ZOE
LIFE CYCLE ASSESSMENT
2012

[avnir] Plateforme pour l'Analyse du Cycle de Vie

DRIVE THE CHANGE

RENAULT

SUMMARY

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I

INTRODUCTION CONTEXT

I INTRODUCTION/CONTEXT

The aim of this report is to present the framework in which the Life Cycle Assessment of the Renault ZOE is conducted. The results of the life cycle assessment presented in this report.

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

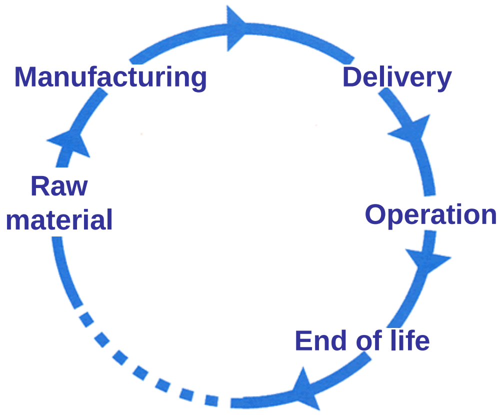

Figure 1 : Life Cycle of a product

The study respects the ISO 14040 and 14044 standards [ISO 2006], and the following framework (fig.2).

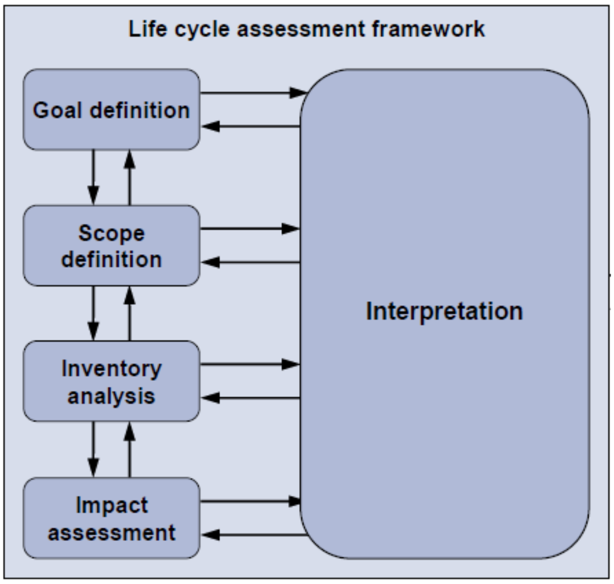

Figure 2 : Schematic table of LCA steps [EC 2010a]

Context: Why, who?

Goal and scope definition: Scope of the study and its context (temporal, geographic and technological)

Inventory analysis: Identify and quantify the system's incoming and outgoing flows. Identify 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

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II.1 GOAL OF THE STUDY

II.1.1 RENAULT GROUP ENVIRONMENTAL COMMITMENT

Since 1995, Renault has developed 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, by taking into account the local ecosystem in one hand and a global level on the other hand, while considering both economic 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's chain and end-of-life treatment of 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 are efficient opportunities to introduce a life-cycle approach to our customers.

In 2011, Renault confirmed its life cycle commitment by setting 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 nowadays 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 goal of the study is precisely detailed 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 opportunities, from defining the group's strategy to some dialogues with stakeholders.

First of all we would like to complete our range of LCA studies in order to be able to integrate electric vehicles in Renault group KPI. It means all efforts and investments in electric cars will contribute to reduce our worldwide average product carbon footprint.

Renault is engaged to reduce by 10% between 2010 and 2013 and 10% more between 2013 and 2016 the average carbon footprint.

Then this study will complete the 2011 Renault Fluence LCA to validate unit processes and Life Cycle Inventory data for their use in our calculation model.

- 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.

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

II.1.3 LIMITATIONS

This report will present LCA results for one electric vehicle. The reader shall keep in mind that electric mobility comes with a brand new technology (new batteries, electric engine, power electronics, etc). Therefore, environmental progresses are expected in a short term thanks to key process improvement and mass production (recycling processes, share of recycled materials...).

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 product as it will be launched in 2012 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 questions occurred while reintegrating this battery LCA in the overall product model. Nevertheless, a tremendous work has been done on this topic and the study consistency has been verified and ensured.

Concerning the use of the product, we consider that all vehicles are operational during the same lifetime and distance.

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. 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 provide the environmental burdens of a newly launched electric vehicle, ZOE, bringing a new technology for mobility.

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 modeled by representing attributionally the existing supply-chain. Primary physical data will be collected and associated to generic processes, which represent the average market consumption mix. Except for 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 first of all dedicated to Renault internal audience. It will be a reference for the Renault management to define future environmental objectives for Renault products 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 reach the highest level of competence

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.

In order to fully comply with the ISO 14 040 norms related to Life Cycle Assessment and to validate the conclusions, an expert in environment and life cycle assessment reviews each report. So they can be used for further application like external communication and marketing.

II.1.6 VIGILANCE FOR PUBLIC DISCLOSURE

The study is planned to be disclosed to the public. It also includes a final comparative assertion to the 2010 Renault average vehicle, a fictive vehicle none gasoline, diesel or electric. In this context, we recommend, as stated in the limitations, not comparing Renault cars with any other car manufacturer based on different LCA studies, without a detailed knowledge and a critical review of both studies.

II.1.7 COMMISSIONER OF THE STUDY AND OTHER INFLUENTIAL ACTORS

LCA actors:
Commissioners: RENAULT SAS., JP. HERMINE, S. MOREL, J.BEAULIEU.
Practitioners: A. BARAT, V. DANG, S. MOREL, N. ADIBI
Critical Review: Ph. OSSET

II.2 SCOPE DEFINITION

This report details and analyses the environmental footprint of ZOE in several countries.

The results are measured based on the ISO 14040:2006 and 14044:2006 norms. The detailed perimeter of the study and data collection are presented below.

II.2.1 PRODUCT'S DEFINITION : RENAULT ZOE

GENERAL DESCRIPTION	
Constructor	Renault
Denomination	ZOE
Production start	November 2012
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 hatchback, 5 seats

DIMENSIONS	
Length	4084mm
Width	1740mm
Height	1568mm
Unladen mass	1470kg

MECHANICAL SPECIFICATION	
TECHNOLOGY	**Electric**
Engine (fig. 3).	2460 cm3 (60 kW)
Gearbox	Automatic, no-gear
Max speed	135 km/h (84mph)
Emission standard for type approval (70/220/CEE)	EURO V
Consumption (NEDC)	140 Wh/km
Drivetrain battery energy content	22kWh

EQUIPEMENT	
Level	Life
Particle filter (FAP)	-
EGR	-
Air conditioning	Yes
Rims	Steel
Low consummation tires	Yes
Opening roof / panoramic	No / no

Table 1: Specifications of ZOE

<u>REMARK:</u> This product definition does not include any driving performance like 0-100 km/h as it is not a homologation data
<u>REMARK:</u> The volume of the electric motor refers to the rotor's volume

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]

<u>Functional unit</u>

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

<u>Reference flow</u>

The reference flow is defined by the vehicle itself, Renault Zoé, sold by Renault, a 4-doors hatchback 5-seats vehicle.

II.2.3 SYSTEM'S BOUNDARIES

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 Production

For detailed information about the standard hypothesis on the vehicle's production and the Renault production capacities, please refer to the methodology report.

II.2.3.1.1 <u>Lithium-ion battery materials production</u>

Concerning ZOE, the drivetrain battery core elements are produced by LG in South Korea. The final battery pack is assembled in a specific assembly line in the Flins factory (France).

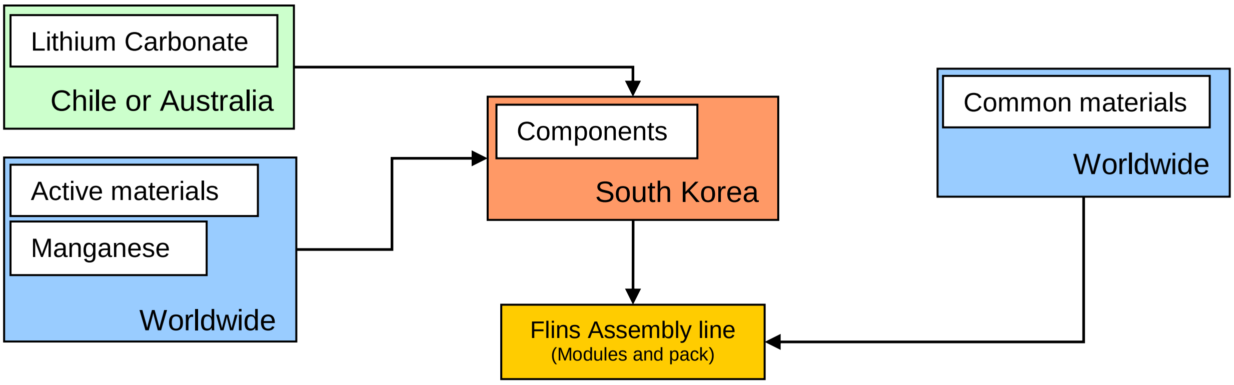


Figure 3: Drivetrain battery production's process tree

II.2.3.1.2 Renault's assembly lines

The following table details the localization of main factories taking part in ZOE's production

Factory	Localization
Engine factory	Cleon (FR)
Gearbox factory (reducer)	Cleon (FR)
Battery final assembly	Flins (FR)
Assembly factory	Flins (FR)

Table 2: Localization of factories taking part in ZOE's production

II.2.3.2 Electricity production

For power supply in the use phase, power grid mixes based on PE-GaBi dataset will be considered. As the product is sold in several countries, the average power grid mix will be determined by a weighting of each country power grid mix based on predicted sales volumes for the chosen year. Nevertheless, this is not sufficient and this value will be challenged by a minimum of three specific electricity mixes: France (the most sold country), the globally less efficient grid mix available in our database and the best one, where the vehicle is also sold.

Data used is PE-Gabi country power grid mix from in GaBi 5.0. (2008 database)

II.2.3.3 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.

ZOE fully answers to this directive. For more information about the treatment of a vehicle at its end of life, please refer II.2.2.8 in the methodology report.

II.2.3.4 Li-ion battery End of life

Renault made the choice to offer the customer to rent its battery to keep the electric vehicle affordable for all. The onboard battery is guaranteed for a standard level of performance that must exceed 75% of its onboard energy. When this level is reached, the battery enters a second life cycle where it can offer new application like domestic or industrial energy storage for example.

If the battery's performance cannot answer this second life use, the battery enters an end-of-life procedure, detailed in the methodology report.

II.2.3.5 System context

II.2.3.5.1 <u>Temporal context</u>

Zoe is launched on November 2012. The first year of production is 2013. We will base our study on 2013 sales predictions and on this temporal context.

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 2023 to prevent lack of data or knowledge about waste treatment or recovery.

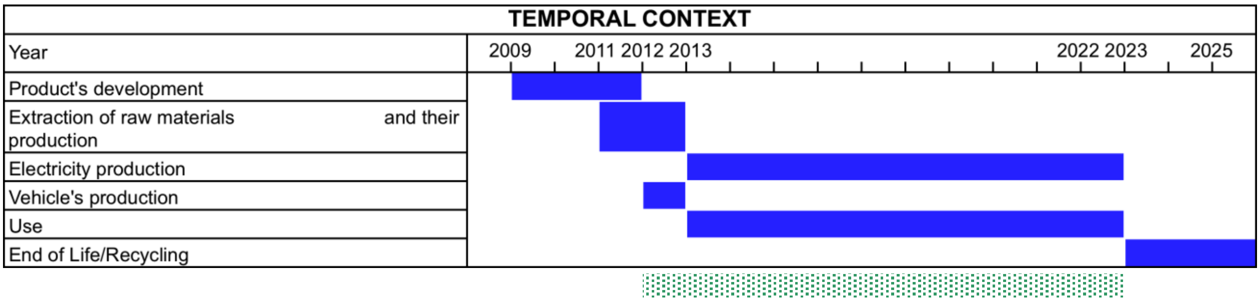
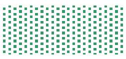


Table 3: Temporal context of the system



Waste elimination phase starts at production of materials needed to build the car. It starts at waste production and the associated need of treatment.

II.2.3.5.2 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: Flins (FR) Electric: Cleon (FR) Parts (equipment) : Europe Battery : Active materials : Worldwide Electrolyte : South Korea Final assembly : Flins	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 4: Geographic and technologic context of the system (electric vehicle)

III

LIFE CYCLE INVENTORY ANALYSIS

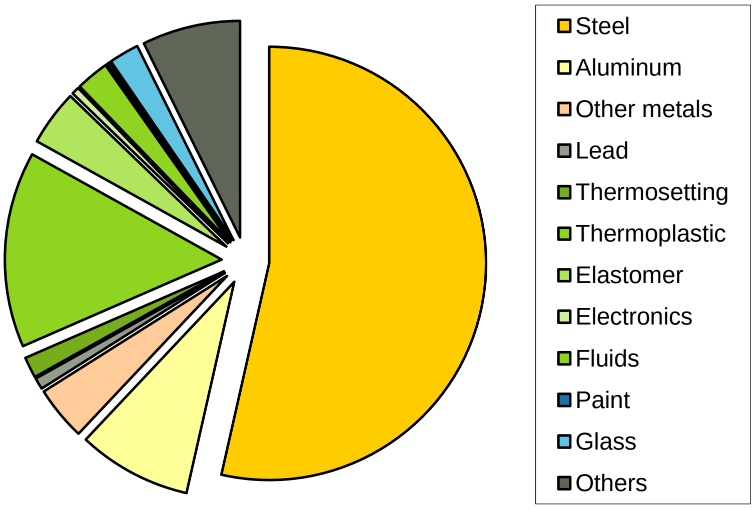
III LIFE CYCLE INVENTORY ANALYSIS

III.1 VEHICLE'S DESCRIPTION AND COMPOSITION

Our study focuses on electric technology on ZOE, which is 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.

For data collection procedure and vehicle's composition pattern, please refer to the methodology report.

Figure 7 gives material composition of ZOE.



Material	Mass (Kg)	%
Steel	786.8	53.5%
Aluminum	124.5	8.5%
Other metals	59.1	4.0%
Lead	12.6	0.9%
Thermosetting	23.0	1.6%
Thermoplastic	214.9	14.6%
Elastomer	60.9	4.1%
Electronics	8.3	0.6%
Fluids	36.0	2.5%
Paint	3.1	0.2%
Glass	32.8	2.2%
Others	107.5	7.3%
TOTAL	1 469.60	100%

Figure 4: Material composition of ZOE

III.2 FACTORIES AND LOGISTIC

III.2.1 FACTORIES

Every plant participating in ZOE production (Cléon and Flins) is ISO14001 certified. They control consumptions and emissions to improve their environmental performances and gather them in Renault factories' environmental reports established each year on December 31. Please refer to the methodology report for more details about vehicle's production scope.

III.2.2 LOGISTICS

This LCA study gathers some data about inbound (from supplier to the factory) and outbound (from factory to customer) logistic.

To determinate average distance done by a ZOE 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 additional 130 or 230 km distance for capital to final customer transport, depending on the country's size.

The average distance calculated (from viamichelin.com and Google maps) is quite random. Sales predictions are for 2013. Then, we have following distances:

Model	Road mileage
ZOE	684 km

Table 5: Average mileage for assembly line to final customer travel

III.3 USE

III.3.1 USE: ELECTRICITY PRODUCTION

Data necessary to achieve this step are:
- Mileage done by the vehicle during its total use phase: 150 000 km (functional unit)
- Vehicle's consumption, available on the homologation certificate: 0.14 kWh/km for ZOE
- Electricity sourcing (country of use): The associated environmental flows (incoming or outgoing) are included in the software (automatic).

According to homologation procedures, consumption includes charging losses. After a full charge of the vehicle, it runs two NEDC cycles and then charged one more time. At this second charge, total energy consumption is measured and then divided per the total amount of kilometers traveled (2*11 km). For more information about the NEDC homologation driving cycle, please refer the methodology report appendix.

III.3.2 USE : CAR USE PHASE

Impacts of this phase are calculated from a 150 000 km mileage.

It requires collecting only electricity consumption and the number of batteries used during the whole life cycle.

- ZOE is zero emission in use and then respects Euro V regulation as well as the future Euro 6 one.

From its engine technology, an electric vehicle does not produce any tailpipe emissions like CO_2, NO_X, SO_2 or particles. Thus, the main emissions from an electric vehicle are particles from brakes and tires use, and also from simple travelling by unsticking particles on the road (pollen, tires debris, other vehicles' emitted particles …). Some further studies will be led to identify the contribution of this aspect towards the electric vehicle environmental footprint.

- Renault made the assumption to consider only one drivetrain battery for the whole life cycle. Without a global statistic of the durability and mileage of the batteries, it is difficult to state on the associated number of batteries necessary to reach 150 000 km. Moreover, Renault is also still working at their second life. From those hypotheses, Renault chose to keep only one battery in its study.

III.3.3 USE : MAINTENANCE

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

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

Table 6: Operation and frequency of maintenance operations

Some studies about car wash have been carried out. Impacts of the vehicle's wash will not be considered. Please refer the methodology report for more information.

III.3.4 USE: ELECTRIC CONSUMPTION AND REGENERATIVE BRAKING

Regarding electric vehicles, the consumption calculation is processed as following:

- 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.

It can be concluded that, this consumption value includes regenerative braking. ZOE brings several major innovations, specifically on regenerative braking. It does not operate at acceleration pedal release but at standard action at the brake pedal and operates with service braking. This deletes the unpleasant engine braking pitch consecutive to acceleration pedal release. From this regenerative braking technology, the additional autonomy can reach a 50 km value, which is a major issue for the customer

III.4 **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 from last database (software V5.0)
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 Flins
Gearbox composition	X					X			RENAULT – Mass ratio compared to another model
Gearbox production and assembly		X		X					RENAULT - EDB Flins
Body and equipment composition	X			X	X				RENAULT - Measure on reference model disassembly
Body production and assembly	X			X					RENAULT - EDB Flins
Body treatment and paint	X			X					RENAULT - EDB Flins + DICAP data
Equipment production	X					X			PE process database
Equipment assembly to body	X	X		X					RENAULT - EDB Flins
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 & version 5.0
1) 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 ZOE
Site specific data : concern data from sites included in ZOE'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 7: 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	
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
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 from last database (software V5.0)

Notes : PE stands for : PE International GMBH Life Cycle Engineering & LBP – GaBi, database & version 5.0)
Measures
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Table 8: Origin and specifications of data collected during analysis (following and end)

III.5 OVERVIEW OF ASSUMPTIONS AND DEFINITIONS FOR THE LCA

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 used in a new calculation model
- Carry a weak point analysis in order to pursue 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 150 000 km total distance (~93 000 miles), during 10 years, respecting M1 type approval norms (e.g. NEDC driving cycle)
- Reference flow:
Renault ZOE, sold by Renault, a 4-doors hatchback 5-seats vehicle.

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, abiotic depletion potential, photochemical ozone creation potential, global warming potential for a reference period of 100 years and acidification potential (please refer paragraph IV in the methodology report for the indicators choice) • Normalisation of the results to average impact per inhabitant values	
Software	
• Life Cycle Assessment software GaBi V5	
Evaluation	
• Evaluation of Life Cycle Inventory and impact assessment results, subdivided into life cycle phases and individual processes • Interpretation of results	

Table 9: Assumptions and definitions for the Life Cycle Assessment

IV

LIFE CYCLE IMPACT ASSESSMENT

IV LIFE CYCLE IMPACT ASSESSMENT

IV.1 IMPACTS ASSESSMENT

IV.1.1 REFERENCE CASE SCENARII RESULTS

Following figure presents repartition of selected impacts all along the life cycle, in EU geographic context and based on year 2013 sales predictions. Associated data is gathered in table 10. For more information about the indicators choice, please report the methodology report.

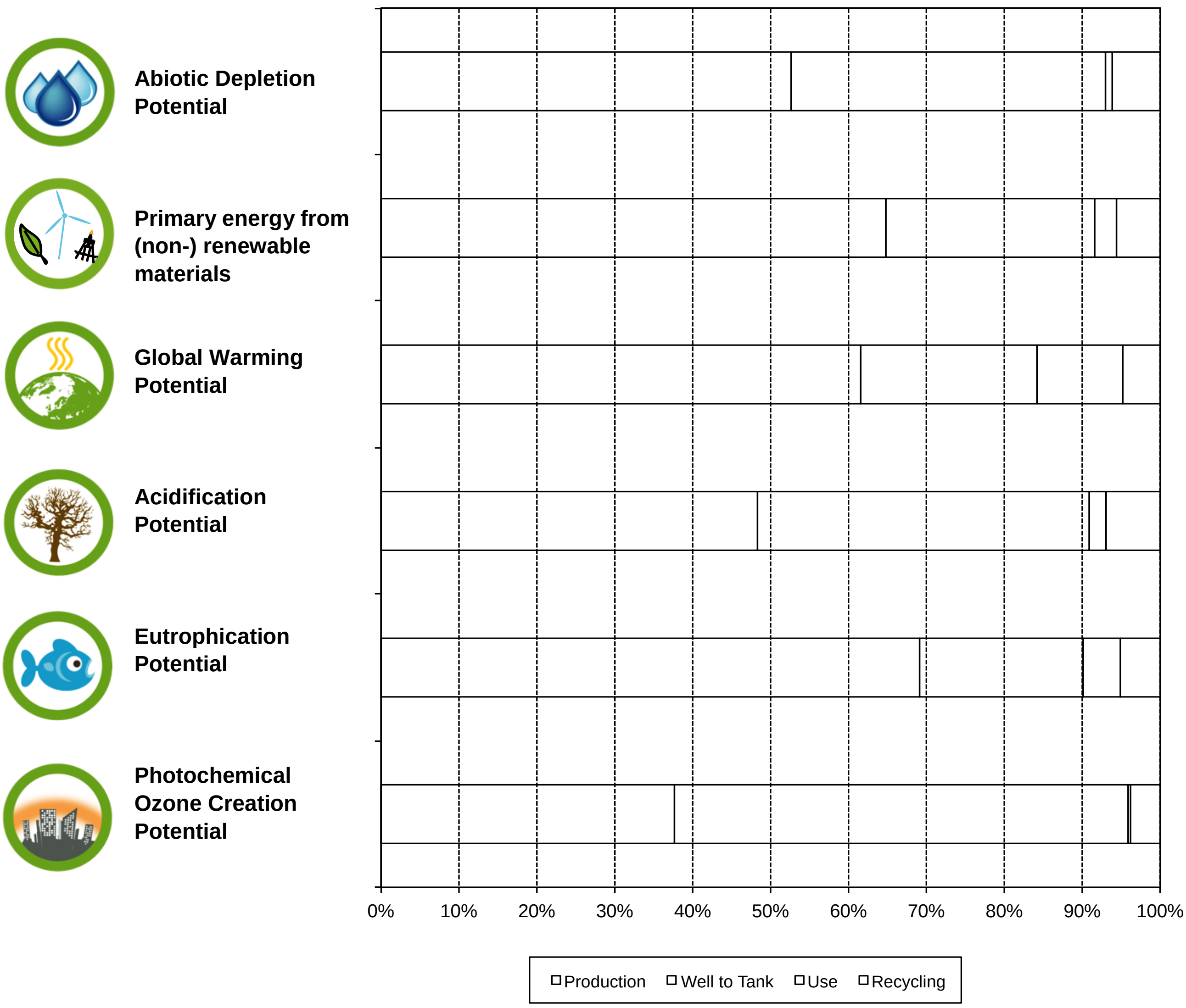


Figure 5: Environmental impacts of ZOE all along life cycle (EU geographic context for electricity production)

	ZOE	
	Quantity	**Part in life cycle (%)**
ADP : Abiotic depletion potential (kg Sb-eq)		
Vehicle production	50,0	52,6%
Well to Tank	38,3	40,3%
Use	0,83	0,9%
End of life	5,84	6,2%
PED : Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]		
Vehicle production	136744	37,7%
Well to Tank	211371	58,2%
Use	1152	0,3%
End of life	13787	3,8%
GWP : Global warming potential (kg CO2-eq)		
Vehicle production	7657	48,3%
Well to Tank	6744	42,6%
Use	342	2,2%
End of life	1102	7,0%
AP : Acidification potential (kg SO2-eq)		
Vehicle production	49,2	64,8%
Well to Tank	20,3	26,8%
Use	2,1	2,8%
End of life	4,3	5,6%
EP : Eutrophisation potential (kg PO4-eq)		
Vehicle production	4,56	61,6%
Well to Tank	1,67	22,6%
Use	0,82	11,0%
End of life	0,36	4,8%
POCP : Photochemical ozone creation potential (kg C2H4-eq)		
Vehicle production	4,48	69,1%
Well to Tank	1,36	21,0%
Use	0,31	4,8%
End of life	0,33	5,1%

Table 10: Comparison of environmental impacts all along life cycle of ZOE without considering credit from recycling

The table 11 presents the total results of the impact assessment over the whole life cycle.

	Renault Zoé
Abiotic depletion (kgSb-eq)	94.9
Primary Energy Demand (MJ)	363054
Global warming potential (kgCO_2-eq)	15845
Acidification (kgSO_2-eq)	75.9
Eutrophisation (kgPO_4-eq)	7.40
Photochemical ozone potential (kgC_2H_4-eq)	6.48

Table 11: Environmental impacts all along life cycle of ZOE without considering credit from recycling

From these results, Renault shows that the possible benefits from recycling are not inconsequential. 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.

Following figure presents repartition of selected impacts all along the life cycle depending on the geographic context (for a clean power grid mix (France) and a less efficient one (Great Britain)), still in a European geographic context. Associated data is gathered in the following table. The differences come from the kind of sourcing for electricity production (nuclear, fossil or renewable)

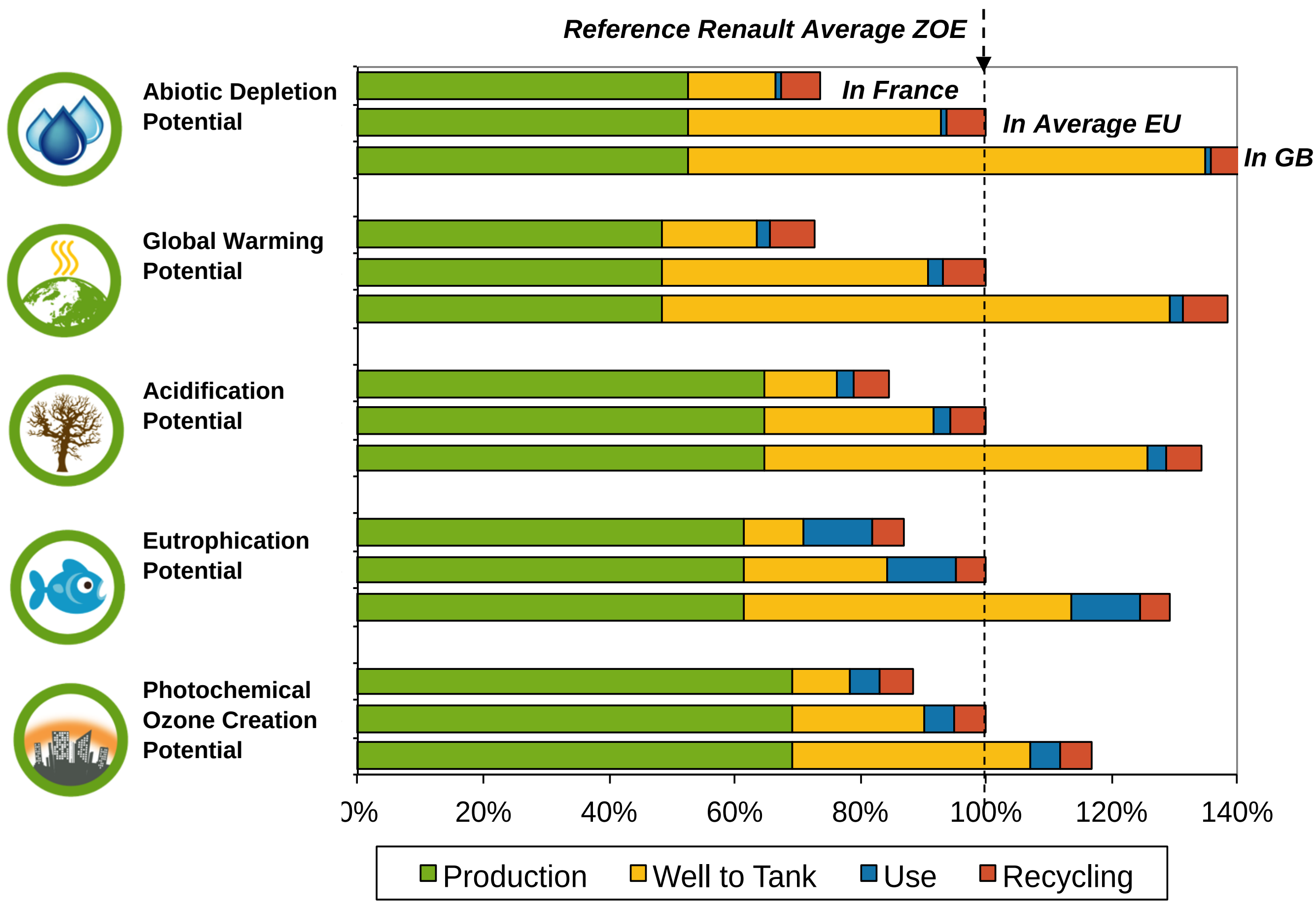


Figure 6: Environmental impacts of ZOE all along life cycle for different geographic contexts: France, Average Europe based on sales predictions, and Great Britain.

Variations on electricity production	EU-->FR	EU --> GB
Abiotic depletion (kgSb-eq)	-65%	+104%
Global warming potential ($kgCO_2$-eq)	-64%	+90%
Acidification ($kgSO_2$-eq)	-57%	+128%
Eutrophisation ($kgPO_4$-eq)	-58%	+130%
Photochemical ozone potential (kgC_2H_4-eq)	-56%	+81%

Impact on the global life cycle	EU-->FR	EU --> GB
Abiotic depletion (kgSb-eq)	-26%	+42%
Global warming potential ($kgCO_2$-eq)	-27%	+38%
Acidification ($kgSO_2$-eq)	-15%	+34%
Eutrophisation ($kgPO_4$-eq)	-13%	+29%
Photochemical ozone potential (kgC_2H_4-eq)	-12%	+17%

Table 12: 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. The use of renewable energies and nuclear one increase environment benefits of the electric vehicle. [EC 2009]

IV.1.2 NORMALIZATION

The results are quite complex to interpret as it is difficult to assess of the impact of the electric vehicle from a single value..

In this condition, it was decided to normalize the several potential impacts presented in this study. Normalization consists in dividing the value of the product per the value of a reference case, here two European inhabitants, on each indicator. This tool gives the contribution of the studied product on the chosen indicators. The normalization methodology is CML2001 Western Europe, which is in line with our scope. The results are presented below.

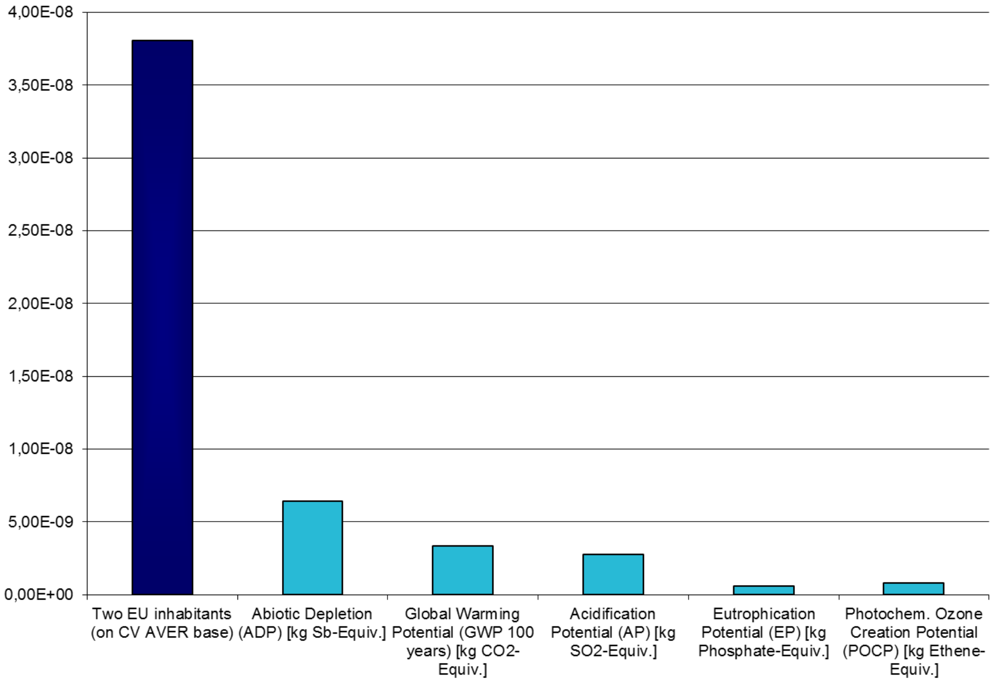


Figure 7: Results presented with Western Europe normalized values

From this normalization, we have seen that eutrophication and ozone potential burdens are very low, below 5% of the annual average of two European inhabitants, considering all vehicles.

The contribution of ZOE in abiotic depletion potential comes from the large use of fossil resources for electricity production, and from not taking into account the potential benefit of recycling. Moreover, this last assumption would also benefit to all other indicators.

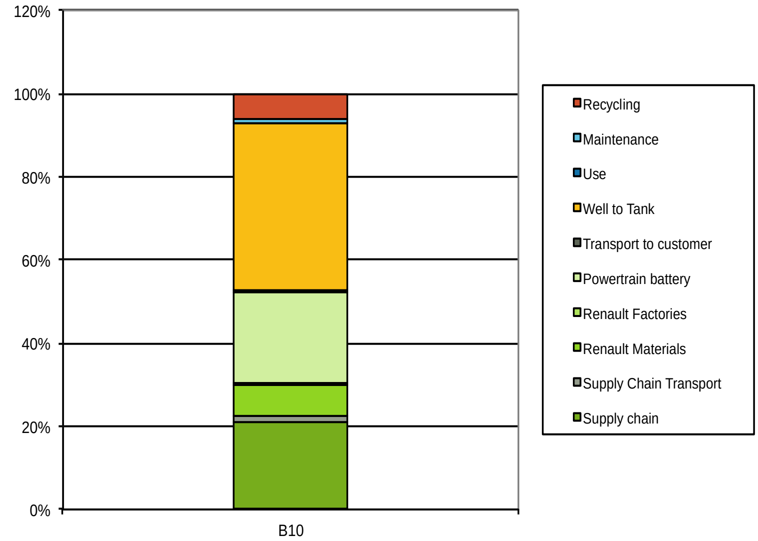
IV.1.3 RESULTS ANALYSIS

IV.1.3.1 Abiotic depletion (ADP)

Following figure shows the distribution of abiotic depletion on different phases of the life cycle. Production phase is distributed in multiple steps in order to identify the key steps defined within our scope. So we identify:

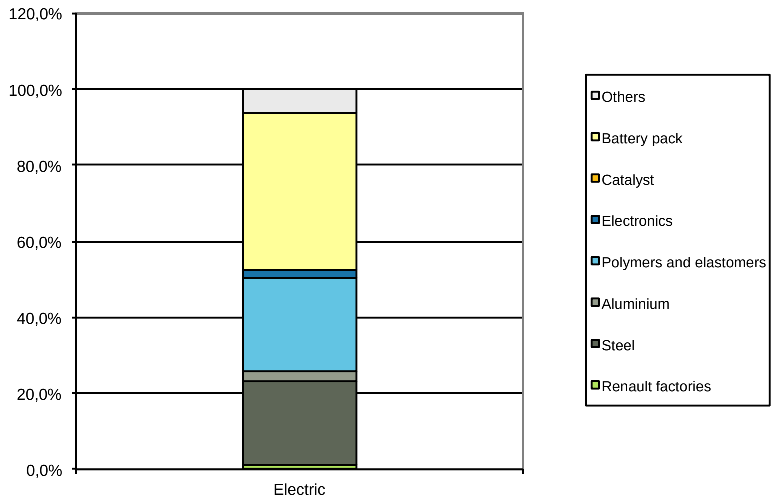
- Material and parts production for supply chain
- Supply chain transport for rank-1 suppliers
- Material production for Renault's factories (aluminum and steel for body's construction only)
- Parts production in Renault factories

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



ADP	ZOE
Supply chain	21,2%
Supply Chain Transport	1,1%
Renault Materials	7,6%
Renault Factories	0,4%
Powertrain battery	22,0%
Transport to customer	0,5%
Well to Tank	40,3%
Use	0,0%
Maintenance	0,9%
Recycling	6,2%
Recycling benefit	-8,6%
Total (kgSb-eq)	94,9
Total with recycling benefit	86,8

Figure 8: Distribution of abiotic depletion from each actor or phase of life cycle



ADP	ZOE
Renault factories	1,20%
Steel	21,74%
Aluminium	2,82%
Polymers and elastomers	24,3%
Electronics	2,1%
Catalyst	0,0%
Battery pack	41,7%
Others	6,1%
Total (kgSb-eq)	50,0

Figure 9: Part of some elements production on abiotic depletion in production phase

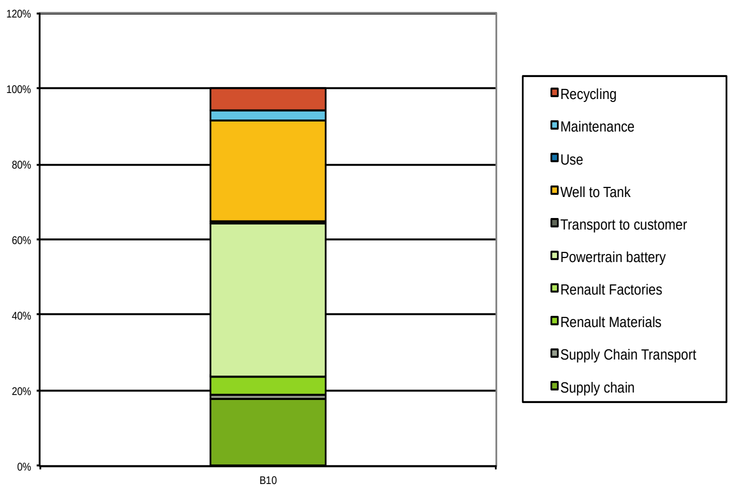
The battery pack production represents the major share of the abiotic depletion potential. With the production of the vehicle itself, the global vehicle's production and delivery to the customer represents more than 52% of the total abiotic depletion. It is a large change comparing ICE vehicles where this share represents about 20% of this total amount.

The share of steel reaches 21.7% of abiotic depletion of production phase, not because of iron ores consumption but from fossil resources extraction to produce the necessary energy for this production. Battery pack of the EV is the main element affecting abiotic depletion potential reaching 41%.

Part from Renault factories is small, only 0.4%, due to major work on energy consumption reduction and positively affected by the French energetic mix.

IV.1.3.2 Acidification potential (AP)

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



AP	ZOE
Supply chain	17,8%
Supply Chain Transport	1,1%
Renault Materials	4,8%
Renault Factories	0,2%
Powertrain battery	40,3%
Transport to customer	0,6%
Well to Tank	26,8%
Use	0,0%
Maintenance	2,8%
Recycling	5,6%
Recycling benefit	-21,4%
Total (kgSO2-eq)	75,9
Total with recycling benefit	59,7

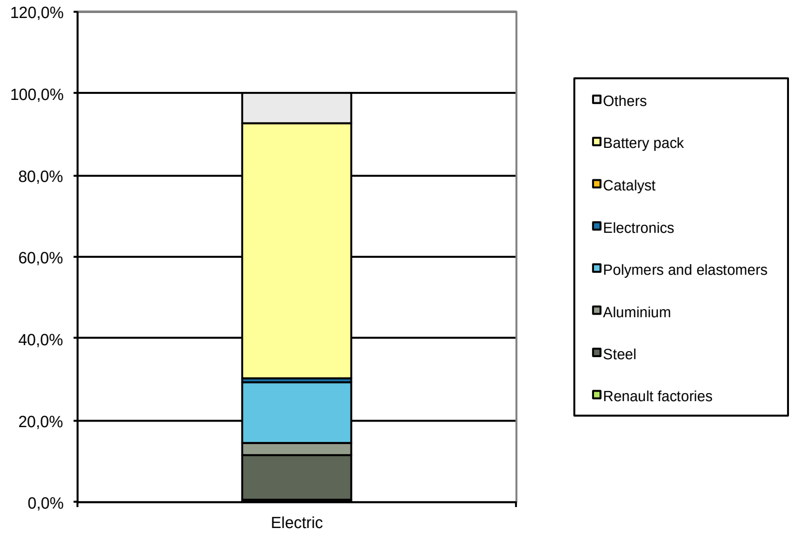
Figure 10: Distribution of acidification from each actor or phase of life cycle

Vehicle's production represents more than 71% of the total impact (supply and its transport, Renault materials and factories, powertrain battery). As we can see, acidification potential with an electric vehicle is mainly due electric mix.

Acidification potential produced by the drivetrain battery comes from raw materials used (Cobalt and Nickel), production countries electric mixes and electrolyte production, which brings the share of the battery production to a 58.7% value.

Considering recycled cobalt and nickel would make environmental score of the battery decrease.

Contribution of Renault factories remains very low representing about 0.2% due to Flins' low SO_2 emissions and its high environmental performance.

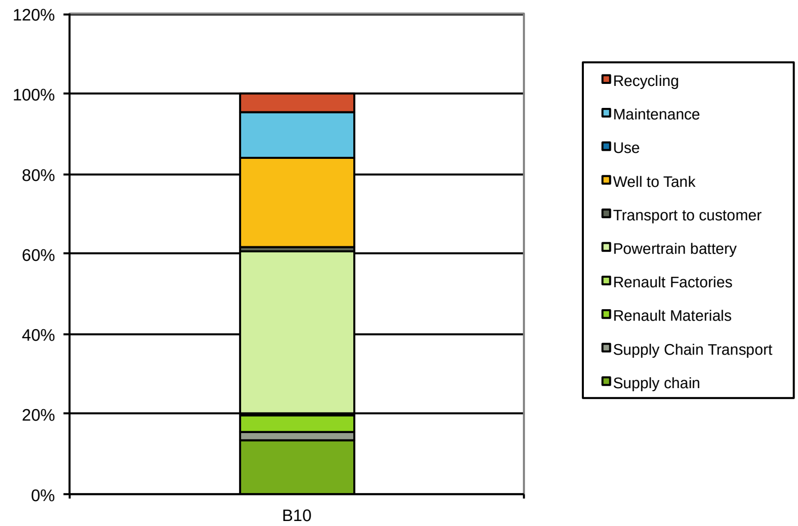


AP	ZOE
Renault factories	0,39%
Steel	11,29%
Aluminium	2,55%
Polymers and elastomers	14,9%
Electronics	1,3%
Catalyst	0,0%
Battery pack	62,2%
Others	7,4%
Total (kgSO2-eq)	49,2

Figure 11: Part of some elements production on acidification in production phase

Steel and aluminum recycling, associated to the battery recycling, can bring to a massive 30% reduction of this impact!

IV.1.3.3 Eutrophication potential (EP)



EP	ZOE
Supply chain	13,7%
Supply Chain Transport	2,0%
Renault Materials	4,0%
Renault Factories	0,2%
Powertrain battery	40,5%
Transport to customer	1,0%
Well to Tank	22,6%
Use	0,0%
Maintenance	11,0%
Recycling	4,8%
Recycling benefit	-7,6%
Total (kgPO4-eq)	7,4
Total with recycling benefit	6,8

Figure 12: Distribution of eutrophication potential from each actor or phase of life cycle

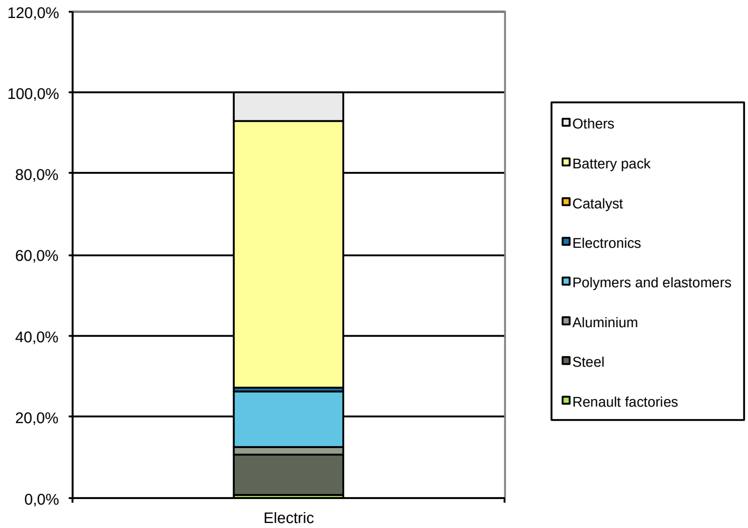
This impact principally depends on NOx emissions and is quite close to the acidification potential behavior.

We must note the importance of maintenance (11% of the global life cycle impact value) 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.

Aluminum and electronics remains important elements in this impact's creation.

Like with the acidification potential, eutrophication potential is mainly penalized by the high emissions of NOx for the drivetrain battery production.

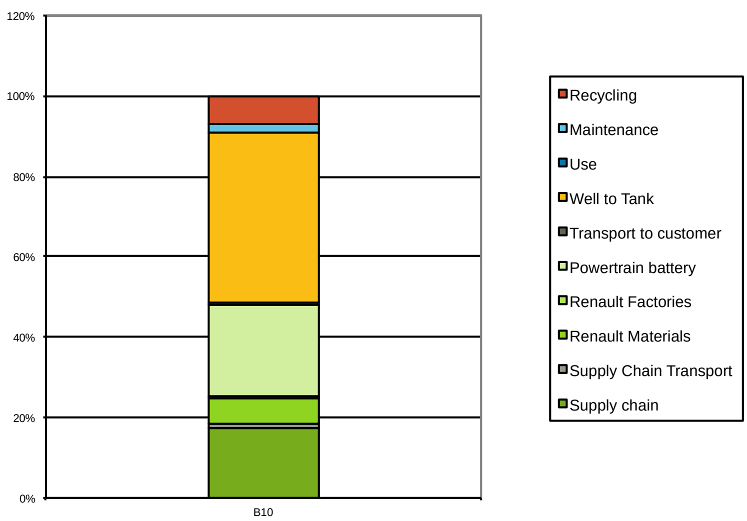


EP	ZOE
Renault factories	0,80%
Steel	10,06%
Aluminium	1,70%
Polymers and elastomers	13,7%
Electronics	0,9%
Catalyst	0,0%
Battery pack	65,9%
Others	6,9%
Total (kgPO4-eq)	4,6

Figure 13: Part of some elements production on eutrophication in production phase

Steel recycling, and in lower contribution aluminum, can bring to a 10% reduction of this impact!

IV.1.3.4 Global warming potential (GWP)



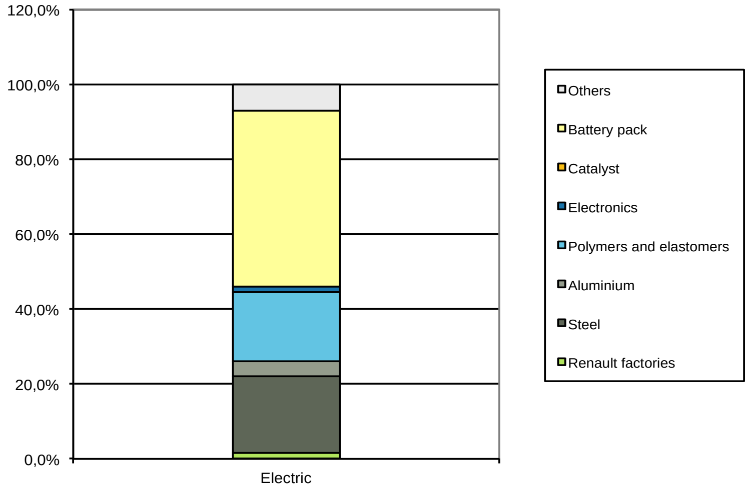
GWP	ZOE
Supply chain	17,5%
Supply Chain Transport	0,9%
Renault Materials	6,4%
Renault Factories	0,3%
Powertrain battery	22,7%
Transport to customer	0,4%
Well to Tank	42,6%
Use	0,0%
Maintenance	2,2%
Recycling	7,0%
Recycling benefit	-10,2%
Total (kgCO2-eq)	15845
Total with recycling benefit	14228

Figure 14: Distribution of global warming potential from each actor or phase of life cycle

This impact is mainly due to CO_2 atmospheric emissions, principally in the well to tank phase of the life cycle: 42%.

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 and like the abiotic depletion potential, production represents about 55% of total emissions. This is due to drivetrain battery production, emitting 3.6 tons of CO_2.



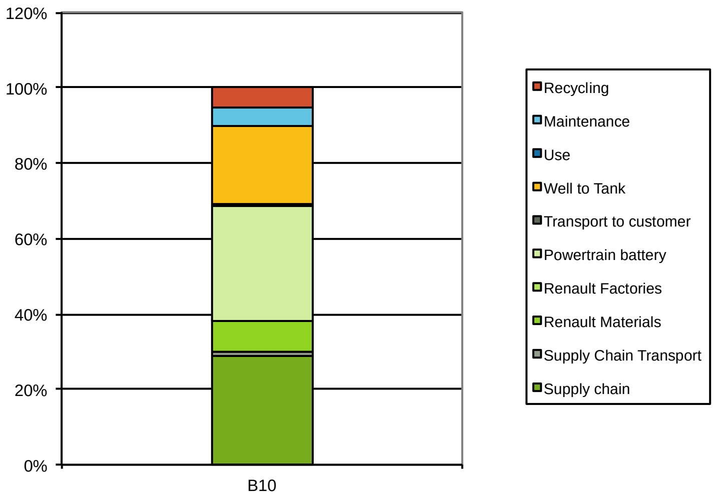
GWP	ZOE
Renault factories	1,53%
Steel	20,68%
Aluminium	3,80%
Polymers and elastomers	18,6%
Electronics	1,5%
Catalyst	0,0%
Battery pack	47,0%
Others	6,8%
Total (kgCO2-eq)	7657

Figure 15: Part of some elements production on GWP in production phase

Due to a low carbon power grid mix in France, GWP of the EV for the production phase is very positive for the overall environmental score.

Steel recycling, and in lower contribution aluminum, can bring to a 13% reduction of this impact!

IV.1.3.5 Photochemical ozone creation potential



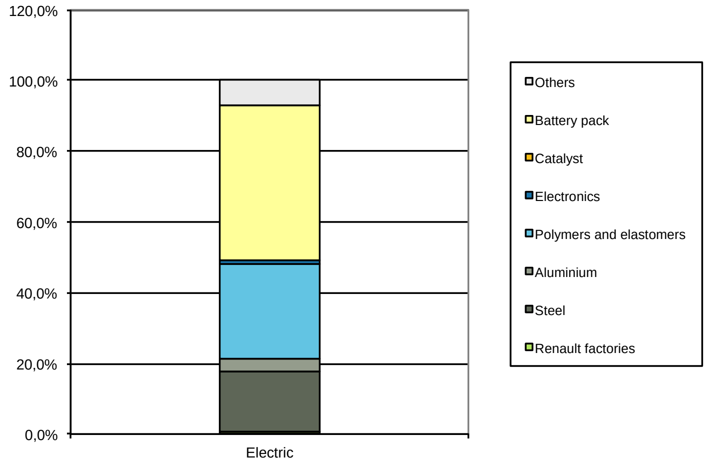
POCP	ZOE
Supply chain	29,0%
Supply Chain Transport	1,1%
Renault Materials	7,9%
Renault Factories	0,2%
Powertrain battery	30,4%
Transport to customer	0,5%
Well to Tank	21,0%
Use	0,0%
Maintenance	4,8%
Recycling	5,1%
Recycling benefit	-18,3%
Total (kgC2H4-eq)	6,48
Total with recycling benefit	5,29

Figure 16: Distribution of photochemical ozone creation potential from each actor or phase of life cycle

This impact is mainly generated by the vehicle and battery production phases.

The production of the drivetrain battery is quite at the same level of emissions as supply chain.

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



POCP	ZOE
Renault factories	0,81%
Steel	17,02%
Aluminium	3,33%
Polymers and elastomers	26,7%
Electronics	1,0%
Catalyst	0,0%
Battery pack	44,0%
Others	7,0%
Total (kgC2H4-eq)	4,48

Figure 17: Part of some elements production on POCP in production phase

V

STUDY'S CONCLUSION

V 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
- Validate the unit process and Life Cycle Inventory data sets (eg battery) defined during the 2011 Fluence LCA and state them as a standard in our calculation model
- Carry a weak point analysis in order to pursue the ecodesign work on this new technology
- Build a comprehensive science based dialogue with expert stakeholders inside and outside of the company

V.1 COMPLETE OUR RANGE OF LCA STUDIES

This work needed many efforts to provide an assessment of this new technology.

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.

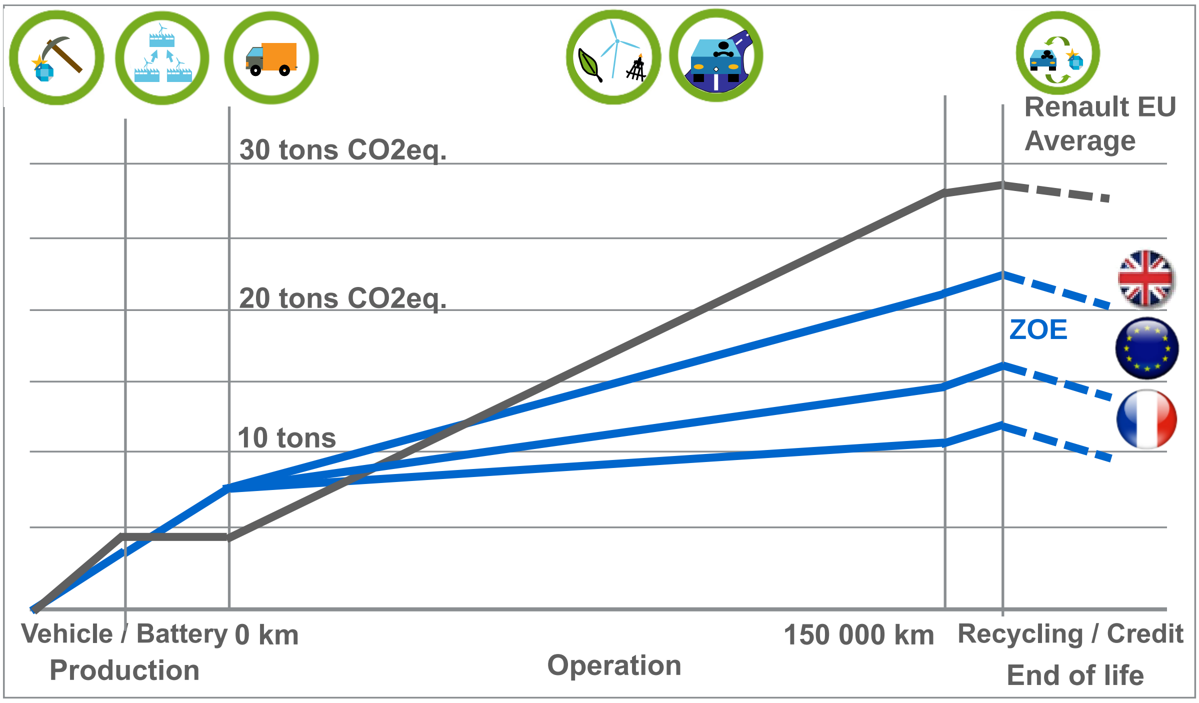


Figure 18: Comparing carbon footprint of ZOE and the 2010 Renault average ICE vehicle.

V.2 VALIDATE 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.

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

V.3 CARRY A WEAK POINT ANALYSIS

- 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 about the same for electric and standard ICE vehicles (complete car excluding drivetrain battery), the production of the drivetrain battery brought some major emissions, affecting negatively the production phase score.
  - As seen in V.1, 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.

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

In order to compare ZOE to a vehicle sold by Renault in a European context, we calculated an average vehicle based on 2010 sales reports. This average vehicle, as defined in the goal and scope, is a fictive vehicle none gasoline, diesel or electric. Its composition and consumption is a global average of all vehicles sold by Renault in 2010. The goal and scope assumptions are the same as defined previously for ZOE.

	Average Renault	Renault Zoé	Variation (%)
Abiotic depletion (kgSb-eq)	183,8	94,9	-48,4%
Primary Energy Demand (MJ)	412151	363054	-11,9%
Global warming potential (kgCO_2-eq)	28588	15845	-44,6%
Acidification (kgSO_2-eq)	62,0	75,9	22,4%
Eutrophisation (kgPO_4-eq)	7,74	7,40	-4,4%
Photochemical ozone potential (kgC_2H_4-eq)	10,34	6,48	-37,3%

Table 13: Comparing ZOE to the Renault average vehicle sold in 2010 (personal + professional vehicles)

ZOE brings a major progress comparing to our average vehicle. The only sensible 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 67kgSO_2-eq in France or in Switzerland.
- 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 on this global life cycle (see V.1), we can deal will two main conclusions:

- At its production phase, ZOE has a more important carbon footprint due to its drivetrain battery.
- Considering power grid mixes in countries of sale, ZOE carbon footprint remains better than an average Renault vehicle in any case. This is due to the global efficiency of the vehicle and then to the lower need of primary energy to achieve all 150 000 km.

V.5 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.

Electric vehicle

The status of “zero emission at use” vehicle of ZOE 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.

Energy used mainly comes from natural gas. It contains a very little share of sulfur 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 would be sourcing recycled material. Using those materials in a new vehicle could reduce from 7 to 21% 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 7% of the impact on the life cycle.

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. Its environmental footprint reduction will be electric suppliers and governments' work and needs to be encouraged.

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 Renault average vehicle sold.

Comparing to an average vehicle sold by Renault in 2010, ZOE is a very interesting solution on a global society level to reduce environmental burdens and secure energy strategy.

On top of these results, the European commitment to reduce carbon emission from industries such as energy suppliers will automatically improve the performance of the electric vehicle fleet on the road year after year.

V.6 METHODOLOGY LIMITS

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

First, study focuses on a brand new vehicle 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, the automotive mobility 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.
- 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).

Last point, we will remark the absence of the Human toxicity indicator that could integrate consequences linked to carcinogen substances and PM10 where electric vehicle bring a major progress. This indicator will be part of the next step of the LCA deployment in the Renault group.

VII

APPENDIX

VI APPENDIX

VI.1 REFERENCES

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VI.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 European Driving Cycle (detailed in Appendix V.7)

POCP: Photochemical Ozone Creation Potential

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