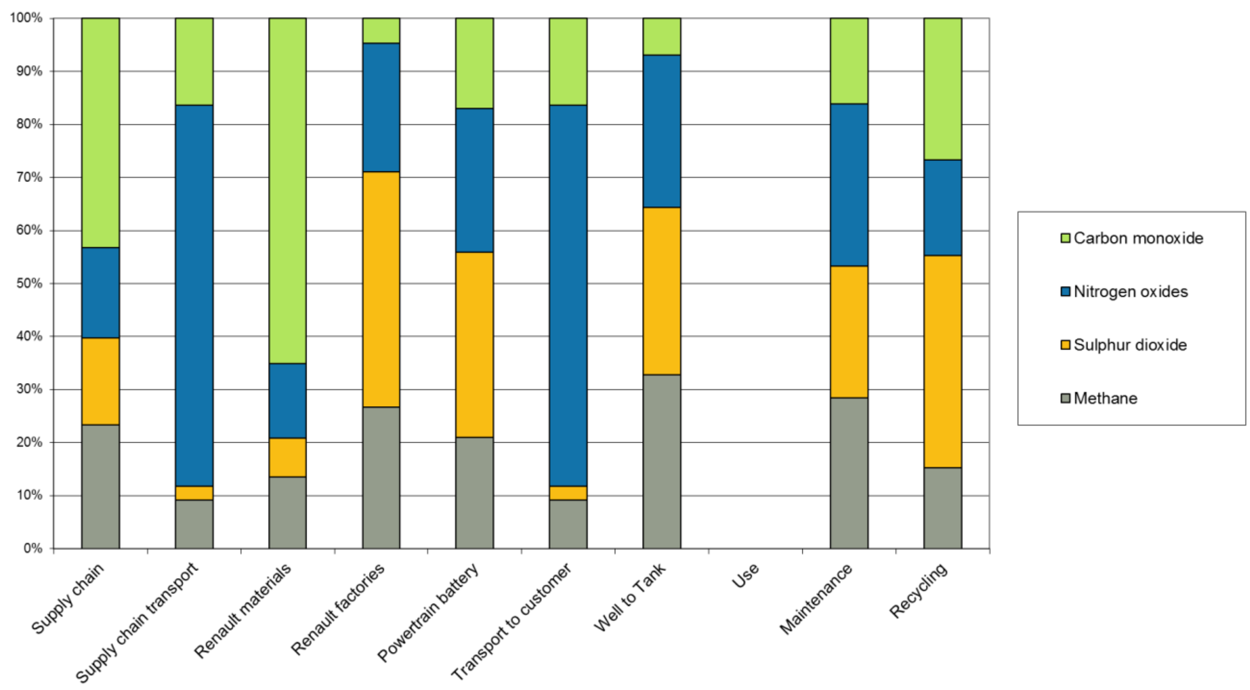


Figure 42 : Proportion of main flows affecting POCP on electric vehicle all along the life cycle

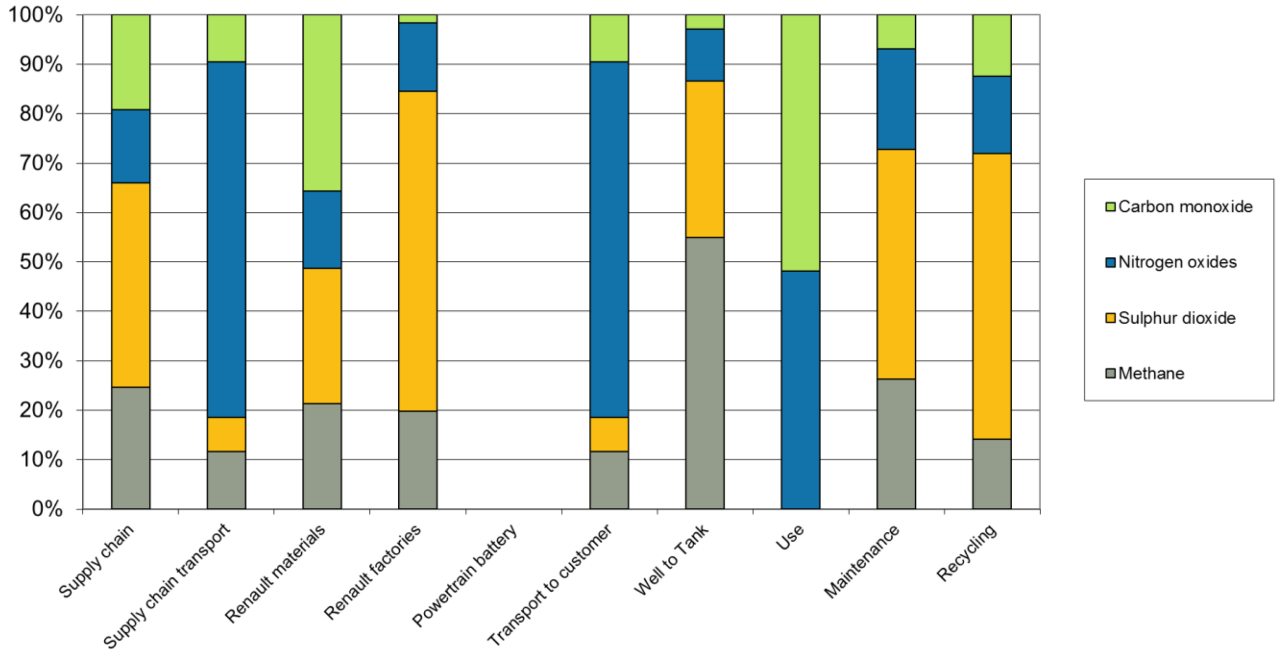


Figure 43 : Proportion of main flows affecting POCP on diesel vehicle all along the life cycle

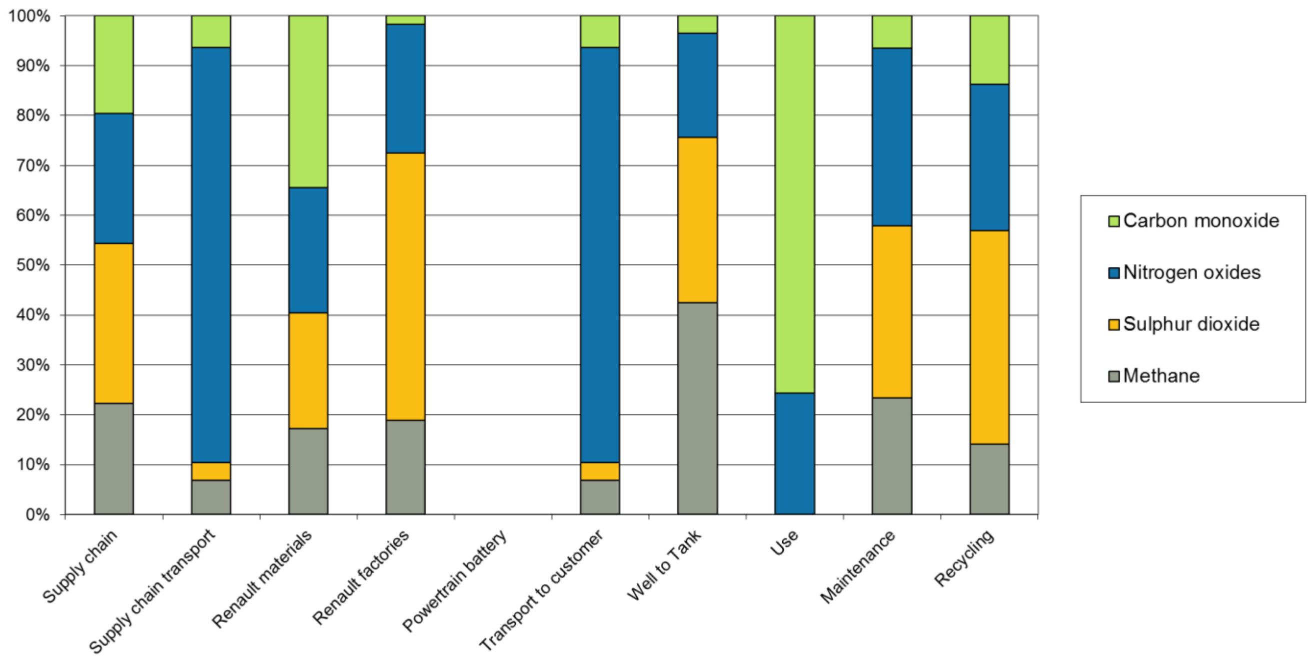


Figure 44 : Proportion of main flows affecting POCP on petrol vehicle all along the life cycle

During the vehicle's production, compounds responsible of this impact are mainly NOx, NMVOC (unspecified) and sulfur dioxide (SO_2).

Renault factories contribute here about 10 to 12% of vehicle's production phase impact. It is mainly from body and assembly line because of VOC emitted during painting and varnish. Difference between vehicles at that life cycle phase is low.

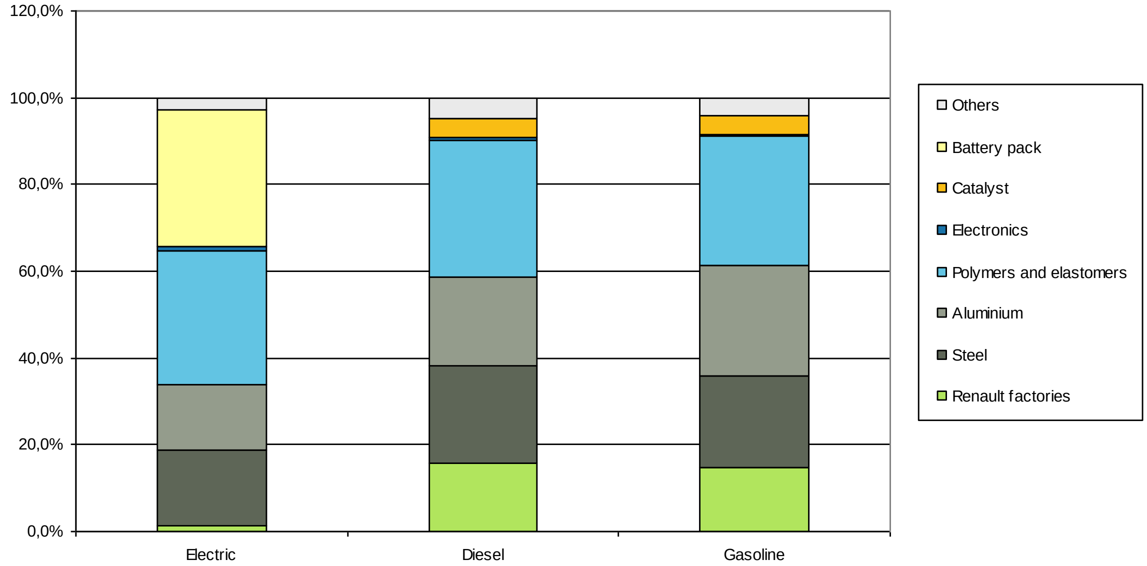


Figure 45 : Part of some elements production on POCP in production phase

POCP	Renault factories	Steel	Aluminium	Polymers and elastomers	Electronics	Catalyst	Battery pack	Others	TOTAL
Electric	1.4%	17.3%	15.2%	30.9%	0.9%	0.0%	31.4%	2.8%	4.41
Diesel	15.7%	22.4%	20.5%	31.6%	0.6%	4.4%	0.0%	4.8%	3.23
Gasoline	14.8%	21.0%	25.6%	29.7%	0.5%	4.2%	0.0%	4.2%	3.43

Table 33 : Part of some elements production on GWP in production phase

V

INTERPRETATION AND SENSITIVITY ANALYSIS

V INTERPRETATION AND SENSITIVITY ANALYSIS

In order to ensure coherence of hypothesis performed and to measure the influence of some parameters, we performed a sensitivity analysis. We apply an important change to a parameter to check if the result is significant or negligible.

V.1 CONSIDERING FACTORIES ?

V.1.1 FACTORIES MASS

Considering a factory mainly made of concrete and steel approaching:
- 40 kg of steel per meter square built;
- 500 kg of concrete per meter square built, following table presents mass of the factory associated to each vehicle for each factory:

Factory	Surface (ha)	Surface (m²)	Concrete mass (t)	Steel frame mass (t)	TOTAL Masses	Number of products (on 40 years)	Ratio M_{total} / product (kg)	Concrete mass (kg) / product	Steel frame mass (kg) /product
Sandouville	60.00	600 000	300 000	24 000	324000	7 700 000	**42.077**	38.961	3.117
Sevilla	8.7627	87627	43 813.5	3 505.08	47318,58	17 000 000	**2.783**	2.577	0.206
Cléon	37.069	370 690	185 345	14 827.6	200172,6	80 000 000	**2.502**	2.317	0.185
Busan*	53	530 000	265 000	21 200	286200	6 464 000	**4.427**	4.100	0.328

Table 34 : Factory quantities allocated to produced built on sites

*Busan factory is quite recent (2000) and is part of Renault – Samsung Motors group. It mainly products Samsung vehicles (SM3-SM5-SM7) and a few engines for Renault.
In 2006 were assembled 161 588 vehicles (approaching 1.5 tons) and built 161 787 engines.
The studied model, M4R, is about 145 kg: 1/10th of the vehicle's total mass. Therefore, we can associate to each engine approx 10% of emissions and environmental impacts.
Considering a constant production over 40 years, 6 464 000 will be produced.
The factory is 53 ha, so it weights 282 620 000 kg
The factory's mass associated to an engine approaches: 282 620 000 / 6 464 000 ≈ 4.4 kg

Therefore, we have:

47 kg of the factory for diesel vehicle
49 kg of the factory for petrol vehicle

These values are inferior to our cutoff criteria but in term of mass, and then quite negligible. However, concrete represents 90% of the factory's mass and it is mainly constituted of aggregate (sand, pebbles). Quantity of energy necessary for its construction is low comparing to energy consumed by the system, and then negligible. Considering now impacts, we show that the part of the factory allocated to each car is negligible on the global life cycle.

V.1.2 IMPACT CALCULATION

Data from concrete production environmental impacts comes from report www.environdec.com/reg/epd108e.pdf giving the impact of 1m3 of concrete composed of 80% of aggregate and needing 2187 MJ (0,94MJ per kg).
Production process of steel is based on Gabi database corresponding to European production, without considering an eventual recycling.
For logistics considerations, all of products are produced in Europe.

Quantities of energy consumed by machines to build the building are not included (cranes, diggers…) However, considering results in following tables, in doubling environmental impacts values of the 50kg of the factory per vehicle, we are still under 1% for each impact on the global life cycle.

Then we can consider factories construction (and other infrastructures) as negligible on the global life cycle.

1,6l 16v (petrol) **Impacts potentials**	**Factory impact**	**System's impact on its life cycle (without considering factories mass)**	**Proportion on life cycle**
Abiotic depletion (kgSb-eq)	0.076	219.79	0.034%
Acidification (kgSO_2-eq)	0.12	60.10	0.20%
Eutrophication (kgPO_4-eq)	0.005	5.35	0.093%
Global warming (kgCO_2-eq)	16.4	34762	0.047%
Photochemical ozone creation (kgC_2H_4-eq)	0.01	12.44	0.080%

Table 35: Part of factory's construction a petrol vehicle's life cycle

1,5l dCi (diesel) **Impacts potentials**	**Factory impact**	**System's impact on its life cycle (without considering factories mass)**	**Proportion on life cycle**
Abiotic depletion (kgSb-eq)	0.073	169.55	0.043%
Acidification (kgSO_2-eq)	0.12	56.84	0.21%
Eutrophication (kgPO_4-eq)	0.004	6.92	0.057%
Global warming (kgCO_2-eq)	15.6	25463	0.061%
Photochemical ozone creation (kgC_2H_4-eq)	0.01	9.25	0.011%

Table 36: Part of factory's construction on diesel vehicle's life cycle

5AGen1 (electric) **Impacts potentials**	**Factory impact**	**System's impact on its life cycle (without considering factories mass)**	**Proportion on life cycle**
Abiotic depletion (kgSb-eq)	0.07	87.48	0.080%
Acidification (kgSO_2-eq)	0.12	77.43	0.155%
Eutrophication (kgPO_4-eq)	0.003	6.25	0.048%
Global warming (kgCO_2-eq)	14.3	15702	0.091%
Photochemical ozone creation (kgC_2H_4-eq)	0.01	6.95	0.143%

Table 37: Part of factory's construction on electric vehicle's life cycle

V.2 FACTORIES ALLOCATIONS

In order to justify established hypothesis or the need of amelioration of factories consumptions and emissions allocations (by the eco-risk tool), we increase values of those parameters by over 10% for all factories. Variations for diesel and petrol vehicles are gathered in the following table:

Impacts potentials	Relative gap (petrol vehicle)	Relative gap (diesel vehicle)
Abiotic depletion (kgSb-eq)	+ 0.04%	+ 0.20%
Acidification (kgSO_2-eq)	+ 0.18%	+ 0.39%
Eutrophication (kgPO_4-eq)	+ 0.19%	+ 0.28%
Global warming (kgCO_2-eq)	+ 0.15%	+ 0.33%
Photochemical ozone creation (kgC_2H_4-eq)	+ 0.44%	+ 0.61%

Table 38: Comparison of environmental impacts following a 10% increase of Renault factories' consumptions and emissions.

We note that none of impacts values reaches 0.7 on the global life cycle. It reveals the weak incidence of an allocation error of factories flows, which contribution stays under 1%.

REMARK: If part of the factories remains weak comparing to the global life cycle of a vehicle, any reduction of consumptions or emissions is beneficial.

V.3 SUPPLY CHAIN TRANSPORT

Considering multiple hypothesis made to obtain and treat data from parts transport from first rank suppliers to the factory (assembly), it is important to verify if hypothesis were reasonable and if data was not over or under-estimated. So, we chose to modify distance of this transport to observe if it consequently changes our results. We doubled supply chain distance, from 2000 to 4000 km.

Following table gives results concerning impacts potentials (only global ones). We observe changes on vehicle production phase because supply chain is only part of this step.

Impacts potentials	Relative gap (petrol vehicle)	Relative gap (diesel vehicle)
Abiotic depletion (kgSb-eq)	+ 0.29%	+ 0.33%
Acidification (kgSO_2-eq)	+ 1.20%	+ 0.94%
Eutrophication (kgPO_4-eq)	+ 2.18%	+ 1.31%
Global warming (kgCO_2-eq)	+ 0.27%	+ 0.32%
Photochemical ozone creation (kgC_2H_4-eq)	+ 0.34%	+ 0.44%

Table 39: Comparison of environmental impacts following a modification of supply transport.

We observe a logical increase of all impacts confirming expected effect of a mileage increase. Larger distances bring to a larger fuel consumption and then of pollutant emissions. But those impacts increases reach at least 0.3%, which is inferior to our cutoff criteria.

We can highlight the low contribution of supply transport on environmental impacts over the global life cycle and the negligibility of an approximation on this parameter.

V.4 CUSTOMER DRIVING CYCLE

V.4.1 CUSTOMER DRIVING CYCLE

Vehicle's real use conditions can quite diverge from theoretical pattern. « Real » cycle evaluation is quite hard because it gathers multiple parameters:

- Driver's profile, i.e. how he drives (calm, aggressive…)
- Engine's type: Additional consumption changes depending on the engine's type (petrol or diesel): reaction to the driver's behavior.
- Where is mostly used the vehicle: urban conditions (traffic?), city + motorway… This data can be directly linked to the vehicle's segment (a sedan would be mostly used on motorways and a smaller car in cities)
- Climatic conditions, period of use :
  - Winter: headlights, electric heating system → additional consumption
  - Summer : Headlights sometimes but air-conditioning will bring to an additional consumption approaching 3-4%

Renault has internally developed a tool considering all those parameters, which added by enquiries and measures brings to a good model of real drive profile and associated consumption.

Then we can calculate CO_2 quantity (id. SO_2) basing this relation:

- 1 l/100km is equivalent to 26.45g/km of CO_2 for a diesel engine
- 1 l/100km is equivalent to 23.65g/km of CO_2 for a petrol engine

For Fluence, performance and consumption department provides real consumptions (average) and CO_2 and SO_2 emissions associated in table 34.

Engine	Customer real consumption	Homologated consumption	Variation	Real customer CO_2 emissions	Real customer SO_2 emissions
1.5l dCi (diesel)	5.05 l / 100km	4.4 l / 100km	+ 14.77%	132 g/km	0.00086 mg/km
1.6l 16v (petrol)	7.7 l /100km	6.7 l/100km	+ 15.19%	215 g/km	0.00115 mg/km

Table 40: Emissions and fuel consumption of vehicles during their use phase for a real customer cycle

For Fluence Z.E., we cannot apply a +15% variation as it cannot be a standard. As the driving range and electricity consumption varies with temperature and driving, autonomy can varies from a quite low value to 215 kms, with a standard 185 kms with a NEDC cycle. With an electric vehicule, this variation is too high to consider a standard variation.

However, to highlight the difference between ICE and electric engines, a 15% increase will be tested.

Considering the 1.6l 16v petrol engine

Following figure presents distribution of selected indicators resp for NEDC and real customer cycle for each step of the life cycle.

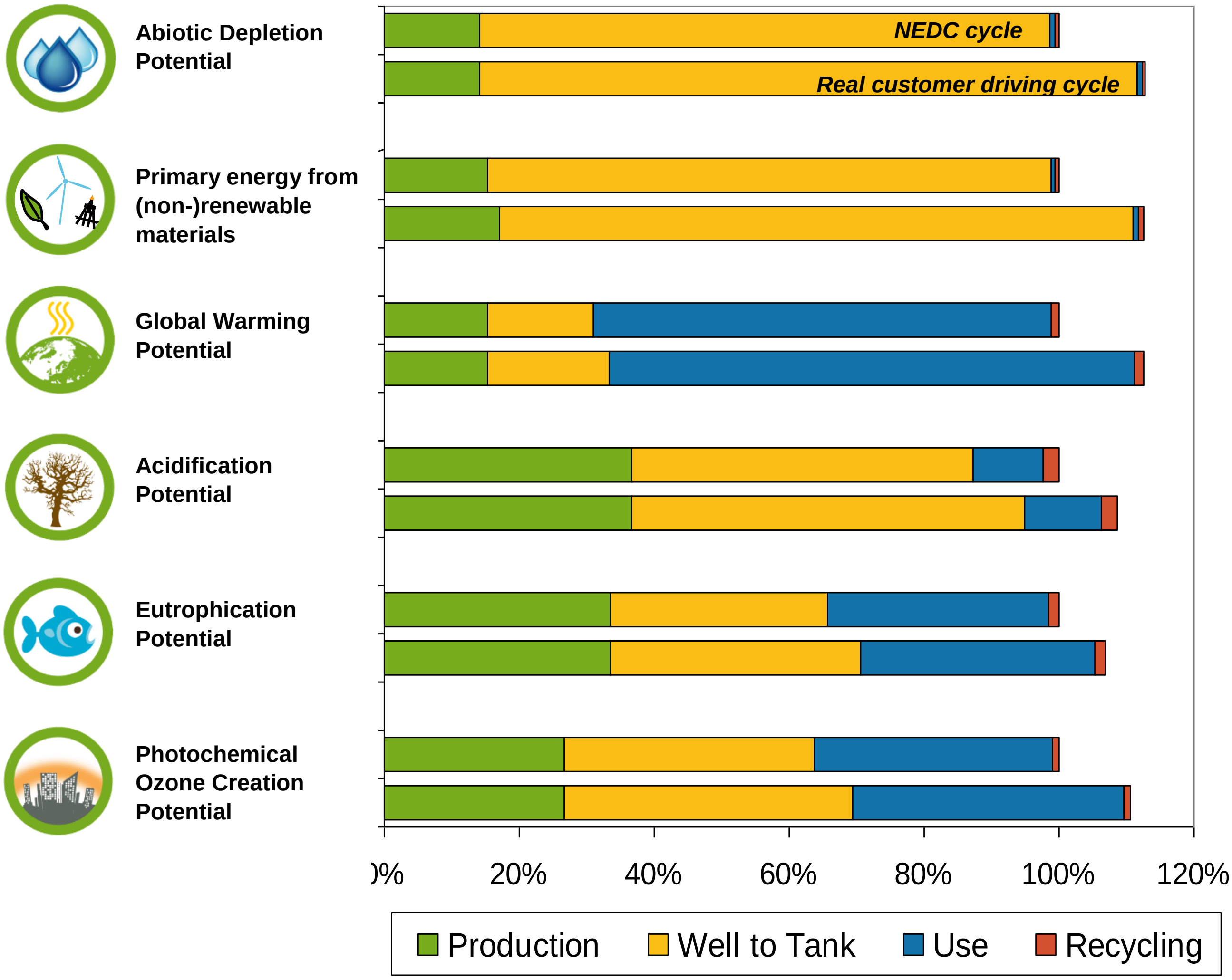


Figure 46: Environmental impacts of NEDC and real customer driving cycles on each step of the life cycle.

Impact on the global life cycle	NEDC --> REAL
Abiotic depletion (kgSb-eq)	+13%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	+12%
Global warming potential (kgCO_2-eq)	+12%
Acidification (kgSO_2-eq)	+9%
Eutrophisation (kgPO_4-eq)	+7%
Photochemical ozone potential (kgC_2H_4-eq)	+11%

Table 41: Environmental impacts of NEDC and real customer driving cycles on each step of the life cycle.

Considering the electric motor

Following figure presents distribution of selected impacts respectively for NEDC and real customer cycle for each step of the life cycle.

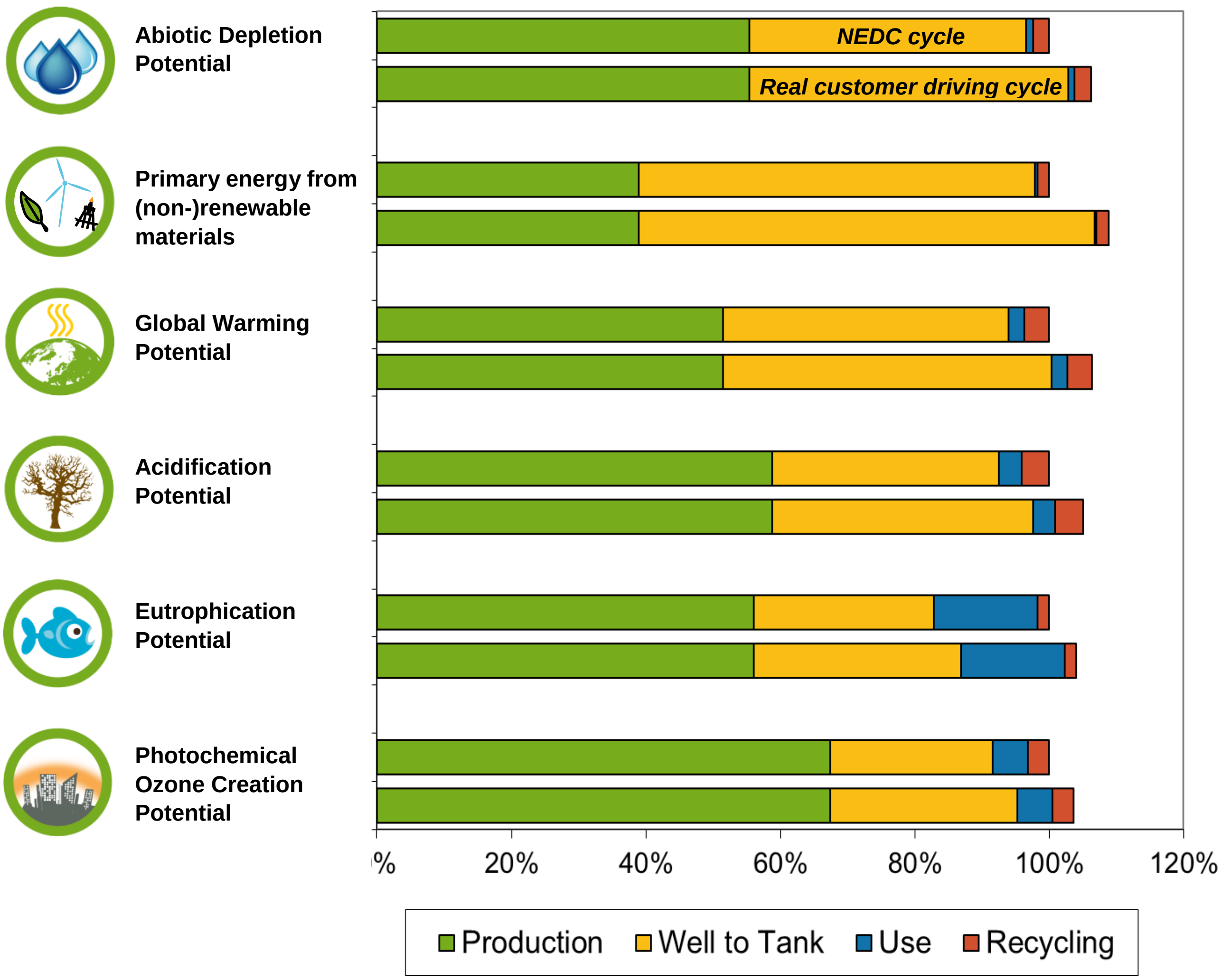


Figure 47 : Environmental impacts of NEDC and real customer driving cycles on each step of the life cycle.

Impact on the global life cycle	NEDC --> REAL
Abiotic depletion (kgSb-eq)	+6%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	+9%
Global warming potential (kgCO_2-eq)	+6%
Acidification (kgSO_2-eq)	+5%
Eutrophisation (kgPO_4-eq)	+4%
Photochemical ozone potential (kgC_2H_4-eq)	+4%

Table 42: Environmental impacts of NEDC and real customer driving cycles on each step of the life cycle.

From this comparison, we can assume that:

Consumption is a very critical parameter. A 15% concumption increase has a major impact on all indicators.

Thanks to its electric technology, an EV driven with a real customer driving cycle only affects electricity production and not the use phase. In that case, electric technology shows one more advantage comparint to ICE vehicles

In another hand, this 15% increase for the EV cannot be considered as a standard. Future reports from electric vehicles owners' real driving cycle will help to obtain an average value comparable to the thermic vehicle's one.

Moreover, Renault assume that not considering an NEDC driving cycle for the LCA study could be a bit far from reality. But, considering literature on automotive LCAs, most of studies are based on NEDC driving cycle. This measurement is made out from Renault and it is then preferable.

V.5 HC ADDITIONAL SOURCE

V.5.1 PROBLEMATIC

The issue deals here with the potential evaporation of hydrocarbon vapors (petrol) during tank filling:

- From petrol delivery truck to petrol station
- From petrol station fuel pump to vehicle tank.

Because of petrol's volatility (not concerning diesel), part of hydrocarbons is emitted in the atmosphere bringing a potential increase of photochemical ozone creation. Moreover, presence of benzene (0.7% in petrol vapors) brings a public heath problem because it is a carcinogen agent.

Current European legislation does not impose vapor recovery systems on those two steps (unless recovery systems are being developed). Automotive manufacturers ensure non-evaporation of petrol vapors once filler hose closed (canister system, tank's sealing)

Here is a sensitivity analysis when the gas station is equipped with a recovery system for vats filling. We only consider the impact on which the constructor can act.

REMARK: During petrol station vats filling, the emitted quantity allocated to each vehicle is the same than the one emitted during tank filling (same quantity of petrol consumed and same hypothesis concerning evaporation calculation. So we double variation of impact measured.

V.5.2 HYPOTHESES AND CALCULATIONS

For environmental impacts calculation, we consider hydrocarbon vapors to HC even if those are quite different (cf remark):

This pattern considers two hypotheses:
Liquid/vapor balance of petrol responds to Clausius-Clapeyron equation or pure, which form is: log P = A/T + B
Petrol vapor responds to ideal gas law.

1) We consider averaged over the year the vapor tension of petrol to a median summer/winter value: 60kPa at 37.8°C (100° Fahrenheit)

Vapor tension is equally placed between Pentane and Hexane vapor tensions, which equations are:

$$\log P_{pentane} = - 1458/T + 6.27$$

$$\log P_{hexane} = - 1649/T + 6.83$$

with decimal log, P in kPa, T Kelvin, data from Handbook of Chemistry and Physics.

We consider petrol as a pure:
Average molar weight between pentane (72) and hexane (86): 79
Average coefficient between pentane and hexane: $\log P_{petrol} = -1550/T + B$; we calculate B with reference vapor tension : $\log P_{petrol} = -1550/T + 6.76$ (1)

With equation (1), we calculate vapor tension a different temperatures. At 20°C, P_{petrol} = 30 kPa.

2) We consider 1 liter of atmosphere saturated of petrol vapor at atmospheric pressure (101.3 kPa) and at 20°C (average temperature supposed).

Petrol partial pressure = 30 kPa

Total pressure = 101.3 kPa

In ideal gas approximation, total number of moles of gas = 1/22.4

Number of moles of petrol = (1/22.4) x (30/101.3)

Weight of petrol’s weight
= (1/22.4) x (30/101.3) x 79 = 1.0 g of petrol vapor per liter of atmosphere in the tank.

Quantity of HC emitted during tank filling approaches 0.079 g/km for a vehicle consuming 7.9 liters/100 km.

At 20°C, this emission is very close to Euro IV emission regulation. If average tank temperature is 10°C, P_{petrol} becomes 19 kPa and emission approaches 0.052 g/km

V.5.3 RESULTS

Figure 44 represents evolution of photochemical ozone creation's impact during use phase, with a tank a 10°C and 20°C considering previous hypothesis.

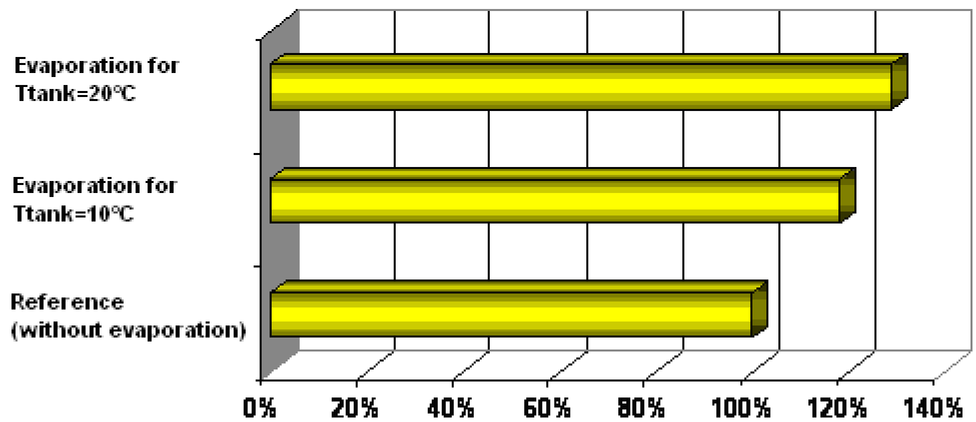


Figure 48 : Evolution of photochemical ozone creation potential, function of tank temperature (i.e. petrol vapors)

Impact potential	Reference (without evaporation)	At 10°C (HC = + 0,052 g/km)	At 20°C (HC = + 0,079 g/km)	Relative gap [10°C – 20°C]
Photochemical ozone (kgC_2H_4-eq.)	14.9	17.8	19.3	+ [19 - 29] %

Table 43 : Value of photochemical ozone creation potential for use phase, function of tank temperature (i.e. petrol vapors)

Fuel vapors are very far from being negligible. There is a real need of vapors recovery.

However, this emission does not have the same geographic dispersion as exhaust gas.

Moreover, as stated previously, in many countries (England, United States…), recovery systems are compulsory and would be extended to rest of the Europe.

Currently in France, May 17th of 2001 order (http://aida.ineris.fr/textes/arretes/text3272.htm) relative to reduction of volatile organic compounds emissions due to petrol tank filling mandates recovery systems in gas station providing more than 3000 m3 per year. Moreover, any newly built gas station must be equipped with that system if it provides more than 500 m3 per year. A bill is currently studied to mandate those systems compulsory for any gas station.
(http://www.assemblee-nationale.fr/12/propositions/pion3471.asp).

Then Renault does not consider these pollutant emissions in the vehicle life cycle.

However, this sensitivity analysis reveals the need of regulating it quickly on European perimeter.

VI

STUDY'S CONCLUSION

VI STUDY'S CONCLUSION

In the goal and scope of the study, the intended applications are the followings:

- Complete our range of Life Cycle Assessment studies in order to be able to integrate electric vehicles in our group KPI monitoring
- Set up new unit process and Life Cycle Inventory data sets (eg battery) to be utilised use in a new calculation model
- Carry a weak point analysis in order to persue the ecodesign work on this new technology
- Benchmarking against the Renault European product group's average (2010 year)
- Build a comprehensive science based dialogue with expert stakeholders inside and outside of the company

VI.1 COMPLETE OUR RANGE OF LCA STUDIES

This work needed many efforts to provide an assessment of this new technologie embedded in the electric vehicle.

As results are now available, Renault will be able to integrate the electric vehicle in its KPI (reduced its worldwide average product carbon footprint) monitoring and have an overview of this carbon footprint reduction on all countries where Renault EVs are sold.

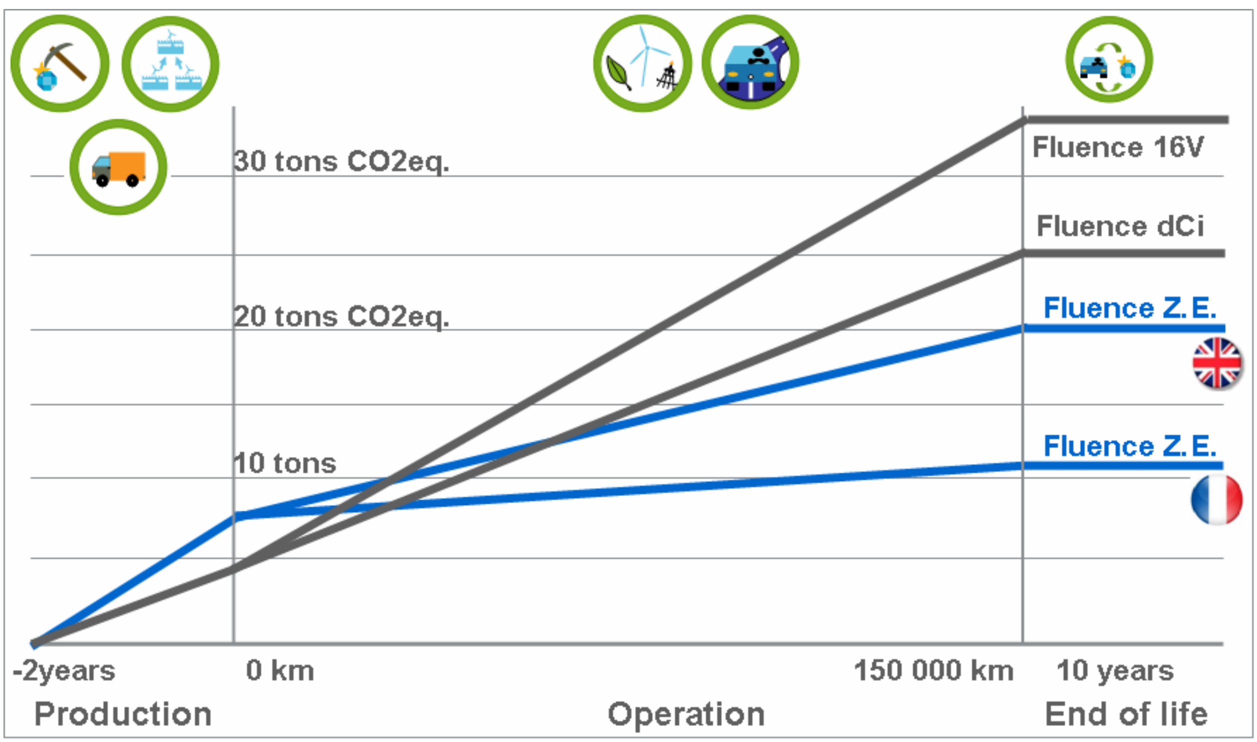


Figure 49 : Comparing carbon footprint of EV and ICE vehicles.

VI.2 SET UP NEW UNIT PROCESS AND LCI DATA SETS

To achieve these results, the Renault group has carried a tremendous work in order to calculate the full life cycle of an electric vehicle.

This detail inventory of the battery will now provide to the group a LCA model, which will enable the company to assess various battery types and from different supplyer in this family of technology. This brings a unique vision of the potential impact of Li-ion batteries on the market.

VI.3 CARRY A WEAK POINT ANALYSIS

First, we need to distinguish EV from the ICE vehicles.

- In thermal engines, vehicle's use phase is the principal source of environmental impacts because of:
  - Pollutant emissions (CO_2, NOx, HC, CO)
  - Fuel consumption in two points:
  - Abiotic depletion
  - Pollutants emissions due to fuel production process (CO, NOx, SO_2, VOC, CO_2 emissions)

Proper technology of the engine acts on environmental impacts. As shown in figure 22, there is a major difference on the global life cycle environmental score depending on the technology used.

We identified that none of each system, petrol or diesel, can be considered as better in all categories than the other. Indeed:
- Petrol model has better results on acidification and eutrophication potentials due to the lower quantities of NOx emitted.
- Diesel model, thanks to its lower consumption, significantly reduces its contribution in global warming potential and abiotic depletion (particularly on fossil resources).

- In EV, use phase is not the principal source of environmental impacts but we can identify two of them: vehicle's production and power supply.

  - Although the vehicle's production impacts are the same for electric and ICE vehicles (complete car excluding drivetrain battery for the EV), the production of the drivetrain battery brought some major emissions, affecting negatively the production phase score.
  - As presented in appendix V.8, the power grid mix really varies from one country to another. Considering those high variations, benefits of the EV varies from a country to another being a major progress for mobility in countries where the electricity production is made from nuclear or renewable energies.
  - Being a zero emission vehicle from engine's operation, emissions from the use phase are only maintenance and non-exhaust ones.

VI.4 BENCHMARKING AGAINST THE RENAULT EUROPEAN PRODUCT GROUP'S AVERAGE (2010 YEAR)

In order to compare Fluence Z.E. to a vehicle sold by Renault in a European context, we calculated an average vehicle based on 2010 sales reports.

	Average Renault	Renault Fluence Z.E.	Variation (%)
Abiotic depletion (kgSb-eq)	190,0	88,8	-53,3%
Primary Energy Demand (MJ)	415732	348027	-16,3%
Global warming potential (kgCO_2-eq)	29632	15580	-47,4%
Acidification (kgSO_2-eq)	60,6	69,3	14,3%
Eutrophisation (kgPO_4-eq)	6,71	5,88	-12,4%
Photochemical ozone potential (kgC_2H_4-eq)	10,23	6,55	-35,9%

Table 44 : Comparing Fluence Z.E. to the Renault average vehicle sold in 2010 (personal + professional vehicles)

Fluence Z.E. brings a major progress comparing to our average vehicle. The only negative point comes from acidification which value depends on two factors: electricity production and drivetrain battery production.

- Considering countries where electricity production is mainly issued from renewable energies or nuclear, acidification decreases and can reach 52kgSO_2-eq in France or in Switzerland. Then, Fluence Z.E. is a progress in our five chosen indicators.
- Acidification for drivetrain battery comes from key materials like Co or Ni, but also from sensitive materials produced in countries like China or Japan. In using less efficient extraction and treatment processes and worse power grid mixes, the environmental score of those materials penalizes the battery. This highlights a feasible progress roadmap, not even taking into account the expected improvement in technology and materials used.

Considering the distribution of the carbon footprint impacts on this global life cycle and the figure 49, we can deal will two main conclusions:

- At its production phase, the EV has a more important carbon footpring due to its drivetrain battery.
- Considering power grid mixes in countries of sale, Fluence Z.E. carbon footprint remains better than its petrol and diesel version in any case. This is due to the the global efficiency of the vehicle and then to the lower need of primary energy to achieve all 150 000 kms.

VI.5 HIGHLIGHT ENVIRONMENTAL PROGRESS FROM ECO-DESIGN

Comparing a Fluence Z.E. and its ICE equivalent is important in order to give information for a customer to see the progress brought by the electric technology. However, in order to highlight the benefits of Fluence Z.E., we also need to compare Fluence to its anterior model. As Fluence do not have an anterior model, we compared it to a Megane II (B84) offering the same performance.

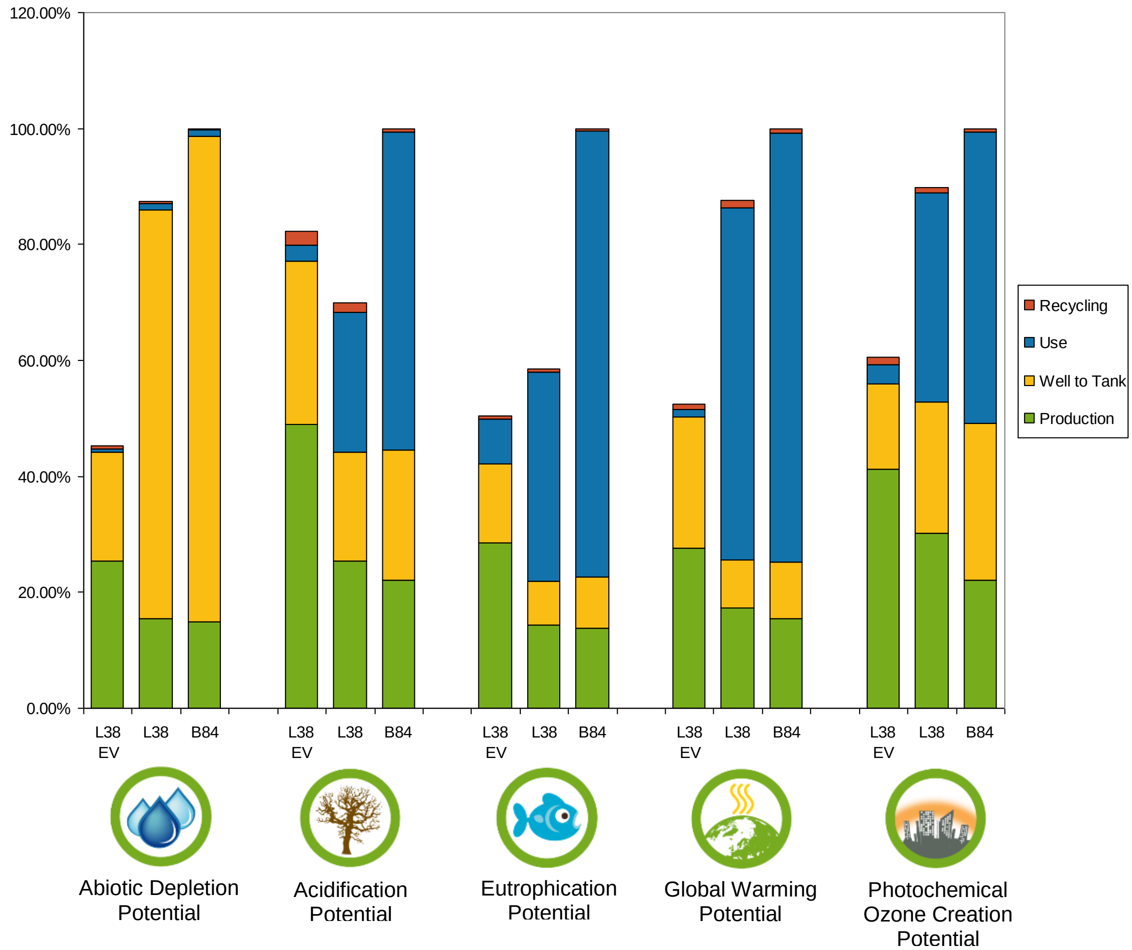


Figure 50 : Comparing Fluence Z.E (L38 EV), Fluence Diesel (L38), and 2004 Euro 3 Megane II 1.9L DCi Diesel, in an EU geographic context.

We can deal with two main conclusions:

1 - Comparing ICE vehicles' production, the 5.4% of mass increase brought a quite equivalent increase of abiotic depletion and eutrophication (Fluence ICE is heavier than Megane II). As Fluence received the Renault eco2 certification, it includes recycled materials and then, those two indicators only increase of about 4%. All three other indicators are increasing from 12 to 36% because of the production center choice. As Megane II was produced in France, its power grid mix advantaged Megane II towards Fluence.

- In addition to this mass increase, emissions from recycling increased too.
- As precised before, the electric technology brought a drivetrain battery in the vehicle, which highly increases emissions from vehicle's production phase.

2 - Megane II was a Euro 3 vehicle and Fluence, Euro 5. As precised in Appendix V.9, major restrictions from Euro 3 to Euro 5 concerned NOx and HC+NOx. As NOx emissions mainly affect Acidification and Eutrophication potentials, we have a major progress on use phase.
- As the vehicles' consumption decreased from 5.1 to 4.4 L/100kms, the fuel production phase followed this 16% decrease.

We can note that Fluence Z.E., in an EU geographic context and with a 2012 sales predictions weighted power grid mix, is better than Megane II on all indicators, approaching or sometimes overpassing a 50% progress.

VI.6 BUILD A COMPREHENSIVE SCIENCE BASED DIALOGUE

The first audience is internal experts in order to point out where potential progress could be made in order to improve future vehicles.

ICE vehicle

As use phase remains the principal source, we need to keep working on atmospheric pollutants reduction, encouraged by EURO regulations

This reduction needs a consumption reduction, which could be:

- An increase of engine's performances (downsizing consequences)
- A vehicle relief
- Awareness of drivers to an economic driving

We have highlighted the problem linked to high quantity of NOx emitted during this phase. It is a major need to work on NOx reduction to take advantage of diesel towards petrol engine. NOxtrap technology has been developed and would be applied for Euro 6 emissions regulation.

Electric vehicle

The status of "zero emission at use" vehicle of the Renault EV brought the use phase as a minor impacting phase of the life cycle, raising the energy supply as a major factor to count with. Moreover, where production phase had a minor share of the life cycle global impact, it has now a major one.

Cars' design and production then need to be studied to choose not only sustainable materials and sustainable processes, but also having sustainable production plants like Tanger's one, which is zero carbon footprint and zero liquid emissions.

Identifying Strategies

On vehicle's production phase, Renault factories impacts stay weak, excluding photochemical ozone creation potential on which we need to work on volatile organic compounds uptake in painting workshop.

Energy used mainly comes from natural gas. It contains a very little share of sulfur (for odour) and then releases very few SO_2 contrary to electricity from coal (in some countries). Using a higher proportion of natural gas could reduce impacts of SO_2 (acidification and photochemical ozone).

The greatest benefit on production phase is including recycled material. Using those materials in a new vehicle could reduce from 8 to 19% some impacts. This is due to high reductions in energy consumptions and pollutants emissions due to materials production brought by recycling. Helped by European regulations, recycling must also be helped by design for disassembly and recyclability of the vehicle.

Moreover, impact of recycling (collection, transport, treatment) never overpasses 5% of the impact on the life cycle (acidification potential on petrol engine)

Another solution would be reducing impacts on materials production. But with current pressure on material prices, it seems to be difficult to pressure on materials supply chain. Recycling seems to be the way to promote.

.

Renault cannot influence on well to tank production and associated technologies. Reduction will be petrochemical industries, electric suppliers and governments' work and need to be encouraged.

We also repeat the need to regulate petrol gas recovery during tank and gas station vats fillings.

The second audience is the dialogue with external experts. This study will reinforce our commitment to achieve the best environmental performance at affordable cost for the customers.

Based on performed studies, we are be able to identify and quantify, with the same methodology, the benefits and disadvantages of each technology and evaluate if this vehicle makes an improvement toward the average Renault vehicle sold.

We saw that electric vehicle is a very intresting solution on a global society level to reduce environmental burdens and secure energy strategy.
In countries like France or Switzerland, the EV provides a progress in all environmental impact categories.
In some other coutries, the results may be sensible. Normalizing showed that on an overall perspective, this new technology bring a benefice to the society.
On top of these results, the European commitment to reduce carbon emission from industries such as energy producers will automatically improve the performance of the electric vehicle fleet on the road year after year.

VI.7 METHODOLOGY LIMITS

Work made here highlights some limits of the LCA methodology in an automotive context:

First, study focuses on brand new vehicles well maintained. However, in order to make an exact comparison, we need to establish a common base, based on manufacturer's recommendations (maintenance). It could be interesting focusing on the impact linked to the driver's behavior with a bad maintenance.

Secondly, automobile is part of the important temporal evolution scope through its lifetime and its environmental and economic issues:
- Evolution of technologies along the vehicle's life cycle.
- Petrol pollution regulations (quantity of sulfur in petrol from 100ppm to 10ppm and diesel from 300ppm to 10 ppm between 2001 and 2006). This work needs energy, which consequence is the increase of abiotic depletion potential and global warming on each step of life cycle.
- Recycling technologies: they are still under development and modeled technologies are not those that will be used at the end of life of the vehicle (in more than 10 years).
- Evolution of vehicle's pollutants emissions along its life cycle. As the engine is used, it emits more pollutants.

Last point, we will remark the absence of the Human toxicity indicator that could integrate consequences linked to carcinogen substances and PM10 and then, highlight another problematic from diesel vehicles.

VII

APPENDIX

CONFIDENTIAL

VII APPENDIX

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VII.2 ABBREVIATION LIST

ADP: Abiotic depletion potential

AP: Acidification potential

CML 2001: name of the environmental impacts calculation method from the Institute of Environmental Sciences of Lieden Faculty of Science

ECU: Electronic control unit

EP: Eutrophication potential

EV: Electric vehicle

GWP: Global warning potential

ICE: Internal Combustion Engine

ISO: International Organization for Standardization

KPI: Key Performance Indicator: industry jargon term for a type of Measure of Performance, here part of the Renault 2016 – Drive the Change strategic plan.

LCA: Life Cycle Assessment

LCI: Life Cycle Inventory

NEDC: New Europeen Driving Cycle (detailed in Appendix V.7)

POCP: Photochemical Ozone Creation Potential

Z.E.: “Zero Emission”: commercial denomination of Renault electric vehicles.

VII.3MATERIALS APPROXIMATION

Denomination found	Closest software denomination	Denomination found	Closest software denomination
Cotton+Wool	Cotton	PBT+PET	Polymer_mix
delta tone, delta seal	PA66_GF50	PBT-GF20	PBT_GF30
Fe/Cu 10 Ni 12 b Cr r	Steel_sheet	PC+PBT	PBT
Fe/Zn 10 c C	Steel_sheet	PE-EVA	Polymer_mix
Fe/Zn 5 B	Steel_sheet	PEhD-GF30	PEHD
Fe/Zn 8	Steel_sheet	PES/CO/PP	Polymer_mix
Fe/Zn 8 B	Steel_sheet	PET,PUR-GF8	Polymer_mix
Fe/Zn 8 C	Steel_sheet	PET+ASA-GF30	Polymer_mix
Glass fiber	Material_mix	Phosphate	PA66_GF50
GF/PE/PF	Polymer_mix	PP-(GF20+MD10)	PP_GF30
LCP (liquid crystal polymer)	Polymer_mix	PP/PES/PE	Polymer_mix
MgAI6Mn	Aluminium_sheet	PP+EPDM,M60	PP_T10_EPDM
P/E/PES/PP	PP_PE_PES	PP+EPDM-TD15	PP_T10_EPDM
P/E-MD15	P_E_M20	PPC	Polymer_mix
P/E-PET	Polymer_mix	PPE-GF10	PPE_GF
P/E-T5	PP_PE_T15	PP-GF30+MD20	PP_GF50
P/E-TD10	PP_PE_T15	PP-HC	PP
P/E-TD15+EPDM	P_E_M15_EPDM	PP-MD	PP_T20
P/E-TD20+TPE	PP_PE_T20	PP-MD20	PP_T20
PA11	PA12	PP-MD20-SEBS	PP_SEBS
PA6-(GF10+GB20)	PA6_GF30	PP-PET	Polymer_mix
PA6-(GF-EPDM10)	PA6_GF15_EPDM	PP-TD-EPDM	PP_T10_EPDM
PA6-(T25-GF15)	PA6_M30	PUR,PS-E,PP-GF	Polymer_mix
PA66-(TD20+GF10)	PA66_T25	PUR/MDS/TDI	Polymer_mix
PA66/6	PA66	PUR-E	PUR_foam
PA66/POM	PA6_POM	PUR-PET-GF	Polymer_mix
PA66/SI	PA66_T25	PUR-RIM-GLYKOL	Polymer_mix
PA66+60%GF	PA66_GF50	PUR-WS/MDI	PUR
PA66+PA6-GF50	PA66_GF50	PUR-WS/TDI	PUR
PA66+VMQ	PA66	PUR-WS/TDI/MDI	Polymer_mix
PA66-GF15-MX10	PA66_GF35	PUR-WS-TDI	Polymer_mix
PA66-GF20	PA66_GF20	PVB	Glass
PA66-GF45	PA66_GF43	SMA	Elastomer_mix
PA66-MD15	PA66_T25	TE(PP+EPDM)	PP_PE_EPDM
PA6-GF10	PA6_GF15	TEP	Polymer_mix
PA6-GF15-MF25	PA6_M30	TISSU	PET50_Cotton35_Wool15
PA6-SI	PA6_M30	TPE-PP, EPDM	PP_PE_EPDM
PA-MD40	PA6_M30	TPS-SEBS	Polymer_mix
PA-PES-PP-PVC-PE	Polymer_mix	UP-(MD60+GF13)	UP_GF28
PBT+ASA-GF30	ASA_PBT_GF30	Tempered glass	Glass
PBT+PC	PBT	Zamak	Zinc

Table 45 : List des materials approximations made for vehicle's modeling

Polymer_mix: sample of polymers most present in a car
Elastomer_mix: sample of elastomers most present in a car
Material_mix: sample of materials most present in a car

VII.4ENGINES COMPOSITIONS

Materials	Mass (Kg)		
	5AGen1 (electric)	1.6l 16v (petrol)	1.5l dCi (diesel)
Steel	45.99	99.62	103.26
Stainless steel	1.86	3.30	3.42
Aluminum	33.56	24.60	25.47
Copper	15.85	0.64	0.66
Electronic components	3.76	0	0
Elastomers mix*	0.61	1.56	1.61
EPDM	1.83	0.02	0.01
Materials mix*	3.02	7.26	7.88
PA6_GF30	0.87	0.30	0.31
PA6_GF50	0	0.03	0
PA66	2.09	1.75	1.79
PBT	0.38	0.03	0.03
PBT_GF30	0.84	0.25	0.26
PET	0.054	0.0007	0.0007
Polymers mix*	2.64	1.51	1.53
PP	0.003	0.02	0.02
PP_GF30	0.001	0.69	0.71
PP_T20	0	0.15	0.15
PUR	0.38	0	0
Renewable materials mix*	0	0.24	0.24
Total	**113.76**	**142**	**147.4**

Table 46: Petrol, diesel engines and electric motors compositions

* Most representative of a car average composition

NB: Electric motor composition includes:

- Electric motor
- Reducer
- Charger
- Converter
- Inverter
- Power cables

VII.5DATA FROM RENAULT FACTORIES ENVIRONMENTAL DASHBOARDS

Incoming	Outgoing	Bursa	Unit
	Oxygen biologic demand (aquatic)	13	t/an
	CO_2	97580	tCO_2eq
	Oxygen chemical demand	35.6	t/an
	Standard waste	86554	t
	Special waste	1797	t
	Metox*	1.93	t/an
	Methane	1970	kg
	N_2O	1236	kg
	NOx	22261	kg
Electric energy (360V)		131770	MWh PCI
	SO_2	258	kg
Thermal energy (natural gas)		137390	MWh PCI
	VOC	1134	t
Industrial water		408185	m3
Demineralized water		103340	m3

Table 47: Consumptions and emissions of Bursa factory for one year

* Metox= (mercury and cadmium quantity) x 50 + (arsenic and lead quantity) x 10 + (nickel and copper quantity) x 5 + chrome and zinc quantity
We consider this number as equal to the quantity of heavy metals emitted by the factory.

VII.6WATER CONSUMPTION, ENVIRONMENTAL REPORTING

Water sourcing	Consumption (m3)
Industrial Water	304297
Drink water	78022
Ground water	25866
Demineralized water	103340
Total	**511 525**

Table 48: Water consumptions from Bursa environmental report for year 2010.

VII.7NEW EUROPEAN DRIVING CYCLE (NEDC)

NEDC is a driving cycle (i.e. a series of data representing speed function of time) constituted of four repeated urban driving cycles (ECE-15 driving cycle), and one extra-urban driving cycle (EUDC). It approaches the representation of a vehicle's use in Europe and is part of the evaluation of vehicle's consumptions and emissions for homologation.

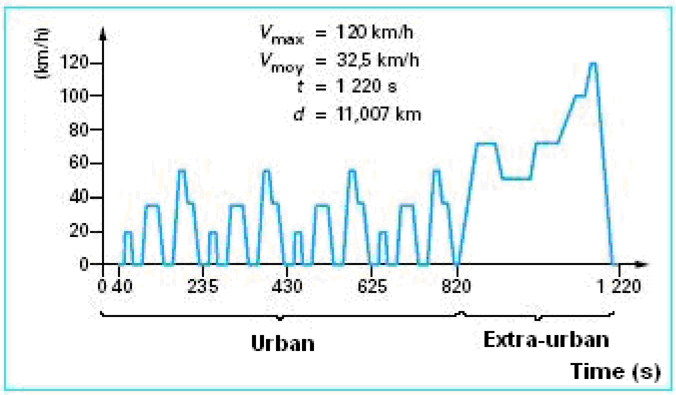


Figure 51: NEDC driving cycle, performed on a chassis dynamometer according to directive 98/69 EC

VII.8 EUROPEAN POWER GRID MIXES, FUEL DATA AND SALES PREDICTIONS

1kWh	CH: Power grid mix	FR: Power grid mix	EU-27: Power grid mix	DE: Power grid mix	IT: Power grid mix	DK: Power grid mix
CML2001 - Dec. 07, Abiotic Depletion (ADP) [kg Sb-Equiv.]	7.94E-04	5.85E-04	2.62E-03	3.04E-03	3.43E-03	2.53E-03
CML2001 - Dec. 07, Acidification Potential (AP) [kg SO2-Equiv.]	3.49E-04	3.57E-04	1.98E-03	1.06E-03	1.29E-03	1.02E-03
CML2001 - Dec. 07, Eutrophication Potential (EP) [kg Phosphate-Equiv.]	3.12E-05	3.14E-05	1.09E-04	9.81E-05	8.36E-05	1.22E-04
CML2001 - Dec. 07, Global Warming Potential (GWP 100 years) [kg CO2-Equiv.]	0.169	0.108	0.485	0.621	0.548	0.510
CML2001 - Dec. 07, Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	2.51E-05	2.47E-05	1.24E-04	7.54E-05	1.05E-04	6.92E-05

1kWh	ES: Power grid mix	GB: Power grid mix	EU: Power from wind power	1kg	Diesel EU-27	Gasoline (premium) EU-27
CML2001 - Dec. 07, Abiotic Depletion (ADP) [kg Sb-Equiv.]	2.70E-03	3.52E-03	3.24E-05	ADP	2.44E-02	2.48E-02
CML2001 - Dec. 07, Acidification Potential (AP) [kg SO2-Equiv.]	2.07E-03	2.11E-03	2.56E-05	AP	2.78E-03	4.14E-03
CML2001 - Dec. 07, Eutrophication Potential (EP) [kg Phosphate-Equiv.]	1.14E-04	1.75E-04	2.34E-06	EP	1.55E-04	2.23E-04
CML2001 - Dec. 07, Global Warming Potential (GWP 100 years) [kg CO2-Equiv.]	0.445	0.585	0.0066	GWP	0.430	0.728
CML2001 - Dec. 07, Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	1.57E-04	1.13E-04	3.86E-06	POCP	4.33E-04	6.30E-04

Table 49: European power grid mixes and fuel data from PE-GaBi database.

Country	Percentage
France	46.0%
Spain	15.9%
Denmark	6.4%
Portugal	4.4%
Germany	4.3%
UK	4.3%
Austria	4.1%
Switzerland	4.1%
Belgium and Luxembourg	4.1%
Netherlands	3.9%
Italy	2.5%

Table 50: Fluence Z.E. 2012 sales predictions (European perimeter).

VII.9EUROPEAN EMISSIONS REGULATIONS & ARTEMIS DATABASE

In mg/km

Diesel

REGULATION	EURO 1	EURO2	EURO3	EURO4	EURO5	EURO6
Nitrous Oxides (NOx)	-	-	500	250	180	80
Carbon monoxide (CO)	2720	1000	640	500	500	500
Hydrocarbons (HC)	-	-	-	-	-	
HC+NOx	970	900	560	300	230	170
Particulates (PM)	140	100	50	25	5	5

Table 51: European emission standards for diesel engines

Petrol, LPG and NG

REGULATION	EURO 1	EURO2	EURO3	EURO4	EURO5	EURO6
Nitrous Oxides (NOx)	-	-	150	80	60	60
Carbon monoxide (CO)	2720	2200	2200	1000	1000	1000
Hydrocarbons (HC)	-	-	200	100	100	100
Particulates (PM)	140	100	50	25	5	5
Non-methanous hydrocarbons	-	-	-	-	68	68

Table 52: European emission standards for petrol, LPG and NG engines

REMARK: For EV, as it is a zero emission from engine's operation, it fits all EURO regulations.

The Artemis project "Assessment and reliability of transport emission models and inventory systems" proposes to combine the experience from different emission calculation models and ongoing research in order to arrive at a harmonised methodology for emission estimates at the national and international level.

This requires first of all additional basic research and a better understanding of the causes of the differences mainly with respect to emission factors.

References:

- André M. (2004): Real-world driving cycles for measuring cars pollutant emissions - Part A : The Artemis European driving cycles (pdf file, 4.3 Mo). Inrets report, Bron, France, n°LTE 0411, 97 p.
- André M. (2006): Real-world driving cycles for measuring cars pollutant emissions - Part B : Driving cycles according to vehicle power (pdf file, 2.3 Mo). INRETS report, Bron, France, n°LTE 0412, 74 p.

This model allows a better evaluation of real life emissions based on the data bellow.

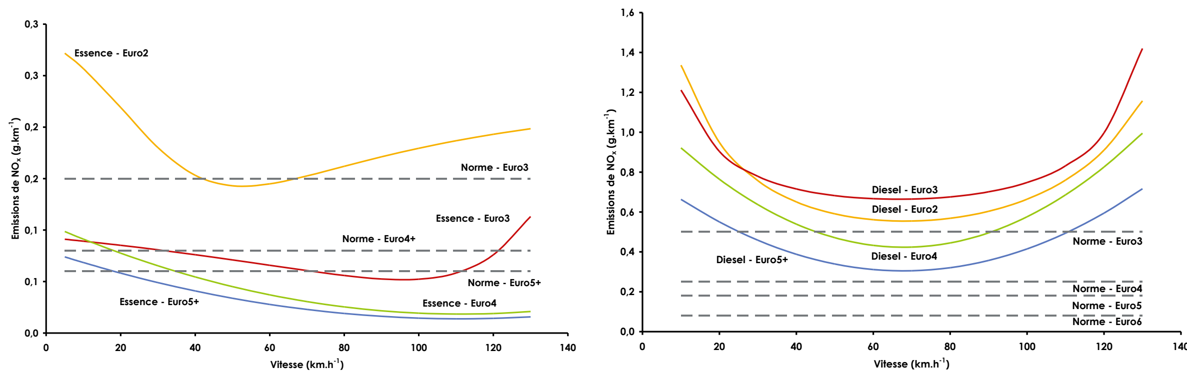


Figure 52: Comparison of Euro norms (lines) and Artemis (curves) emissions related to vehicle speed for gasoline on the left and diesel on the right

Based on these datas, gasoline appears to have lower emissions than the norm while diesel ones are higher. This will of course increase significantly the impact on acidification potential of diesel vehicles versus gasoline and even more versus electric ones. Nevertheless, the authors could not compare with the same studies for electricity production and therefore, it is recommended not to conclude on the superiority of one vehicle technology without further investigation.

VII.10 DATABASE DOCUMENTATION

Exemple: Polypropylene, 2005, DE, PE-ELCD, http://database-documentation.gabi-software.com/index.php?id=6699

GaBi Software
A Software Solution by PE INTERNATIONAL

PE INTERNATIONAL
EXPERTS IN SUSTAINABILITY

Process data set: Polypropylene granulate (PP); technology mix; production mix, at producer; (en)

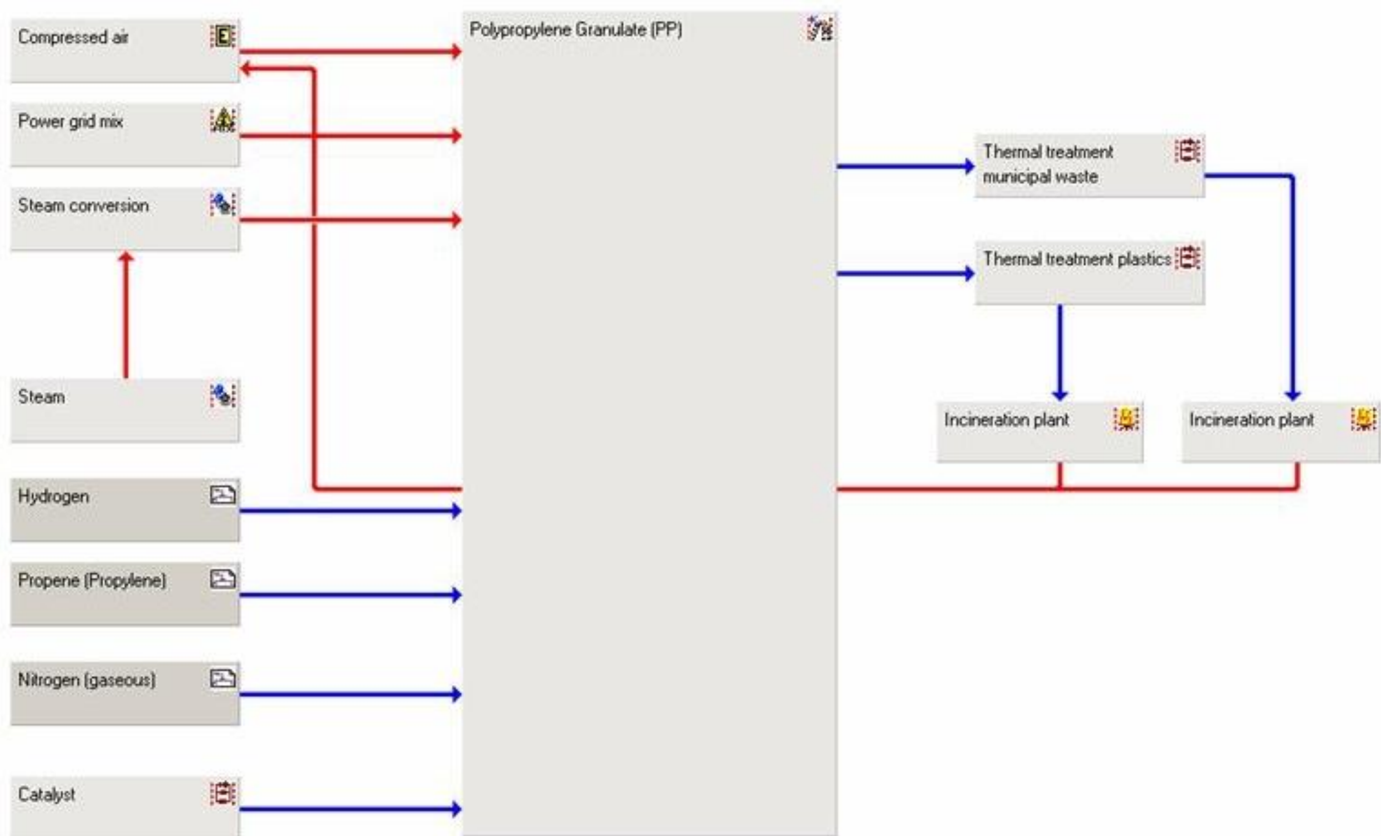
Table of Contents: Process information - Modelling and validation - Administrative information - Inputs and Outputs

Process information

Key Data Set Information

Location	DE
Geographical representativeness description	The data set represents the country / region specific situation, focusing on the main technologies, the region specific characteristics and / or import statistics.
Reference year	2005
Name	Base name; Treatment, standards, routes; Mix and location types Polypropylene granulate (PP); technology mix; production mix, at producer
Use advice for data set	The data set represents a cradle to gate inventory. It can be used to characterise the supply chain situation of the respective commodity in a representative manner. Combination with individual unit processes using this commodity enables the generation of user-specific (product) LCAs.
Technical purpose of product or process	Provision of a standard technical product according to the applied technology.
Classification (http://gabi-dataset-documentation.gabi-software.com/xml_data/GaBiCategories.xml)	Class name / Hierarchy level / Hierarchy level Production / Material production / Plastic production
General comment on data set	The data set covers all relevant process steps / technologies over the supply chain of the represented cradle to gate inventory with a good overall data quality. The inventory is mainly based on industry data and is completed, where necessary, by secondary data.

	Copyright? Yes Owner of data set (contact data set) PE INTERNATIONAL
Quantitative reference	
Reference flow(s)	Polypropylene granulate (PP) - 1 kg (Mass)
Time representativeness	
Data set valid until:	2012
Time representativeness description	Annual average
Geographical representativeness	
Technological representativeness	
Technology description including background system	The basis for the production of polypropylene is crude oil. Polypropylene is polymerised from propene (propylene), which is extracted by cracking naphtha or gas oil in a steam-cracker. PP is produced in a low-pressure process. For polypropylene many different polymerisation processes exist, such as solution polymerisation, bulk polymerisation in liquid propene (propylene), and several gas-phase processes. Here a 50:50 combination by weight of two gas phase processes, the gas phase process in a fluidised bed reactor and a gas phase process in a vertical reactor because of their industrial importance is regarded. The gaseous propene (propylene) enters the reactor through a distributor plate which provides an even distribution of gas and must also prevent powder falling through when the gas flow is stopped. The fluidised bed functions more or less as a continuous stirred-tank reactor in which mass transfer provides back mixing of material and heat throughout the reactor. There is an up-flow at the centre and down-flow at the walls. The conversion per pass is approx. 2 % for PP. The background system is addressed as follows: Electricity, Thermal energy: The electricity (and thermal energy as by-product) used is modelled according to the individual country-specific situation. The country-specific modelling is achieved on multiple levels. Firstly the individual power plants in service are modelled according to the current national grid. This includes net losses and imported electricity. Second, the national emission and efficiency standards of the power plants are modelled. Third, the country-specific fuel supply (share of resources used, by import and / or domestic supply) including the country-specific properties (e.g. element and energy contents) are accounted for. Fourth, the import, transport, mining and exploration processes for the energy carrier supply chain are modelled according to the specific situation of each power-producing country. The different mining and exploration techniques (emissions and efficiencies) in the different exploration countries are accounted for according to current engineering knowledge and information. Steam: The steam supply is modelled according to the individual country-specific situation with regard to the technology efficiencies and energy carriers used. Efficiencies range from 84% to 94% in relation to the representative energy carrier (gas, oil, coal). Coal, crude oil and natural gas used for the generation of steam are modelled according to the specific import situation (see electricity). Transports: All relevant and known transport processes used are included. Overseas transport including rail and truck transport to and from major ports for imported bulk resources are included. Furthermore all relevant and known pipeline and / or tanker transport of gases and oil imports are included. Energy carriers: Coal, crude oil, natural gas and uranium are modelled according to the specific import situation (see electricity). Refinery products: Diesel, gasoline, technical gases, fuel oils, basic oils and residues such as bitumen are modelled via a country-specific, refinery parameterized model. The refinery model represents the current national standard in refinery techniques (e.g. emission level, internal energy consumption,...) as well as the individual country-specific product output spectrum, which can be quite different from country to country. Hence the refinery products used show the individual country-specific use of resources. The supply of crude oil is modelled, again, according to the country-specific crude oil

	situation with the respective properties of the resources.
Included data sets (process data set)	Power grid mix
	Process steam from natural gas
	Propene (propylene)
	Hydrogen
	Nitrogen
Flow diagramm(s) or picture(s) (source data set)	Polypropylene Granulate (PP) 

Modelling and validation	
LCI method and allocation	
Type of data set	*LCI result*
LCI method principle	*Attributional*
Deviation from LCI method principle / explanations	None
LCI method approaches	*Allocation - exergetic content*
	Allocation - net calorific value
	Allocation - market value
Deviations from LCI method approaches / explanations	For details please see the document "GaBi Databases Modelling Principles"
Modelling constants	All data used in the calculation of the LCI results refer to net calorific value.
Deviation from modelling constants / explanations	None
LCA methodology report (source data set)	GaBi Modelling Principles
Data sources, treatment, and representativeness	
Data cut-off and completeness principles	Cut-off rules for each unit process: Coverage of at least 95 % of mass and energy of the input and output flows, and 98 % of their environmental relevance (according to expert judgement). For further details please see the document "GaBi Databases Modelling Principles"
Deviation from data cut-off and completeness principles / explanations	None
Data selection and combination principles	For details please see the document "GaBi Databases Modelling Principles"
Deviation from data selection and combination principles / explanations	None
Data treatment and	For details please see the document "GaBi Databases Modelling Principles"

extrapolations principles	
Deviation from data treatment and extrapolations principles / explanations	None
Data source(s) used for this data set (source data set)	Industrial Inorganic Chemistry, 2000
	Industrial Organic Chemistry, 2003
	CD Römpp Chemie Lexikon, 1995
	Ullmann's Encyclopedia of Industrial Chemistry, 2006
	Die Kunststoffe und ihre Eigenschaften, 2005
	Saechtling Kunststofftaschenbuch, 2004
	Chemische Prozesskunde, 1996
	Handbook of Petrochemicals Production Processes, 2005
	Handbook of Petrochemicals and Processes, 1999
	Best Available Techniques in the Production of Polymers, 2006
	Ressourcenschonende Herstellung von Polymerwerkstoffen am Beispiel Polyolefine, 2000
	Kunststoffkunde, 2000
Percentage supply or production covered	100.0 %
Completeness	
Completeness product model	*All relevant flows quantified*
Validation	
Review	*Dependent internal review*

Scope of review	Method(s) of review
Raw data	*Validation of data sources*
	Sample tests on calculations
	Cross-check with other source
	Expert judgement

	Unit process(es), single operation	*Validation of data sources*
		Sample tests on calculations
		Energy balance
		Element balance
		Cross-check with other source
		Expert judgement
		Mass balance
	LCI results or Partly terminated system	*Validation of data sources*
		Sample tests on calculations
		Energy balance
		Element balance
		Cross-check with other source
		Expert judgement
		Mass balance
	LCIA results	*Cross-check with other source*
		Expert judgement
	LCIA results calculation	
Review details	The LCI method applied is in compliance with ISO 14040 and 14044. The documentation includes all relevant information in view of the data quality and scope of the application of the respective LCI result / data set. The dataset represents the state-of-the-art in view of the referenced functional unit.	
Reviewer name and institution (contact data set)	PE INTERNATIONAL	
	LBP-GaBi	

Compliance declarations

Compliance	Compliance system name (source data set)	Approval of overall compliance	Nomenclature complianceNomenclature compliance	Methodological complianceMethodological compliance	Review complianceReview compliance	Documentation complianceDocumentation compliance	Quality complianceQuality compliance
	ILCD compliance 1.1 draft	*Not defined*	*Not defined*	*Not defined*	*Not defined*	*Not defined*	*Not defined*

Administrative information	
Commissioner and goal	
Commissioner of data set (contact data set)	PE INTERNATIONAL
Intended applications	The data set represents a cradle to gate inventory. It can be used to characterise the supply chain situation of the respective commodity in a representative manner. Combination with individual unit processes using this commodity enables the generation of user-specific (product) LCAs. The data set does not necessarily fit for any possible specific supply situation - especially if significantly different technology routes exist - but is representative for a common supply chain situation.
Data set generator / modeller	
Data set generator / modellerData set generator / modeller (contact data set)	PE INTERNATIONAL
	LBP-GaBi
Data entry by	
Time stamp (last saved)	2010-07-31 00:00:00 +01:00
Data set format(s) (source data set)	ILCD format 1.1
Data entry by: (contact data set)	LBP-GaBi
Official approval of data set by producer/operator: (contact data set)	No official approval by producer or operator
Publication and ownership	
UUID of Process data set	c8e9efd5-fd8f-4da2-89ed-5a78e7ba6e42
Date of last revisionDate of last revision	2010-07-31T00:00:00+01:00
Data set version	02.00.000
Workflow and publication status	*Data set finalised; entirely published*
Unchanged re-publication of: (source data set)	GaBi databases 2006

Owner of data set (contact data set)	PE INTERNATIONAL
License type	*Other*
Access and use restrictions	GaBi (source code, database including extension modules and single data sets, documentation) remains property of PE International GmbH. PE International GmbH delivers GaBi licenses comprising data storage medium and manual as ordered by the customer. The license guarantees the right of use for one installation of GaBi. Further installations using the same license are not permitted. Additional licenses are only valid if the licensee holds at least one main license. Licenses are not transferable and must only be used within the licensee's organisation. Data sets may be copied for internal use only. The number of copies is restricted to the number of licenses of the software system GaBi the licensee owns. Data sets may not be published without written permission of PE International GmbH. Similarly, transferring data sets for any purpose is not allowed without written permission. The transfer of single data sets as well as their distribution or disposition is only allowed with the previous written permission of PE International GmbH. The right of use is exclusively valid for the licensee. All rights reserved. Users may not publish individual data sets. Only aggregated or calculated results produced using GaBi data may be published. In any published materials, GaBi 4 must be acknowledged when its data or software has been used, e.g.: #GaBi Databases 2006#

Inputs and Outputs

For intellectual property rights reasons the inputs and outputs have been removed from this documentation

Inputs

Type Of Flow	Classification	Flow	Resulting amount	Mean amount	Relative StdDev in %	Data source type	Data derivation type / status

Outputs

Type Of Flow	Classification	Flow	Resulting amount	Mean amount	Relative StdDev in %	Data source type	Data derivation type / status
Product flow		Polypropylene granulate (PP)	1 kg (Mass)	1	0.000 %	*Mixed primary / secondary*	*Unknown derivation*