Graduation assignment
Thermal-management for battery electric vehicles and benchmarks

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Thermal-management for battery electric vehicles and benchmarks

Master :

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I thank Rastislav TOMAN for his support and interesting discussions we had during my internship. I did not know a lot about how a Czech master's thesis was working and he helped me to apprehend it correctly and to organize my working methods.

I also want to thank Isabelle's apprentices, Diego VASQUEZ and Fabian MOUTAULT, with who I work and talked a lot during this 6-month internship. They helped me getting familiar with the work and getting comfortable with the team.
Mr. Patrick MERLANT, the DEA-MSM1 team chief, also did his best to integrate me in the team, to give me feedback about my work, and for this I would like to thank him.
More generally, I am grateful to every member of the team for sharing their experience, their help and their opinions during these 6 months.

Finally, I thank all employees of Renault I interacted with, I met people driven by their passion and I wish them all the best.

Abstract

Current automotive sector is ruled by energetic consumption , especially in Europe. Vehicles have to pass precisely defined cycles on roller bench or on open road in order to measure their energetic consumption as accurately as possible.

Cycles are technical processes evaluating parameters of the car while it is being driven, whether on a roller bench with robots or on open roads with real humans. Some are official and validate vehicle consumptions, others are intern to car manufacturers and evaluate more specific parameters.

Recently introduced, WLTC aims to evaluate energetic consumption. It is even more necessary for Battery Electric Vehicles (BEV) as their autonomy is a key factor for customers.

As Battery Electric Vehicles are quite new, many improvements are to be made by car manufacturers, especially regarding their autonomy, their energetic consumption and their performances.

Even if WLT-Procedure is mandatory to be studied, some intern cycles evaluating specific parameters can lead to a global improvement of the vehicle. As these cycles are not official ones, their parameters can vary between tests, therefore results can lose some of their interest.

The aim of this master's thesis is to study the need of thermal-management in future Battery Electric Vehicles, and then to work on most interesting cycles in order to evaluate the thermal-management of current vehicles.

This thesis deals with the interest of thermal-management for Battery Electric Vehicles, with the way to evaluate it and the parameters to measure while processing the cycle. From 52 cycles, 20 cycles have been highlighted and defined to evaluate correctly thermal-management. Temperatures and slopes have been defined so the cycle is as representative as possible, and instrumentation is under discussion.

The involved master's thesis is based on bibliographic research and on Renault Thermal-Management Working Group results.

Keywords : Thermal-management, WLTC cycles, Intern cycles, Cooling and heating needs, Battery Electric Vehicles (BEV)

Présentation

La formation traditionnelle d'un ingénieur en France se termine avec une immersion de 6 mois dans un environnement professionnel.
Passionné par le monde automobile et ayant déjà réussi plusieurs expériences dans ce domaine en plus d'une formation axée autour de l'architecture des véhicules, j'ai eu l'opportunité de réaliser cet ultime stage au sein d'un des acteurs principaux de l'automobile en France : le groupe Renault.

Je suis arrivé dans ce secteur à une période charnière à de nombreux niveaux.
Tout d'abord parce que le groupe Renault est au milieu d'une grande phase de transition, d'un côté par une restructuration depuis le départ forcé de l'ancien Président Directeur Général Carlos Ghosn, et de l'autre par un changement fondamental de technologie pour l'automobile : l'électrification de tous ses véhicules. De plus, la crise sanitaire de la COVID-19 a particulièrement affecté les grosses entreprises, avec l'adoption massive du télétravail et de toutes les méthodes qui en découlent (les logiciels de travail, le bureau, le Cloud, la non-déconnexion, …). Enfin, ma tutrice de stage Isabelle BONFAND récupérait le périmètre électrique début 2021 après plusieurs années à gérer le périmètre essence. Nous sommes tous les deux biens conscients que l'avenir de l'automobile en Europe passera par l'électricité, et nous avons pu accorder nos méthodes de travail en conséquence, à travers des retours réguliers.

Intégré au sein de l'équipe concurrence mécanique, la DEA-MSM1, mon projet de fin d'étude a été axé sur deux points principaux :

- Travailler sur le thermo-management des véhicules électriques dans le but d'établir une liste précise et détaillée d'essais à réaliser sur les futures identifications de moteurs (prévues à partir du 4e trimestre 2021).
- Assister la cheffe de projet véhicules électriques dans ses missions.

Ce rapport de stage, ou thèse de master, traite ces deux axes de travail. Dans un premier temps, je discuterai de mon travail lié au thermo-management, des raisons pour lesquelles ce sujet va devenir essentiel dans un avenir proche et surtout, comment l'évaluer correctement. Dans un second temps, je reviendrai plus en détails sur mon expérience pure au sein de l'équipe DEA-MSM qui fut incroyablement riche.

Mots clés : Thermomanagement, Cycles réglementaires WLTC, Cycles internes, Besoins en refroidissement et en chauffage, Véhicules électriques

Presentation

Traditional French engineer scholarship ends up with a 6-month internship in a professional environment.
Passionate about this automotive sector, I already have some smaller professional experiences in this world, added up to an engineer training focused on vehicle architecture. For this finale experience, I had the opportunity to join one the principle automotive actors in France : Renault Group.

I have joined the company during a transitional period regarding many points.
Firstly, Renault Group currently is at a turning point, on the one hand, the company is getting restructured since the forced departure of its CEO Carlos Ghosn ; on the other hand, private automotive sector is going through the biggest change since its creation : the total electrification of the vehicles. Secondly, the COVID-19 sanitary crisis had and still has a massive impact on how big companies are working, with remote working adoption and all the habits coming along (working software, desk, Cloud, …). Finally, my internship tutor Isabelle BONFAND became electric vehicles project leader at the beginning of 2021 after being gasoline vehicles project leader for several years. We both are conscient that the future of European automotive will go through EVs, and we have been able to share our working methods thanks to regular feedbacks.

Within the mechanical competition team DEA-MSM1, my master's thesis has been oriented around 2 principal notions :

- Working on thermal-management of electric vehicles in order to raise a detailed and precise list of tests to planned to be realized from the last quarter of 2021.
- Assisting EV's project leader Isabelle BONFAND in her missions.

This master's thesis, or internship report, deals with both these subjects. First, I will talk about thermal-management, about the reasons why this topic will become central in a close future and eventually how to evaluate it properly.
Then, I will come back on my experience in DEA-MSM1 Renault team, which has been incredibly rich.

Keywords : Thermal-management, WLTC cycles, Intern cycles, Cooling and heating needs, Battery Electric Vehicles (BEV)

Summary

List of abbreviation

- **ICE :** Internal Combustion Engine (either Gasoline or Diesel, traditional engines)
- **EV :** Electric Vehicle
- **BEV :** Battery Electric Vehicle (full electric vehicle)
- **HEV :** Hybrid Electric Vehicle
- **PHEV :** Plug-in Hybrid Electric Vehicle
- **DEA-MSM1 :** Team I was working in
- **EHRS :** Energy Heat Recovery System
- **EM :** Electric Machine, more accurate name for electric motors
- **PTC :** Positive Temperature Coefficient, electronic resistance
- **CTL :** Centre Technique Lardy, Renault Technical Center in Lardy
- **TCR :** Technocentre, main Renault R&D center
- **WLTP :** Worldwide harmonized Light vehicle Test Procedure
- **WLTC :** Worldwide harmonized Light Vehicle Test Cycle, precise cycle
- **Barcelona cycle :** Barcelona cycle is an internal Renault cycle simulating intense city traffic in Barcelona, a city with high temperatures and therefore higher needs in cooling
- **Corri-door cycle :** Corri-door cycles are cycles during which the vehicle is driving on the highway the whole time, with charging phases if necessary, common Corri-door cycle is Paris-Monaco on a straight 900 km highway line
- **CAN network :** standing for Controller Area Network, is a robust vehicle bus standard designed to allow microcontrollers and devices to communicate with each other's applications without a host computer
- **OBD :** standing for On-Board Diagnostic an automotive term referring to a vehicle's self-diagnostic and reporting capability. OBD systems give the vehicle owner or repair technician access to the status of the various vehicle sub-systems
- **RUET :** Réunion d’unité élémentaire de travail, weekly team meeting (currently on Teams)

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1. Context

1.1. Automotive industry in western countries

Automotive industry is born on the Old Continent at the end of the 19th century, at that time, many inventors become car manufacturers thanks to the oil revolution. Engines are no more powered by steam but become internal combustion engines (ICE).
This new technology will become predominant by the end of both World Wars. ICE vehicles now are ruling alone the automotive market.

Since their creation, manufacturers' goal has always been to produce more power from their engine so vehicles could have better performances. In order to do so, the only solution was to have bigger engines, but also heavier and more polluting.
At the end of the 20th century, it was widely accepted that the main cause of the Global Warming was CO_2 emission, and therefore directly related to the automotive sector and internal combustion engines.

Since that date, European governments have agreed to reduce these emissions by taxing polluting oils and vehicles, "*For the final agreement on cars, a phase-in provision that effectively delays the 95 g/km target from 2020 to 2021, was introduced*" (The International Council on clean transportation 2014), by encouraging supposedly less polluting strategies (Diesel vehicles during the 2000s decade, especially in France) (*fig. 1*) and by forcing car manufacturers to find alternatives to their polluting methods.

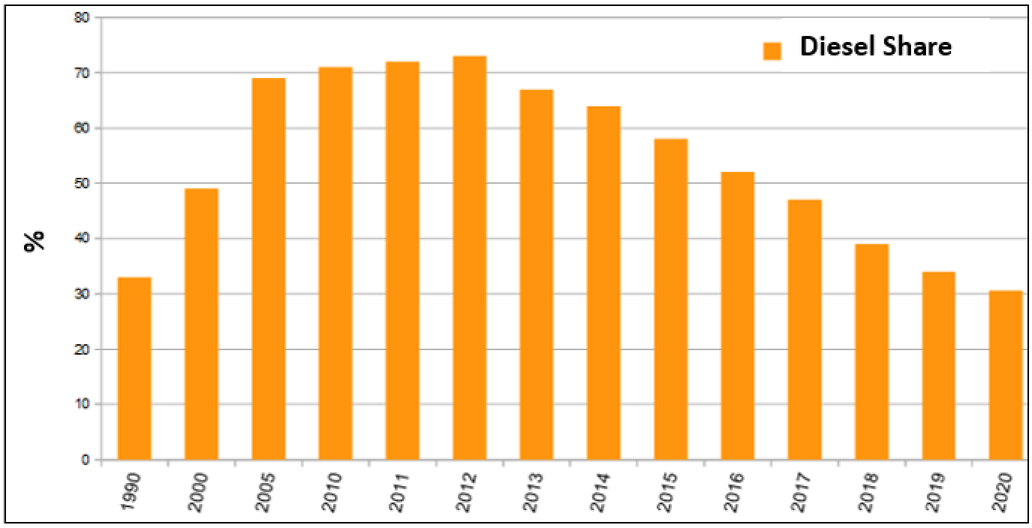

Figure 1 : French Diesel car fleet evolution (Fiches-Auto.fr 2021)

1.2. History of Renault

History of Renault begins at the end of the 19th century, in 1898, with 3 brothers developing the automotive brand “Renault Frères” (standing for Renault Brothers). Success came from their home-made invention, the direct gearbox, allowing vehicles to climb slopes more easily.
The first vehicle using this revolutionary gearbox was the A-Type (*fig. 2*). Of course, this vehicle was gasoline powered thanks to a one-cylinder engine.

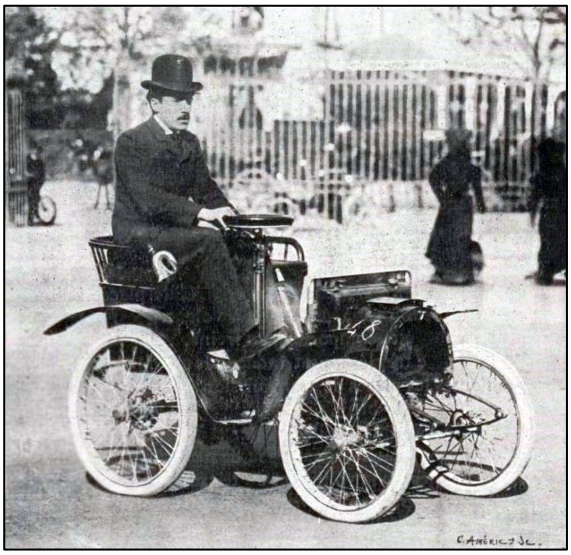

Figure 2 : Louis Renault showcasing A-Type car (1898)

Through its history, Renault has evolved many times and changed its logo in order to promote its ambitions.
During First World War for example, government requested Renault to create military vehicles such as protected vehicles, trucks, planes and even tanks, this one had a great success. For this reason, Renault logo will represent a tank from now (*fig. 3*).
In the next figure (*fig. 3*) are displayed important Renault dates related with specific logos all representing a precise state of mind.

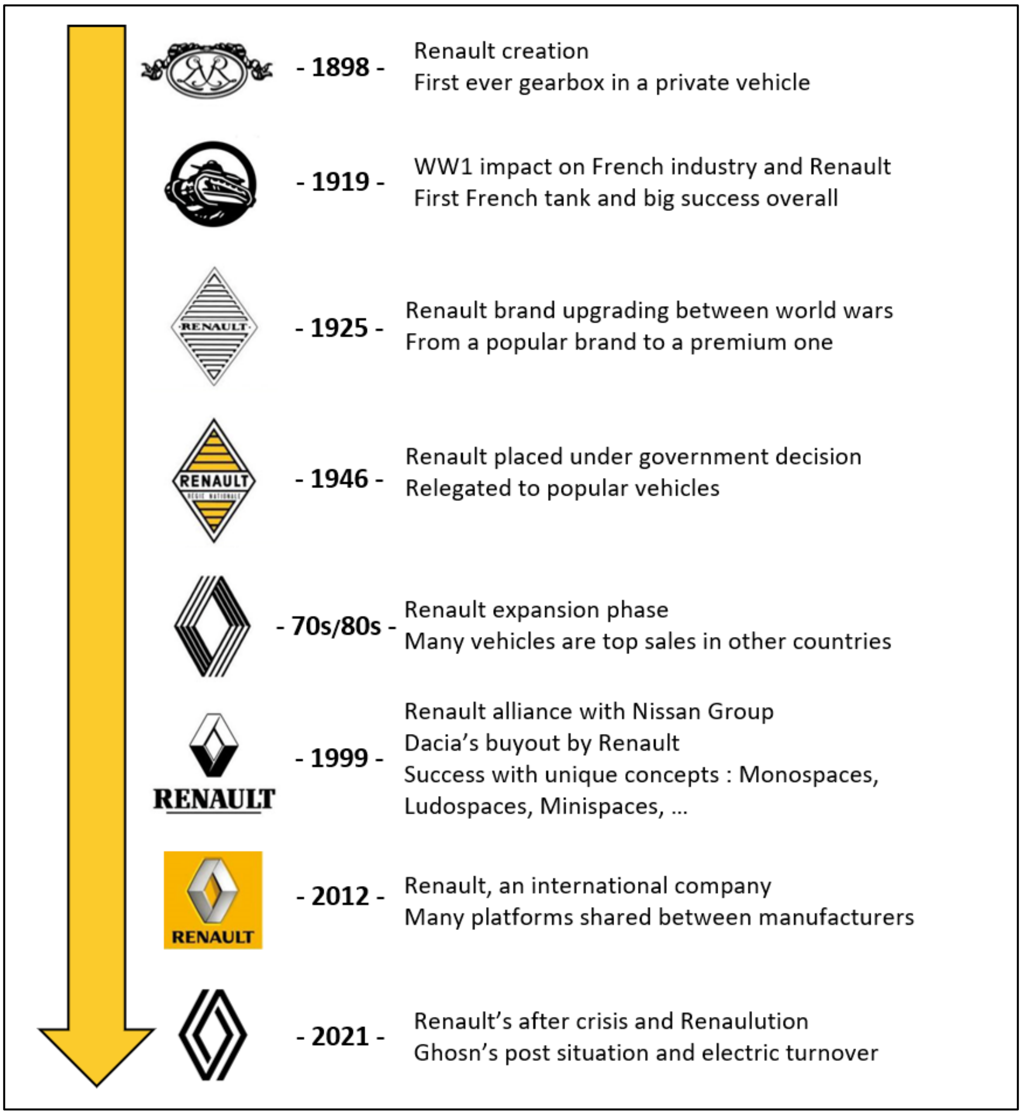

Figure 3 : Renault's history through important dates

Nowadays, Renault is one of the 3 historical French car manufacturers remaining (Citroën, Peugeot and Renault) and has become an international company with many partnerships (Nissan Group, Daimler, PSA, …) and purchasing (Dacia, Lada, Samsung motors, …) and even brand reviving with Alpine during the last decade (*fig. 4*).

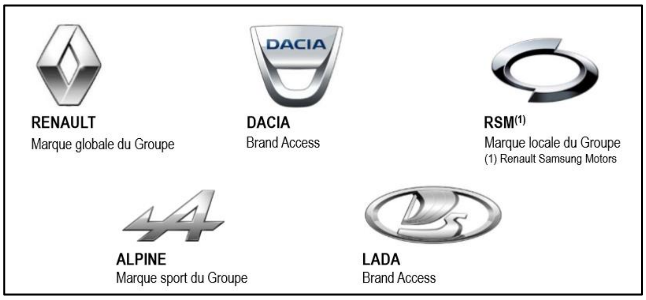

Figure 4 : Renault Group brands at the end of 2010s decade

1.3. Renault and the automotive market at the beginning of the 2020s decade

Current automotive industry is being deeply transformed and new technologies are on the rise. Among these alternative solutions, the total electrification of the vehicle is probably the biggest one at the moment. Battery Electric Vehicles (BEV) are encouraged by most of EU-governments, "*For individuals, the maximum bonus of €6,000 for vehicles with CO2 emission levels up to 20 g/km, primarily battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs), is maintained but is now capped at a vehicle purchase price of €45,000*" (Sandra Wappelhorst 2020) and car manufacturers try to update their line-up with as much BEV as possible.

Battery electric vehicles (BEV) do not have much in common with traditional Internal Combustion Engines (ICE) vehicles. Even is the engine can be smaller, these cars are significantly heavier because of the battery pack. Progressively, battery electric vehicles are getting their own platform design and modularity. Battery-packs are usually located below the passengers, the electric machine is located between the wheel it is powering, allowing more space in the passenger compartment because there is no more need of a long traction chain, but also some space in the back or front trunk (*fig. 5*).

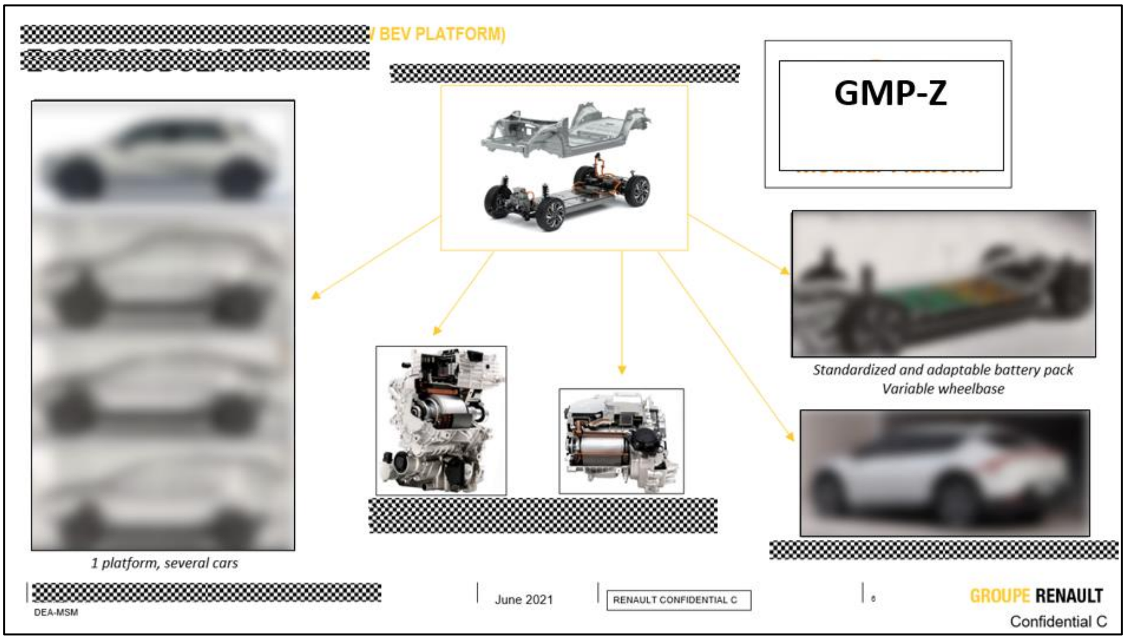

Figure 5 : Car Manufacturer Z – Presentation of the new GMP-Z platform, May-June 2021

Except a few models on the EU-Market, many manufacturers recently formalized BEV dedicated platforms in order to have better vehicles, despite the price increase.
For instance, Volkswagen AG (VAG) now has 3 BEV-dedicated platforms (Viknesh, Vijayenthiran 2021) (*fig. 6*) in order to provide various electrical vehicles to their several brands :

- **MLB evo platform :** current platform used for many ICE vehicles in VAG group, but optimized for electrified vehicles such as PHEV or BEV (current platform for Q4 e-tron)
- **MEB platform** : currently the most used platform in VAG group, it is a BEV-dedicated platform used by Volkswagen, Škoda, Seat but also Audi.
- **J1 Performance platform :** a BEV-dedicated platform for high performances vehicles, such as Audi and Porsche brands (current Porsche Taycan and Audi e-tron GT)
- **PPE platform :** future platform of the group for premium BEV (next gen Porsche and Audi)

Figure 6 : VAG BEV platforms (Viknesh, Vijayenthiran 2021)

As mentioned, MEB platform is currently being distributed for many VAG brands. Volkswagen ID.3 is the first vehicle to beneficiate of it, but many electric vehicles from the group will be built on this platform, such as the ID.4, but also other generalist models from Škoda, Seat and Cupra (*fig. 7*), or even premium models like the Audi Q4 e-tron.

Figure 7 : VAG MEB platform 2021 generalist line-up : Enyaq IV / Born / ID.4 / ID.3

Having such a wide line-up is interesting regarding the huge investment developing a new platform requires, and many others are sharing this strategy since the beginning of the century, with big groups gathering brands which were formerly independent, such as PSA Group merging with Italian FCA Group in order to become Stellantis, BMW Group sharing architectures with MINI and Rolls Royce, or, in my internship case, Renault Group allying with Nissan and Mitsubishi (*fig. 8*).

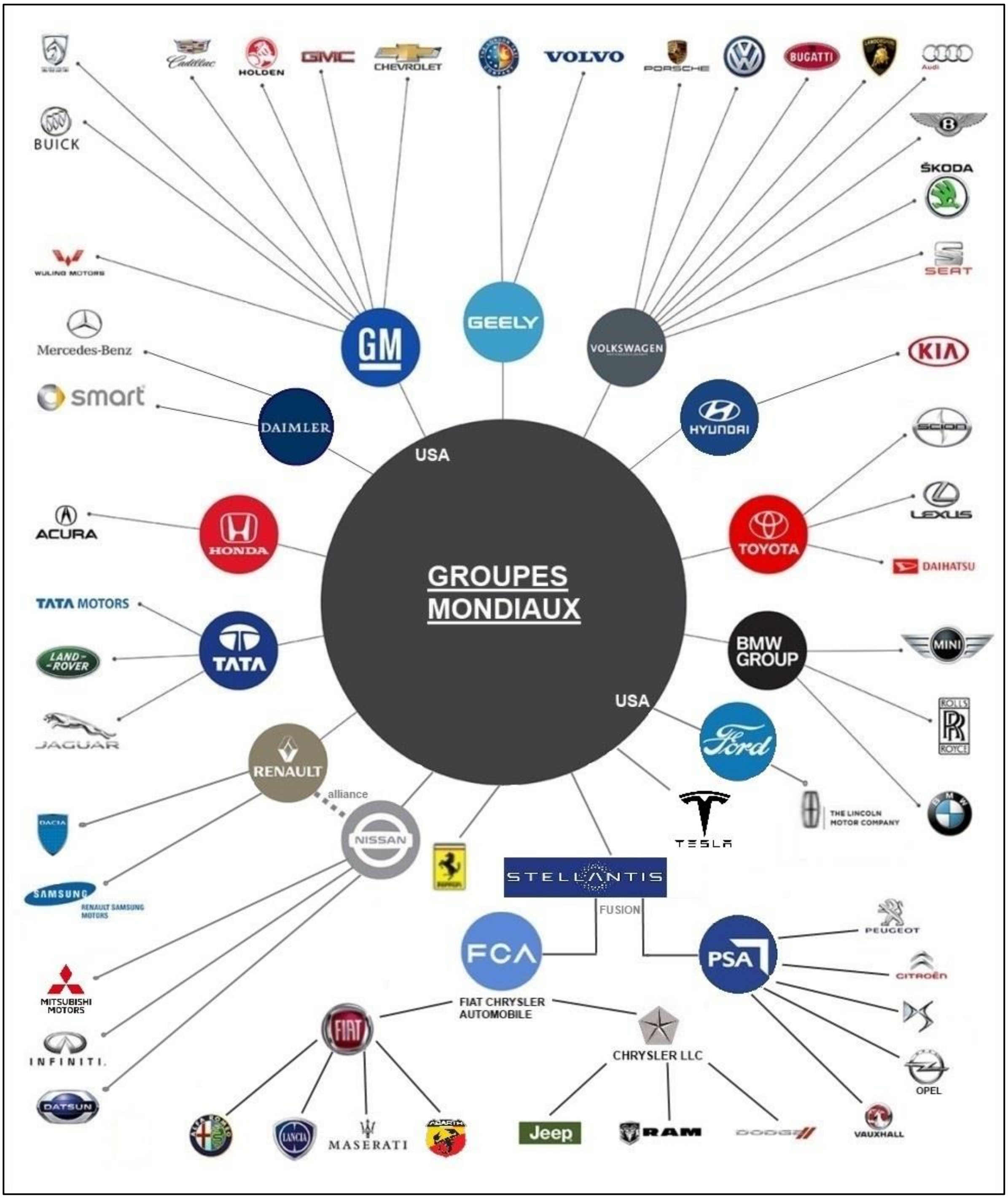

Figure 8 : Car companies and brands in 2021

These BEV platforms are fully built around an electric machine and a battery-pack, therefore it is easier to think on the thermal-management between the several devices.

1.4. Problem statement

If we take a closer look at the losses in an electric powertrain, we can see (fig. 5) that they are located mostly between the electric machine and the battery pack. Losses in the powertrain are separated between losses in the single gear transmission, in the electric machine, and in the inverter. Sometimes, inverter and single gear transmission are located in the same device, so called Power Electric Box (PEB).

Most of the time, the electrical machine requires cooling in order to increase its efficiency, whereas the battery pack has to be maintained at a minimal temperature in order to correctly use the battery State of Charge (SOC, the real amount of energy left in the battery, independent of external conditions that can reduce the usable amount of energy, called the User State of Charge, U_{SOC}, displayed to the driver), but also to be cooled during precise driving situations or, more often, during powerful charges, especially if a drive-time is planned right after.

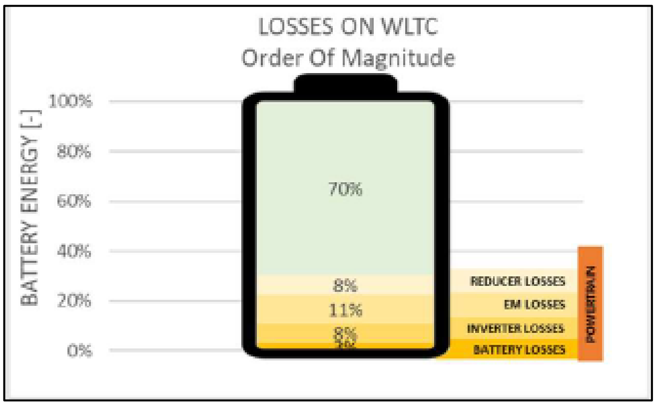

Figure 9 : Powertrain losses in Renault Test Vehicle A during WLTC 23°C

Cumulated, these losses represent around 65 MJ dissipated in the powertrain during a standardized international cycle called "**Worldwide harmonized Light vehicle Test Cycle**" (WLTC 23°C) with Renault Test Vehicle A (C-Segment vehicle), equally divided between the machine, the single gear transmission and the inverter (*fig. 9*). If they were ignored, they could damage devices because of the heat released without any control.

Regarding the battery-pack, losses are highly temperature dependent and can occur during both charging and driving. On the hand, charging phases at low temperatures will cause many losses and so a long-time charge (*fig. 10*) but also losses in the electric system. On the other hand, driving phases at unexpected temperatures will cause higher losses in the battery-pack, which can slowly damage it and ultimately induce overheating.

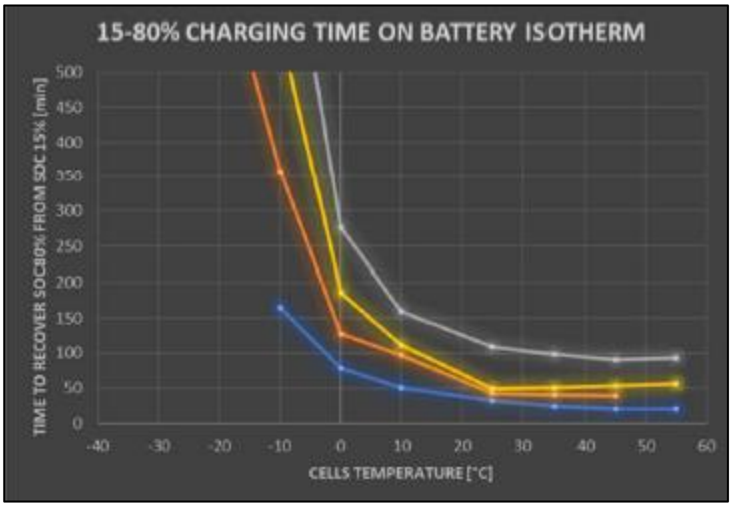

Figure 10 : Renault's EV line-up charging performances depending on the temperature

Furthermore, traditional manufacturers are getting more and more challenged by competitors : their ICE vehicle history makes them look uncomfortable with new technologies, whereas new brands such as the Chinese ones (BYD, NIO …) or more obviously Tesla perfectly embrace their posture, seducing customers with modern and performing cars.

Because of the current situation, car manufacturers are currently working on thermal-management concept, defined as the study of heating and cooling fluxes in the vehicle in order to improve its efficiency, its autonomy and performances but also passenger comfort.

If we keep comparing ICE and battery electric vehicles, autonomy is a new critic parameter that has more impact for electric vehicles compared to ICE ones.
Because of the European position regarding battery electric vehicles (BEV), the autonomy is almost the only technical parameter customers are looking at. This autonomy is more meaningful now that the WLTP is set, but still relies on a unique cycle. Therefore, improving autonomy during WLTC test is the ultimate goal for every car manufacturer and working on thermal-management is a good solution to find where to make economies but also where and how to re-use some energy.

Renault currently is at a turn-around, its most known BEV vehicle Renault Zoe is at the end of its life, and the company has to entirely re-think its strategy because if 10 years ago this fully electric vehicle was almost the only one in western countries, nowadays all other car manufacturers have launched at least one BEV.
In order to stay at the top of the market, Renault's next products have to be compared with current competitors' models. But as electric vehicles are still quite new, we need to define and settle tests comparing these vehicles.

The aim of this master's thesis can be defined as :

Define and highlight relevant tests to evaluate thermal-management of Renault and competitors' vehicles in order to develop process specifications for subcontractors in 2022.

1.5. Outline

To answer this issue, the master thesis is organized as follow :

Chapter 2 : Thermal-management
This chapter presents thermal-management for battery electric vehicles. It deals with the cooling and heating needs a vehicle requires depending on it is driving or charging. Thanks to this, I will discuss about theoretical ideas to improve thermal-management but also which cycles and tests are the most interesting to evaluate thermal-management of BEV.

Chapter 3 : Proposal of specifications to improve benchmark studies
Now that several cycles have been highlighted, this chapter presents the specifications and the parameters of the tests Renault's teams are aiming to keep. For these studies, several teams have been talking together in order to have the widest point of view possible.

Chapter 4 : Proposal of communication formalism for the results
Finally, when all cycles are settled, this chapter presents a way to develop process specifications for subcontractors in order to have these tests done for 2022 BEV line-up.

In the 5th chapter, I will talk more about the experience of working in such an international company as Renault Group and about the missions I had in order to assist the Project Leader.

In two last chapters, I will conclude, discuss the results talk more about the global experience I had regarding the internship, the master thesis and my whole year for the Master of Automotive Engineering in Prague.

2. Thermal-management

2.1. Definition

One of my major tasks during my internship was to study thermal-management in order to find the most relevant characteristics to measure in order to define precise benchmarks evaluating cooling and heating performances of the fully electric vehicles tested by DEA-MSM1 team.

Thermal-management is the study of the cooling and heating fluxes in the vehicle, the better it is, the better will be the performances, the comfort, the autonomy and many other parameters. Thermal-management study is even more important for full electric vehicles : The engine (or e-machine) is not the only device to cool anymore, the battery pack requires a dedicated system to cool it in order to deliver its entire power (*fig. 11*). Furthermore, the battery pack can require heating phases if temperatures are getting too low, or if a charging phase is planned.

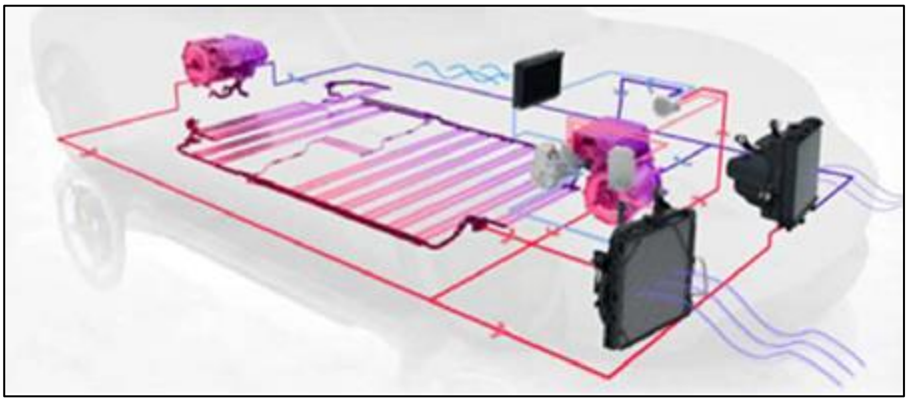

Figure 11 : Cooling system for the Porsche Taycan

Because the technologies used for thermal-management are recent, strategies can vary between car manufacturers, and it is getting interesting to evaluate these solutions in order to adapt Renault's strategy in the future.

2.2. Presentation of cycles studied in the thesis

In the following table (*Table 1*) are displayed and explained some recurrent cycles studied during the internship and presented in this master thesis :

Cycle name	Origin	Details
WLTC	International Cycles	*Worldwide harmonized Light vehicles Test Cycle, official cycle evaluating energy consumption and displayed to the customer. Cycle separated in 4 parts simulating low speed, middle speed, high speed and very high speed, with acceleration and deceleration phases and stop phases*
WLTP		*Worldwide harmonized Light vehicles Test Procedure, cumulating several WLTC cycles and 100km/h stabilized phases in order to be as close as possible to real drive situations (1,5 WLTC + 100km/h + 1,5 WLTC + 100km/h until SOC reaches 0%)*
RDE		*Real Drive Emissions test measuring pollutant emissions emitted by car while driven on opened road (while WLTC / WLTP are done on roller benches), it does not replace WLTC but complements it*
City Cycle	Renault Intern Cycles	*Cycle simulating a city driving phase, with several defined parameters depending on the city (Barcelona, London, Monaco, …)*
Corridoor Cycle (+ City)		*Straight cycle from Technocentre to a City (Le Touquet, Monaco, …) with the highway and charging phases if necessary*
Highway Cycle		*Cycle simulating a highway driving phase, with high speed, small decelerations and accelerations*
Mountain Cycle		*Cycle simulating a mountain climb driving phase, with important slopes*
Repeta 10-60		*Cycle simulating an intense city driving phase, with important accelerations from 10 to 60 km/h followed by instant braking phases to 10 km/h, repeating during the entire cycle*
Repeta 80-120		*Cycle simulating an intense highway driving phase, with important accelerations from 80 to 120 followed by instant braking phase back to 80 km/h, repeating during the entire cycle*
Vmax Cycle		*Cycle simulating an intense driving phase pushing the car to its maximum limit until derating occurs*

Table 1 : Recurrent studied cycles in the Master Thesis

2.3. Measurement characteristics of BEV thermal-management system

2.3.1. Cooling needs during driving phases

A really good way to evaluate the cooling needs in the different parts of the car is to run several relevant cycles and to compare the losses in the studied part regarding the time scale of the cycle. Fully electric Renault Test Vehicle A has run these cycles and we can extract significant results for the battery pack but also for the electric machine.

- **Battery pack :**

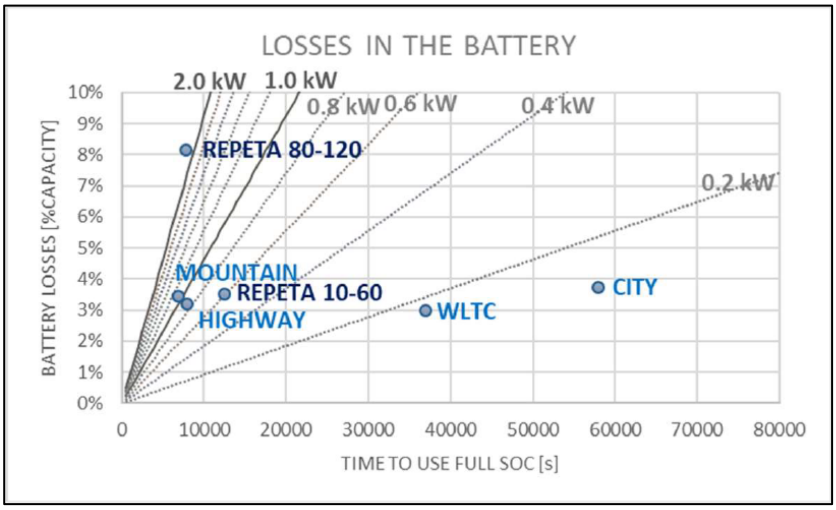

Figure 12 : Losses in the battery pack for different Renault cycles

Figure 12 presents losses in the battery pack for different cycles, on the horizontal axis is represented how long lasts the cycle, and on the vertical axis are displayed battery losses during the axis. Therefore, losses in Watts can be drawn.

Through this graphic (*fig. 12*), we can spot a significant point that previous losses graphs (*fig. 9*) could not highlight : City cycle and Repeta 10-60 cycle induce the same number of energetic losses, a bit less than 4%, but the cycle time is way longer for the City cycle (5800 seconds against 1200 seconds for the Repeta 10-60 cycle). Therefore, the heat dissipation is 5 times higher during a Repeta 10-60 cycle than a City cycle.

This type of graphic is useful, because it is easier to size the cooling needed for the battery pack, a small city car (Twingo EV, Dacia Spring, …) will not need a powerful cooling whereas a performant car (for example future Alpine, which will be a BEV) will require a high-end cooling because it is designed to perform more demanding cycles.

As we can see, Repeta 80-120 is by far the hardest cycle for the battery cycle, but it also represents such a rare situation. Still, it is important for car manufacturers (especially generalist brands like Renault) not to over-size their systems in order to maintain reasonable costs.
For that reason, Renault's "Politique Technique" (Pol-Tech, stands for the engineering rules in the company) regarding losses in the battery sector are the following :

Global rules nowadays used by Renault Group :

$P_{cooling}[Batt] \geq 0{,}035 \frac{kW_{cooled}}{kWh_{batt}}$ - Zero risk of thermal derating for the battery pack

$P_{cooling}[Batt] \geq 0{,}020 \frac{kW_{cooled}}{kWh_{batt}}$ - Thermal derating risk contained to demanding situations

$P_{cooling}[Batt] < 0{,}020 \frac{kW_{cooled}}{kWh_{batt}}$ - Significant risk of thermal derating for common situations

Equation 1 : Renault Global rules regarding battery cooling

- **E-traction chain (Electric Machine + Power Electric Box) :**

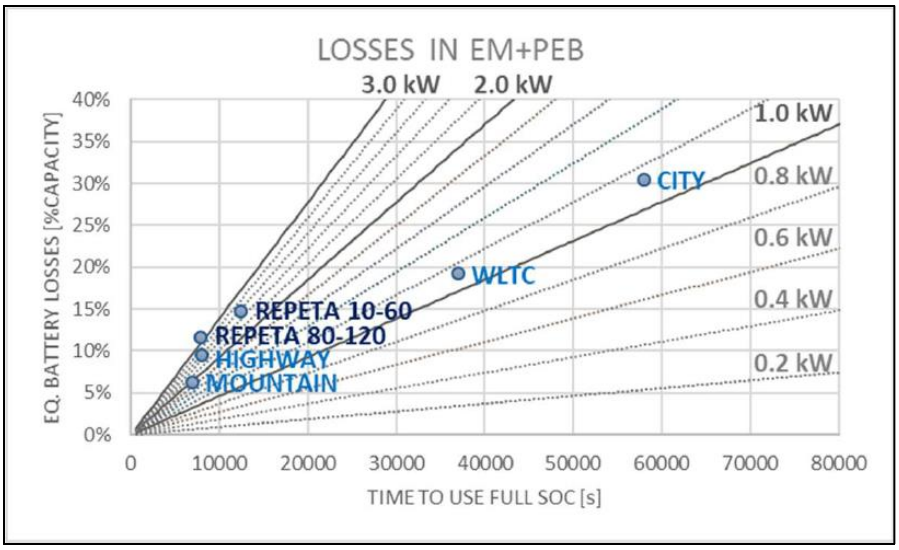

Figure 13 : Losses in the e-traction chain for different Renault cycles

This time, maximum speed cycles is the hardest one, but Repeta cycles also are intense (*fig. 13*). For example, Renault Test Vehicle A cannot last more than 10 seconds at maximum speed (160km/h) with a 5% slope if there is no cooling.

Renault's "Politique Technique" regarding losses in the electric machine sector are the following :

Global rules nowadays used by Renault Group:
$P_{cooling}[e\ traction\ chain] \geq 3$ kW - Zero risk of thermal derating for the e-traction chain
$P_{cooling}[e\ traction\ chain] \geq 2{,}5$ kW - Thermal derating risk contained to demanding situations
$P_{cooling}[e\ traction\ chain] < 2{,}5$ kW - Significant risk of thermal derating for common situations

Equation 2 : Renault Global rules regarding e-traction chain cooling

It is important to note that nowadays the only solution to evaluate the autonomy of an electric vehicle for the customer is the WLTC result. For that reason, it is important for every car manufacturer that their models are in the best situations to perform this cycle.
WLTC cycle's goal is to recreate real life driving situations, so the autonomy and electric consumption are the closest possible to what the customer will experience. This process replaces NEDC cycle, which was not significant enough and could lead to issues. WLTC cycle is composed of 4 phases standing for different situations : low speed city, medium speed city, high speed rural and high speed.
In Europe, the WLTC standardized process for BE vehicles is the following (*fig. 14*):

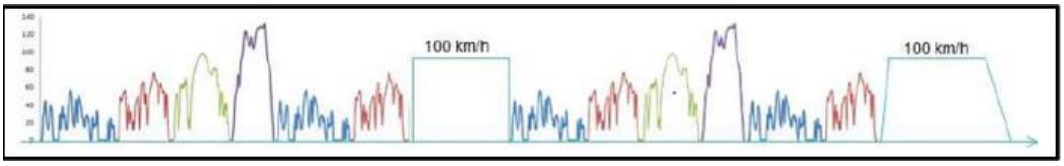

Figure 14 : European standardized WLTP process for BEV

First there is 1,5 WLTC cycle, followed by a constant speed (100 km/h) phase, then there is another 1,5 WLTC cycle, and finally a last constant speed (still 100 km/h) phase, which lasts until the vehicle has no more power. This process is set at 23°C on a roller bench, but also at -7°C and on public roads with no specific conditions regarding the weather or air temperature (it is the Real Drive Emission test, RDE).

Hopefully, WLTC cycle easily meets cooling needs, either for the battery pack or for the electric machine. For this reason, it is really important for car manufacturers to not activate battery or electric machine cooling during such easy situations to save as much energy as possible, and therefore increase the global autonomy of the vehicle.

2.3.2. Cooling needs during charging phases

Compared to traditional ICE vehicles, battery electric vehicles have dedicated charging phases are which long but also stressful for the components.
In fact, charging powers are getting higher and components such as battery cells or inverter have to endure such power without ageing significantly. Moreover, filling a tank with gas is the same procedure for almost any car, whereas there are plenty of charging powers when it comes to charge a BEV. Traditional charging phase using common sockets is not risky at all for the car components, as the charging power is very low, and the charging time quite high, but if charging power increases, concerned components have to be tougher or some strategy has to be set in order to evacuate heat caused by high power induced.
One of the battery main characteristics regarding charging power tolerance is its capacity : the higher it is, the higher the charging can be done without any risk. If the charging power is too high for the battery, a thermal-management can be necessary in order to reach this charging power without risking damages.
As Renault is a general (i.e. non premium) car manufacturer, models should not be over-priced and therefore for should not be over-tuned. Taking this point in count, we can settle a global rule described here (*fig. 15*) :

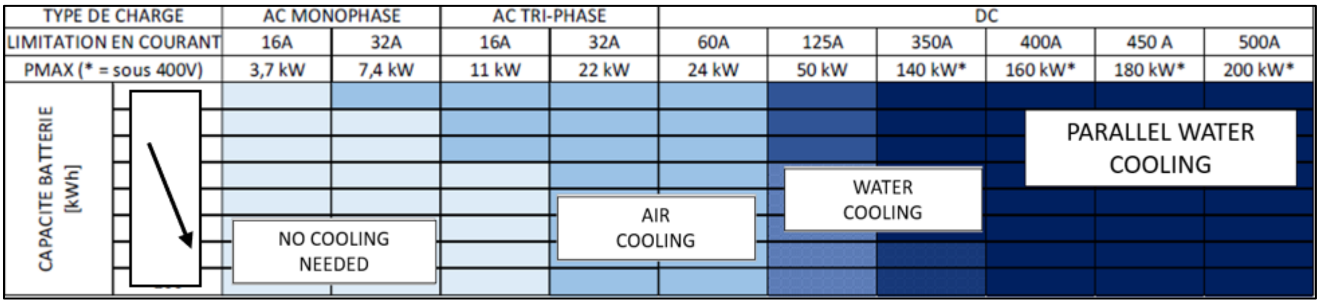

Figure 15 : Thermal-Management so use regarding charging power and battery capacity

Charging powers :

- AC monophased : regardless of the battery capacity, charging power is little enough to not require any kind of cooling.
- AC tri-phased : in the worst cases, air cooling is sufficient to dissipate heating, and some high-capacity batteries can resist charging without any cooling.
- Low DC : charging powers are become significant, performing water-cooling is mandatory even for high-capacity batteries.
- High DC : more than a simple loop, a dedicated water-cooling is necessary for every battery.

As we discussed before, WLTC performances are crucial. For that reason, cooling during charging phases must not impact autonomy, especially during WLTC cycles and must not cause any kind of derating on typical customer cycles like house charging, daily travels, and Barcelona cycle mostly (Barcelona cycle is an internal Renault cycle simulating intense city traffic in Barcelona, a city with high temperatures and therefore higher needs in cooling).

To activate battery-cooling if T_{batt} ≥ 40-45°C during driving or charging phases is a good limit estimated by Renault specialists.

However, this chosen limit can be set stricter, as does Porsche with its Taycan, activating battery-cooling as soon as the temperature exceeds 33°C. (*fig. 16*)

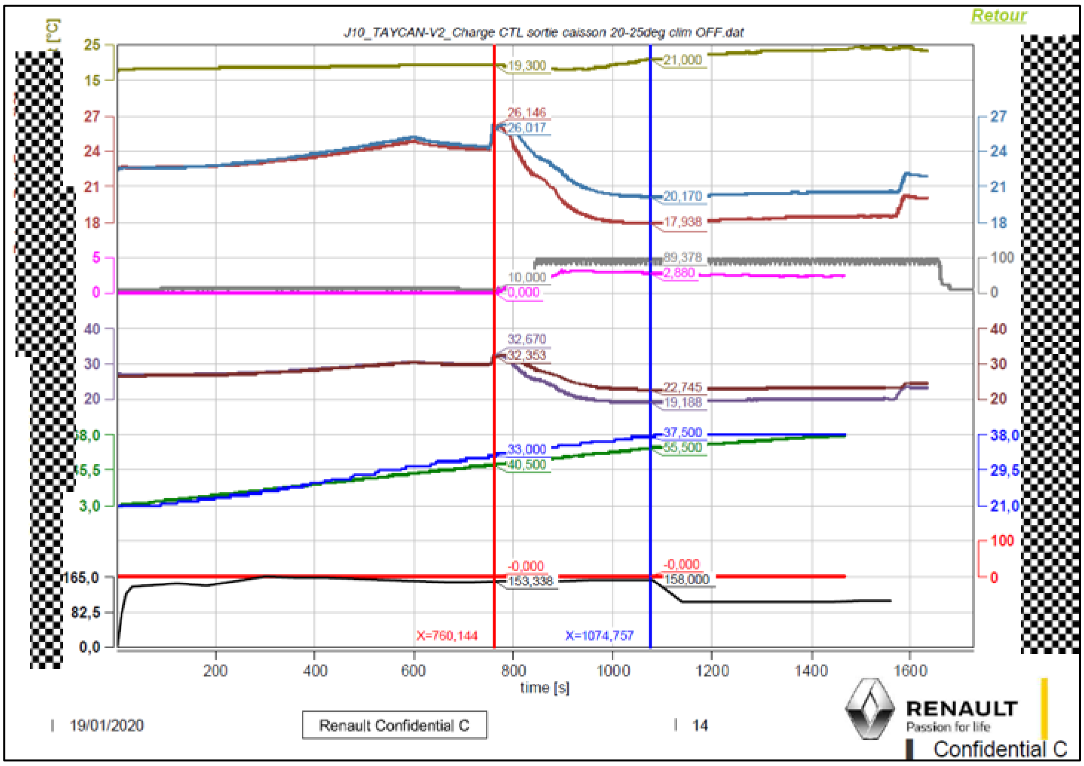

Figure 16 : Porsche Taycan parameters during fast charging phase (175kW)

To be noted : batteries are all new and settled so when they are tested. Ageing batteries will have worse charging performances because their temperature gradients slowly increase.

2.3.3. Heating needs during driving phases

Battery electric vehicle performances depend a lot on exterior temperatures. Mandatory WLTC is currently set at 23°C but it is being discussed to also add a WLTC -7°C in order to depict BEV performances at low temperatures.

Indeed, low temperatures have two serious impacts on batteries.

On the first hand, low temperatures cause much more losses in the battery perimeter, whereas powertrain losses are almost temperature independent. During WLTC cycles at 23°C and -7°C, Renault Test Vehicle A for example has two times more losses in the battery pack at low temperatures (*fig. 17*), while other losses remain equal.

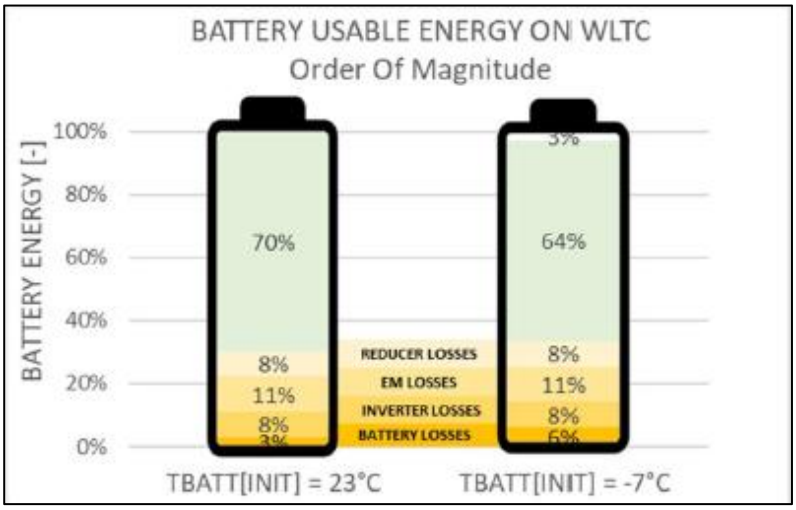

Figure 17 : Losses variations regarding temperatures for Renault Test Vehicle A during homologation cycles

On the other hand, extractible energy from the battery gets lower as the temperature decreases, which means that $\mathrm{U_{SOC\,min}}$ increases. For the customer, it means that the battery is significantly smaller with lower temperatures (*fig. 18*).

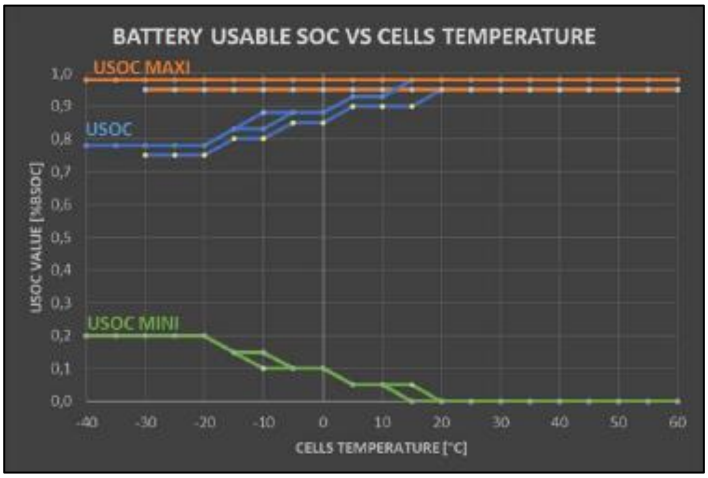

Figure 18 : User SOC (U_{SOC}) evolution regarding battery cells temperature

In order to compensate these two points, the logical thing to do is to heat the components in order to maintain them at reasonable temperatures. However, heating has an energetic cost which must remain lower than the losses previously highlighted.

Unfortunately, battery heating at low temperatures is costly and this spending is not worth the gain it will allow. Battery losses, even if they double up, remain low regarding the entire energy consumption and heating the battery-pack from 30°C would cost much more than this.
However, extractible energy is an issue only if the client aims to totally empty the battery or if the battery was really low before the driving phase. During most common cycles, these two situations do not occur and therefore represent a small amount of client situation. At the moment some working groups are questioning whether it is interesting or not to heat the battery-pack if there is a long trip that will require low percentages exploitation is planned.

To be noted : This discussed strategy can become way more interesting if the trip is planned directly with the car system, because it would therefore be able to adapt heating or cooling in real time. This strategy is used by the Porsche Taycan's Smart Planner : cooling or heating is directly linked to the software and the GPS, and any change of trajectory can have an impact on the whole thermal-management strategy (*fig. 19*).
When the driver changes the trip parameters, the system immediately reacts, battery heating is activated and the battery-pack is now maintained at 30,5°C.

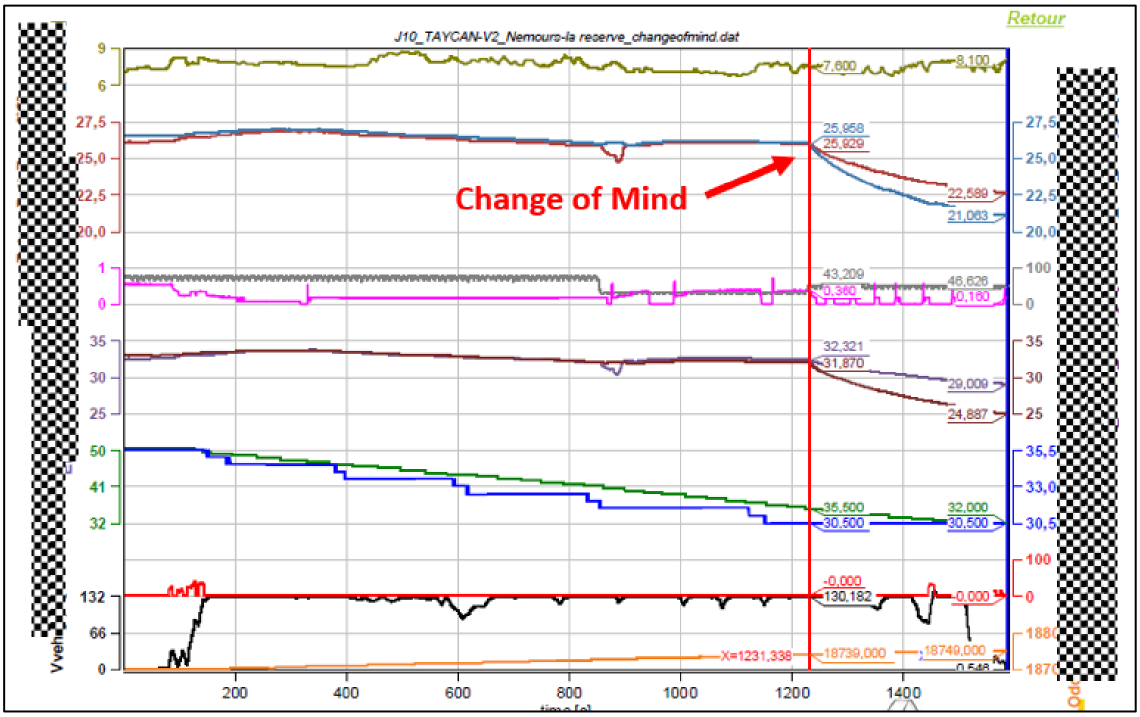

Figure 19 : Porsche Taycan's characteristics variation over time with 'Change of Mind'

2.3.4. Heating needs during charging phases

As we discussed earlier, charging performances are highly impacted by temperatures. When it comes to battery heating while charging, two options are considered : curative and preventive battery pack heating.

Curative heating means that when the vehicle begins its charging phase at low temperatures, a dedicated heating system will increase battery-pack temperature. Unfortunately, this strategy efficiency is weak and not interesting at all. Indeed, heating components takes some time, but as highest charging powers are available at low SOC, it has not so much value (*fig. 20*).

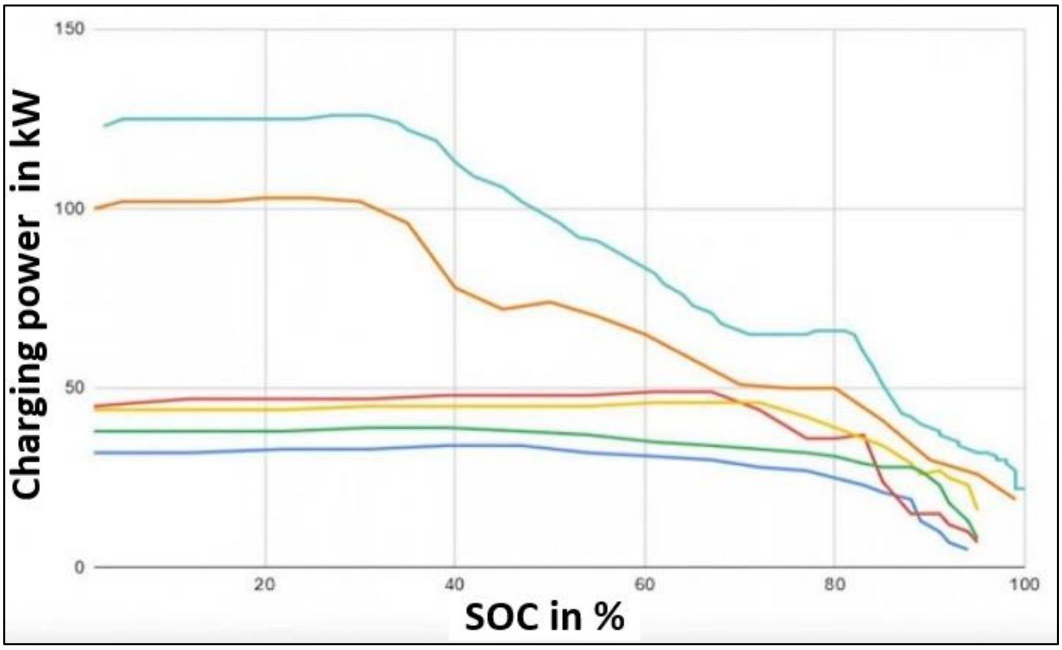

Figure 20 : charging power availability depending on battery SOC (for several C-Segment EU-market BEV)

However, preventive heating can be interesting as soon as there is a driving phase before the charging phase (*fig. 21*). One of the easiest solutions to heat the battery pack is to use PTCs (PTC stands for Positive Temperature Coefficient, an electronic resistance) :

During a cold Corri-door cycle on Renault Test Vehicle A (Corri-door cycles are cycles during which the vehicle is driving on the highway the whole time, with charging phases if necessary, common Corri-door cycle is Paris-Monaco on a straight 900 km highway line), this preventive heating can lead to a 33% more efficient 30 minutes charging phase.

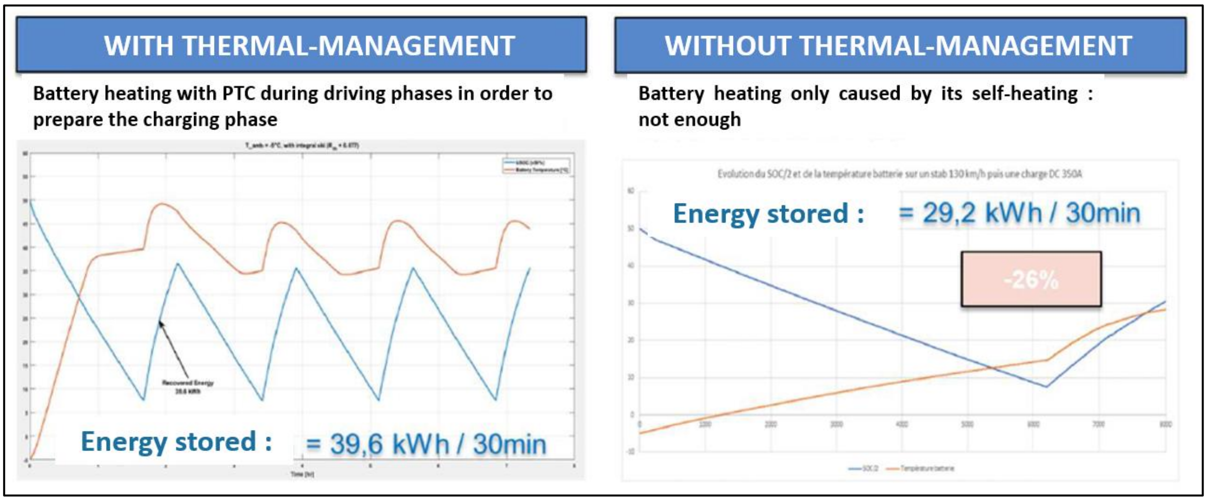

Figure 21 : preventive heating interest during a Corri-door -5°C cycle for Renault Test Vehicle A

This example is quite a rare case and preventing heating power can vary depending on the need. For bigger vehicles such as light commercial vehicles, the heating need may be smaller but it will still increase charging performances (*fig. 22*).

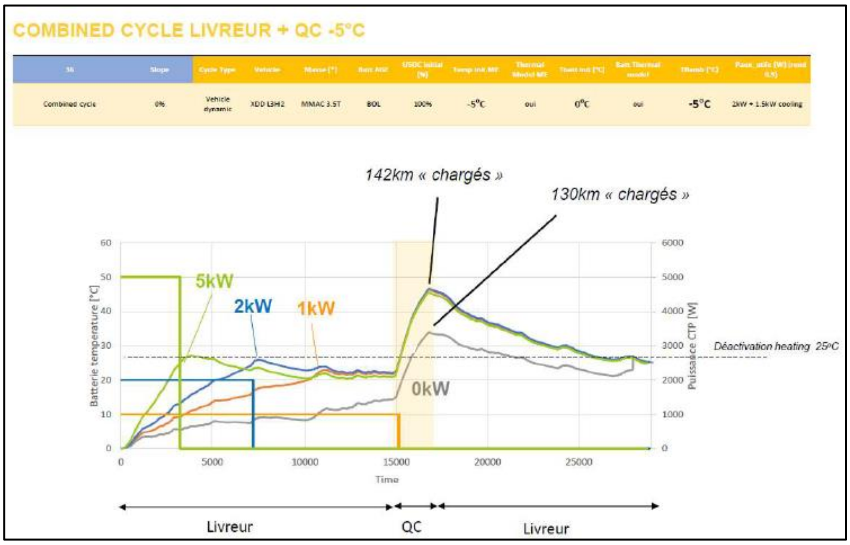

Figure 22 : Cold Delivery cycle with different preventive battery pack heating powers to prepare the 350A charging phase

At the moment, the solution proposed by Renault Group's specialists is to encourage preventive battery heating before a charging phase up to 10°C below the optimal charging temperature. If so, the battery will already be conditioned before the charging phase begins and all the performances will be correct. It will also allow to minimize the energetic cost of the heating process.

$$T_{batt} = T_{batt\ opt\ for\ charging} - 10°C$$

Equation 3 : Optimal battery temperature before a charging phase

Preventive heating before charging phases actually is a common scenario. That is why this process is interesting. Yet, cold charging phases without any driving phase before have no real solution to prevent from the poor performances. Hopefully, this situation is quite rare or does not require any impressive charging performances.

To be noted : preventive heating of the battery pack is a mandatory parameter to reach correct charging performances at low temperatures but is not a sufficient one. Good battery pack isolation is required to keep it at an isotherm, but also to increase the global energetic efficiency.

2.4. Theoretical solutions to improve thermal-management discussed by Renault teams

2.4.1. Energy Heat Recovery System (EHRS) strategy

Energy Heat Recovery System (EHRS) is a promising strategy currently studied by Renault engineers. Its goal is to re-use energetic losses to heat systems that need high temperatures to perform better. The situation when this strategy is the most efficient is the beginning of driving phase for low temperatures. With these parameters, the electric machine and battery pack are at low temperatures but the EM will heat quite fast and require cooling whereas the battery pack will have low performances until it reaches an optimum temperature, which can take some time during a slow driving phase. In this situation, EHRS' goal is to re-use the losses in the powertrain to heat the battery pack "for free". This will allow economies regarding the heating cost but also regarding the battery pack, as it will be performing sooner than originally planned.

Temperature gains in the battery pack if all the powertrain losses are re-used during a WLTC 23°C cycle				
Time (s)	0-450 s	450-900s	900-1350s	1350-1800s
PWT losses (W)	~ 600	~ 1000	~ 1250	~ 1500
$Gains_{T_{batt}}$ (°C/min)	+ 0,1 + 0,2	+ 0,15 + 0,25	+ 0,17 + 0,34	+ 0,2 + 0,4
Total T_{batt} gain (°C)	+5 / +9,6 °C			

Table 2 : theoretical impact of EHRS strategy for Renault Test Vehicle A during a WLTC 23°C cycle

Without thermal isolation
With thermal isolation

These results (*Table 2*) can be improved again if the temperatures get lower. For the same situation but at -7°C, the maximum theoretical temperature gain in the battery pack for a single cycle is around 50°C.
During a full discharging cycle, EHRS strategy can save up to 2kWh, leading to a maximum autonomy increase of 4%.

But if this strategy sounds perfect, some points are to note : EHRS strategy is composed of mechanical systems, and their efficiency has to be considered. Moreover, the generating heat cannot stand alone for all the heating needs situations, and will therefore require an additional dedicated system, with its own efficiency, weight but also cost.

2.4.2. Cycling battery strategy

The other strategy studied by Renault Group's teams currently is the cycling of the battery pack. The goal is to force additional energetic fluxes in the battery in order to over-use it during a short period of time, causing additional losses and therefore a higher self-heating.

APPLICATION	TV A – 50kWh	TV B – 90kWh	TV C – 104kWh
HAUSSE DE TBATT LIEE AU CYCLAGE REPETA 80-120 A 25°C	+0,70°C/min	+0,58°C/min	+0,45°C/min
EQUIVALENT PTC	4,2kW	4,6kW	3,9kW

Figure 23 : Temperature increase and PTC equivalence for the Cycling battery strategy during Repeta 80-120 25°C cycle

This strategy could be interesting to reduce systems costs, because it does not require additional devices, and could even replace PTC currently used. It is even more performing in repetitive situations such as Repeta 10-60 or Repeta 80-120 cycles (*fig. 23*).
However (and fortunately in a way), intern losses in the battery pack remain low and could not sustain all the heating needs the battery pack require. Finally, this strategy could be a good addition to some already existing thermal-management solutions.

2.5. Relevant tests to expose thermal-management limits

There are many ways to test a vehicle and lots of things to highlight during these tests :

- Homologation cycles, ruled by national and European governments, such as WLTC and RDE cycles. As mentioned earlier, WLTC cycle is one of the most important cycles as the results are displayed to the clients.
- Intern Renault cycles, described by Renault teams, in order to highlight or evaluate a specific parameter of the vehicle.

In 2.2 part (*fig. 12 and 13*), we discussed a lot about cooling needs for the vehicle during specific cycles, thanks to them, we are able to order cycles depending on how hard they are for the vehicle :

Repeta HW >> Mountain > HW > Repeta City > WLTC > City

Figure 24 : Cycles ordered by efforts exposed to the battery pack

V_{max} > Repeta HW > Repeta City > HW > Montage >> WLTC > City

Figure 25 : Cycles ordered by efforts exposed to the e-traction chain

Thanks to previous figures (*fig. 24 and 25*), it is easier to know which tests are the most representative in order to evaluate specific parameters of the vehicle.

For example, V_{max} and Repeta (HW or City) cycles are really interesting if we plan to highlight the cooling limits of the e-traction chain, whereas Repeta HW and Mountain cycles will highlight the cooling limits of the battery pack.
Regarding charging phases thermal-management limits, cold situations are interesting to spot derating during charging, and charging phases following intense driving phases can also spot cooling limits.

Now we know which cycles globally are the most interesting to spot thermal-management limits, we have to clearly define these cycles regarding the needs of Renault engineering teams, but also what to measure and where to put the captors (Ollivier 2020).

3. Proposal of specifications to improve benchmark studies

3.1. Current benchmarks for electric vehicles (EVs)

Historically, homologation cycles on roller bench have been designed for internal combustion engine (ICE) vehicles. First, they were interesting to evaluate the performances but also the level of pollutants and the fuel consumption of the vehicle and its engine. Now that the EU-governments are forcing car manufacturers to decrease CO_2 emissions, cycles and tests have become more and more important.

Taking these points into account, we can list several cycle families depending on what they are aiming to evaluate :

- **Performances :** the goal is to evaluate how good the performances of the tested vehicle are how long it can maintain maximum speed, how long it can maintain Repeta cycles.
- **Consumption :** the goal is to evaluate how much the vehicle consumes its energy depending on several situations : hot, cold, at low speed with intense traffic or at high speed on the highway. Obviously, WLTC cycle is in this category.
- **Comfort :** the goal is to evaluate comfort parameters like heating or air conditioning depending on external conditions, and evaluate their impact on global autonomy and services.

Now that EU-governments have reached an agreement regarding the official type of cycle determining pollutant emissions of the vehicle (WLTC cycles and RDE test) to consider, it is also really important for car manufacturers to make every vehicle pass these cycles.
First in order to check that their own vehicles fit well the standard levels settled in Europe, but also to check if other vehicles from competitors also fit these standard levels.

For Battery Electric Vehicles (BEV), one more type of tests is required : charging tests.
Indeed, traditional ICE vehicles do not need to be tested to evaluate how the tank is getting filled, because thanks to standardization there is nowadays only one. However, because there is still no technological consensus and because there is much to gain on this aspect, it is mandatory to evaluate the charging phase of an electric vehicle. And this is costly from many points of view : it takes time to charge and then discharge the battery, especially with low AC powers, but it also requires several types of chargers, and finally, temperature can have a big impact on charging performances.

But most of current cycles used for BEV were originally designed for thermal vehicles (except for charging phases of course) and now that electric vehicles start prevailing, it is mandatory to define BEV oriented cycles.

In order to define precise cycles evaluating, several R&D employees have been questioning mechanical and

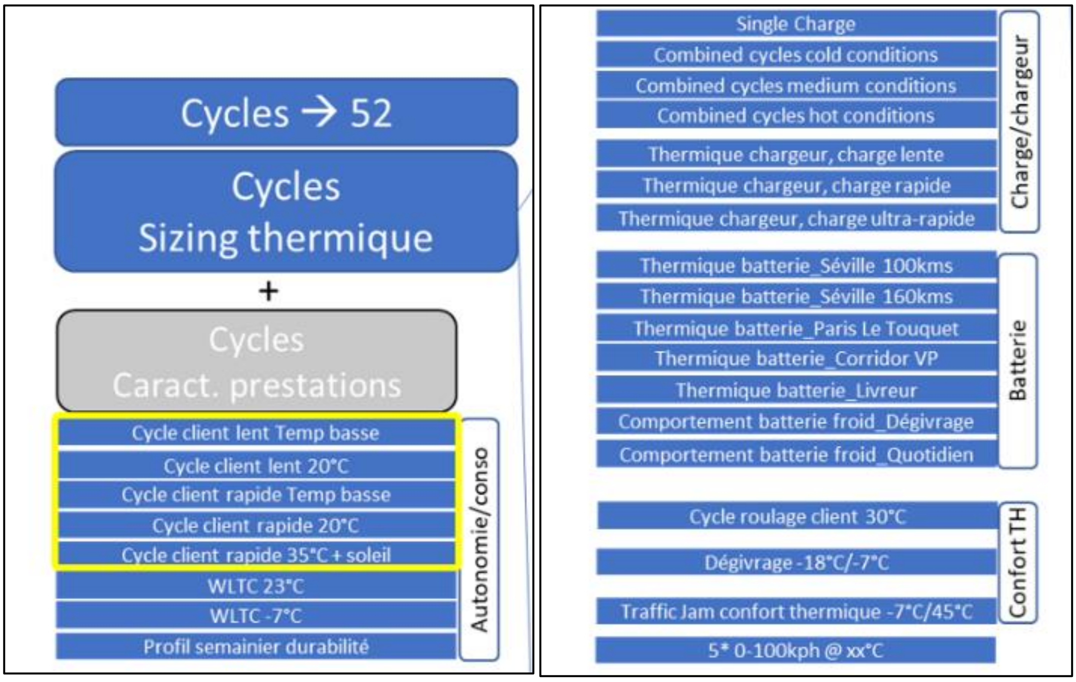

Figure 26 : Entire list of tests registered for a Battery Electric Vehicle (BEV)

At the moment 52 cycles are registered for Battery Electric tested vehicles, divided depending on the sector they are evaluating (*fig. 26*) :

- Autonomy and energy consumption
- Charging phases
- Battery
- Thermal comfort (heating or air conditioning)

From these 52 cycles, 22 cycles can be assimilated to thermal sizing specifically (*Table 3*) :

Thermal sizing cycles				
Cycle name		Slope	Temperature	Vehicle weight
Cooling	***Fast Customer***	→ 0 %	35 °C	Curb Weight + 2
	Corri-door Monaco	↑ var %	-5 °C	Curb Weight + 2
	Corri-door Monaco	↑ var %	35 °C	Curb Weight + 2
	Corri-door Monaco	↑ var %	20 °C	Curb Weight + 2
	Combined Cycle	→ 0 %	45 °C	Curb Weight + 2
	Derating Repeta 10-60	↑ 15 %	45 °C	Max autho. Weight
	Derating Repeta 80-120	→ 0 %	45 °C	Curb Weight + 2
	Derating Vmax	→ 0 %	45 °C	Max autho. Weight
	Derating Vmax slope	↑ 5 %	40 °C	Max autho. Weight
	Combined Vmax *3	↑ 0-5 %	45 °C	Max autho. Weight
	Mountain Climb 15km	↑ 9 %	30 °C	Max autho. Weight
	Mountain Huez hot	↑ var %	35 °C	Max autho. Weight
	Take-off on slope	↑ 26 %	35 °C	Max autho. Weight
	Slope staying	↑ 26 %	25 °C	Max autho. Weight
	Slope staying	↑ 12 %	25 °C	Max autho. Weight
	Perfo A/C	→ 0 %	45 °C	Curb Weight + 2
	WLTC 23°C	→ 0 %	23 °C	Curb Weight + 2
	Perfo peak variable temp	→ 0 %	xx °C	Curb Weight + 2
Heating	***Standard Heating***	→ 0 %	- 18 °C	Curb Weight + 2
	Perfo Recovery cold	→ 0 %	- 20°C	Curb Weight + 2
	WLTC -7°C	→ 0 %	- 7 °C	Curb Weight + 2
	E-traction Chain	↑ var %	30-45 °C	Curb Weight + 2

Table 3 : List of studied cycles

From this list, the final goal is to have 15 cycles optimized in order to evaluate correctly thermal-management of a vehicle.

3.2. Test programs

From previous list (*Table 3*), studies and meetings have led to some modification or replacement of some cycles in order to correspond more to thermal-management evaluating. At the end of July, the list was reduced to 20 cycles (*Table 4*) :

Thermal sizing cycles					
Cycle name		Slope	Temp	Vehicle weight	Details
Cooling	***Corri-door Monaco***	↑ var %	40°C	Curb Weight + 2	DC charge + HW
	Barcelona	→ 0 %	45 °C	Curb Weight + 2	AC charge + City
	Derating Repeta 10-60	↑ 15 %	40 °C	Max autho. Weight	Max accel/decel
	Derating Repeta 80-120	→ 0 %	40 °C	Curb Weight + 2	Max accel/decel
	Derating Vmax (60km)	→ 0 %	45 °C	Max autho. Weight	Vmax flat road
	Derating Vmax slope	↑ 5 %	40 °C	Max autho. Weight	Vmax towing
	Combined Vmax HW WE	↑ 0-5 %	45 °C	Curb Weight + 2	Combined Vmax
	Mountain pass towing	↑ 9 %	30 °C	Max autho. Weight	Mountain up/down
	Mountain Up / Down	↑ var %	30 °C	Max autho. Weight	Mountain up/down
	Take-off on slope	↑ 30 %	35 °C	Max autho. Weight	EM cooling
	Slope staying	↑ 26 %	25 °C	Max autho. Weight	EM cooling
	Perfo A/C	→ 0 %	45 °C	Curb Weight + 2	Comfort cooling
	WLTC 23°C	→ 0 %	23 °C	Curb Weight + 2	No cooling activat°
	Perfo peak variable temp	→ 0 %	xx °C	Curb Weight + 2	Max system perf
Heating	***Standard Heating***	→ 0 %	- 18 °C	Curb Weight + 2	Thermal comfort
	Perfo Recovery cold	→ 0 %	- 20°C	Curb Weight + 2	Heating needs
	Corri-door Touquet with QC	→ 0 %	-5°C	Curb Weight + 2	Thermal comfort
	AC charging phase	→ 0 %	- 15°C	Curb Weight + 2	Thermal comfort
	WLTC -7°C	→ 0 %	- 7 °C	Curb Weight + 2	Thermal comfort VS autonomy
	E-traction Chain	↑ var %	40 °C	Curb Weight + 2	Synthesis cycle

Table 4 : Thermal-management evaluating cycles list at the end of July, 20 cycles, goal is to reach 15

Compared to the first list with 22 cycles, 2 Corri-door cycles have been removed because they were evaluating more or less the same parameters, and temperatures have been updated to be as relevant as possible for the evaluation of thermal-management.

The higher temperatures are, the more thermal-management will have to be efficient in order to maintain performances and comfort. Regarding low temperature cycles, it works the same way.

Regarding vehicle weight, "Curb weight + 2" on the one hand is quite common in real life situations so it will be applied to comfort dedicated cycles. On the other hand, derating cycles require to put the vehicle in a difficult situation to see how good it can resist, therefore max authorized weight is more relevant.

3.3. Instrumentation

3.3.1. Passenger compartment instrumentation

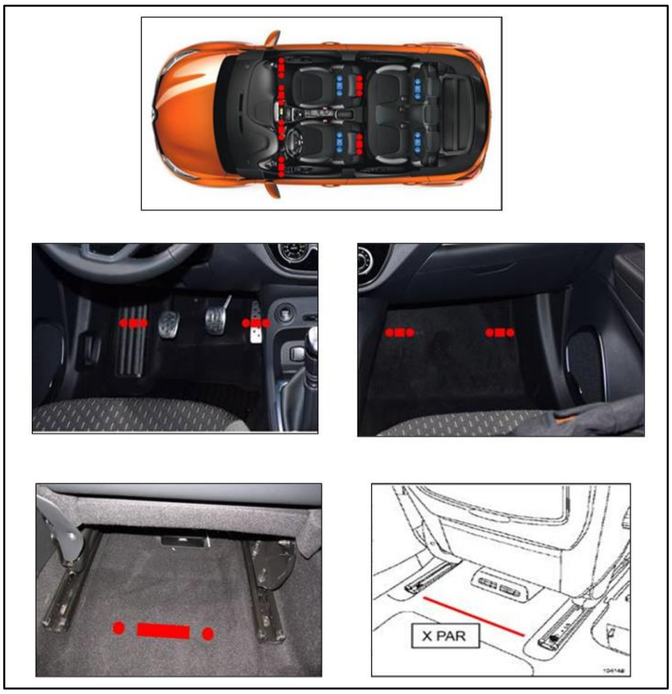

Figure 27 : thermal instrumention in passenger compartment (Renault information)

Passenger compartment instrument (*fig. 27*) can be interesting for Battery Electric Vehicles (BEV) because it allows to evaluate comfort but also to evaluate how comfort is treated when the vehicle is in difficult cycle.
In order to evaluate temperatures in the passenger compartment, thermocouples are installed near aerations for the 4 main passengers (driver, front passenger and back passengers), these thermocouples measure temperatures and evaluate how efficient the air conditioner or heating is.

3.3.2. Mechanical perimeter instrumentation

Battery and Electric Machine (EM) instrumentation on the other hand is a bit more complicated. Indeed, these devices are complex systems that require deep instrumentation that could modify performances. Even if they do not, it is complicated to reach these devices.
Fortunately, some solutions are interesting in order to reach this information without disassembling the whole vehicle, through informatic network collecting all the data of the vehicle. This solution will be discussed in the next chapter.

4. Proposal of communication formalism for the results

Unfortunately, current COVID-19 sanitary crisis the world is facing is slowing down the whole process and the results are still being studied and discussed.

Indeed, thermal-management identification cycles are mandatory to be done, but results also need to be studied after that.
Of course, some of these information are quite simply to measure, intensity, power, temperature of accessible components, but some may be way harder to reach.
For example, electric machine intensity and voltage or battery cell tension cannot be measured with traditional instrumentation.

Many information needed to be studied can be reached through the CAN network (*fig. 28*) (standing for Controller Area Network, is a robust vehicle bus standard designed to allow microcontrollers and devices to communicate with each other's applications without a host computer) of the vehicle, only accessible with the OBD socket (*fig. 29*) (standing for On-Board Diagnostic an automotive term referring to a vehicle's self-diagnostic and reporting capability. OBD systems give the vehicle owner or repair technician access to the status of the various vehicle sub-systems).

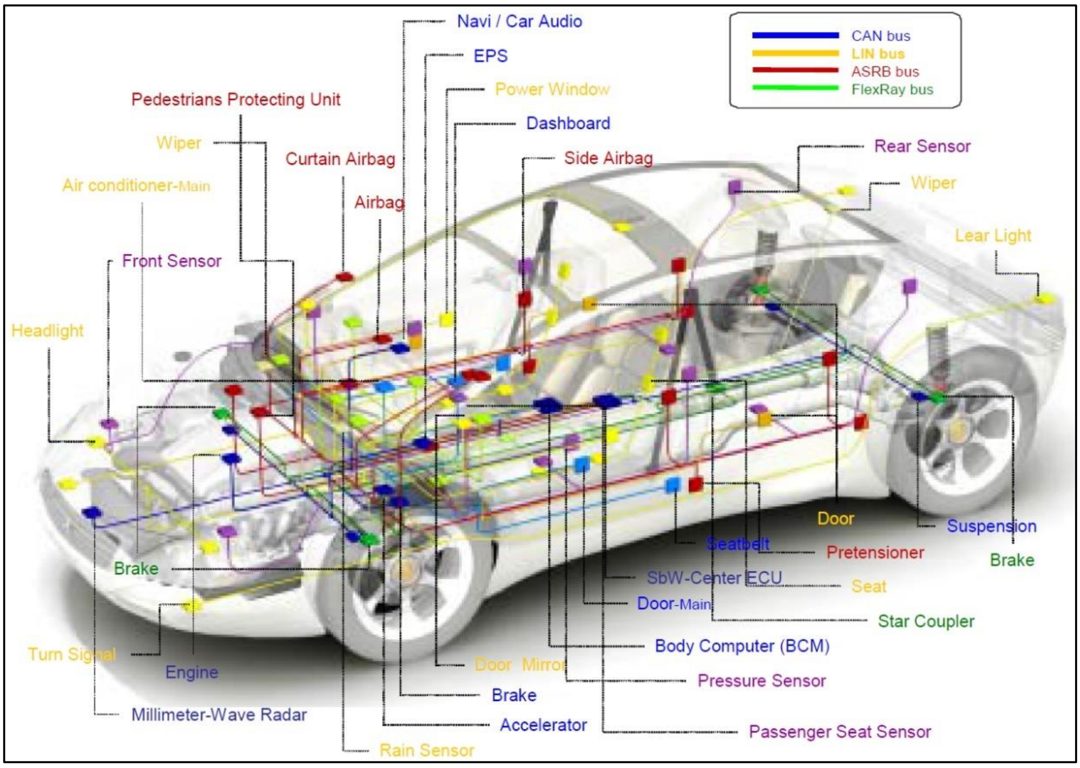

Figure 28 : Typical CAN network and linked devices in a Light Vehicle (Flexautomotive.net 2015)

Even if CAN data can be easily found, it is encrypted and therefore unusable. In order to deal with this information, signal translation is required so numbers can match units and scales. In order to understand information moving along the CAN network, a “Translation File” is required.

Figure 29 : OBD socket in Renault Kadjar and OBD reader (Wikipedia.en 2021)

Of course, this file is confidential and no car manufacturer would share it, even less with competitor trying to have better vehicles.
However, some companies are specialized in this area, technicians and engineers study the CAN network information and translate it in order to have usable data.

Actually DEA-MSM1 is working with this type of companies in order to have usable data for currently studied vehicles (DEA-MSM1 Test Vehicle 1, 2, 4 and Fiat 500e). But as this type of request is quite expensive (at least 30k€) and can become complicated if not all team have agreed on the data they need and that more information is requested. In the beginning of July, a first list has been written (*Table 5*) in order to know what was easily measurable and what requested a Translation File.

Sector	Information	Ways to get it
Technical	Vehicle Speed	Rolling bench + CAN
	Power to wheels	Rolling bench + road-load
Electric Machine	EM rotational speed	Rolling bench + gear ratio
	EM electric current	CAN
	EM electric voltage	CAN
	EM temperatures	?
	EM maximum allowed temperature	CAN
	EM cooling fluid temperature (in/out)	CAN
Battery	Battery current	CAN
	Battery voltage	CAN
	Battery SOC	CAN
	Battery maximum allowed temperature	CAN
	Battery cooling fluid temperature (in/out)	CAN
Air Conditioner	A/C temperature	Ok (thermocouples)
	A/C compressor rotational speed	CAN
	A/C position	Ok
Others	External temperature	Ok
	Amount of sunshine	Ok
	12V auxiliary socket	Ok
General parameters	Initial temperature of components	Ok
	Drive mode (Range / Normal / Sport / …)	Ok
	Regenerative braking mode	Ok
	Vehicle weight	Ok
	Vehicle km	Ok

Table 5 : First List of measurement Data

The situation is quite uncomfortable in Renault because of the sanitary crisis and the electric technical revolution so this budget has to be discussed in intern in order to evaluate what information truly is important and if it is worth to spend money for that.
After this, DEA-MSM1 project leaders have to write the functional specification and to do a request for proposals in order to choose the best company to do the requested tasks.

At the moment, Alliance Cost Office (ACO) and DEA-MSM1 have agreed on a budget and DEA-MSM1 are working on a list of data to collect using previous document and talking with several technical teams in order not to miss any parameter to measure.
In September, request of proposals will be submitted in order to have the first results by the hand of the year for at least one car (DEA-MSM1 Test Vehicle 2, C-segment).

5. Competitors Powertrain Project Leader Internship

5.1. Working in a big company during a pandemic

Because of the current sanitary crisis the world is facing, working habits have been deeply modified, especially in the biggest companies.
If I had done my internship in 2019, I would have worked 5 days a week and spend my day at the office with the whole team. But this sounds like ancient world memories : since the beginning of the pandemic and thanks to French government help, most of Renault employees are not working on Fridays in order to reduce costs and to deny the virus transmission, but moreover, employees are encouraged to work from home as much as possible.

DEA-MSM1 team is split between two engineering centers in "Île-de-France" (the region around Paris, France's main city), therefore team members are familiar with meeting softwares and have remote working habits for a while. For instance, weekly team meeting called RUET (réunion d'unité élémentaire de travail, standing for elementary working unit meeting) is organized on Microsoft Teams software for some years.

Hopefully, I had the opportunity to work a lot from the office and to meet in person everyone in the team. During the first 3 weeks, I was able to come in person to the office, so I got familiar with my working environment and my colleagues. Thanks to this, the locked-down period that followed (which lasted around a month) has been really easy to overcome as I already had working habits.
After this, the situation was better and I had the opportunity to work a lot at the office. However, Fridays remained locked until August, so on these days I was focusing myself on the master's thesis.

5.2. Assisting the Project Leader

Miss Isabelle BONFAND, my internship tutor, has been working in Renault for more than 20 years. She has worked with many teams for several projects but since a few years she is in the Mechanical Market Intelligence team. First, she was Project Leader for spark ignition (SI) engines but she became Project Leader for electric vehicles (BEV) since the beginning of 2021.
During the first part of the report, we discussed about the first half of my task during my internship : thermal-management and benchmarks. Now we will talk about the other half : assisting the project leader in her tasks.

5.2.1. Renault's team DEA-MSM1

Renault's employees are separated in sectors depending on the topics they are working on.
The team I was working in is in the Mechanical Engineering sector (M), more precisely it is working on mechanical strategies to adopt for future vehicles (S). Finally, my unit works on other car manufacturers solutions and technologies and evaluate them compared to Renault's solutions, defining it as the Market Intelligence Unit (M).
All combined, the team name is DEA-MSM1 (*fig. 30 and 31*)

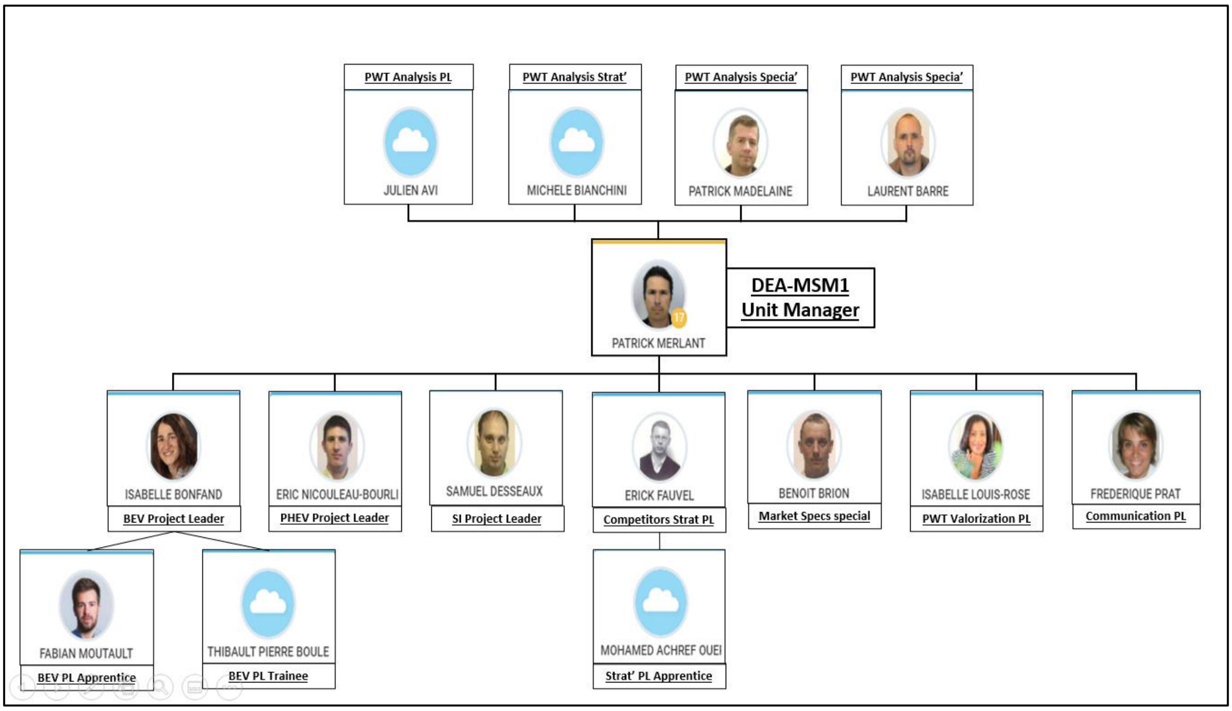

Figure 30 : DEA-MSM1 Organization Chart on August 2021

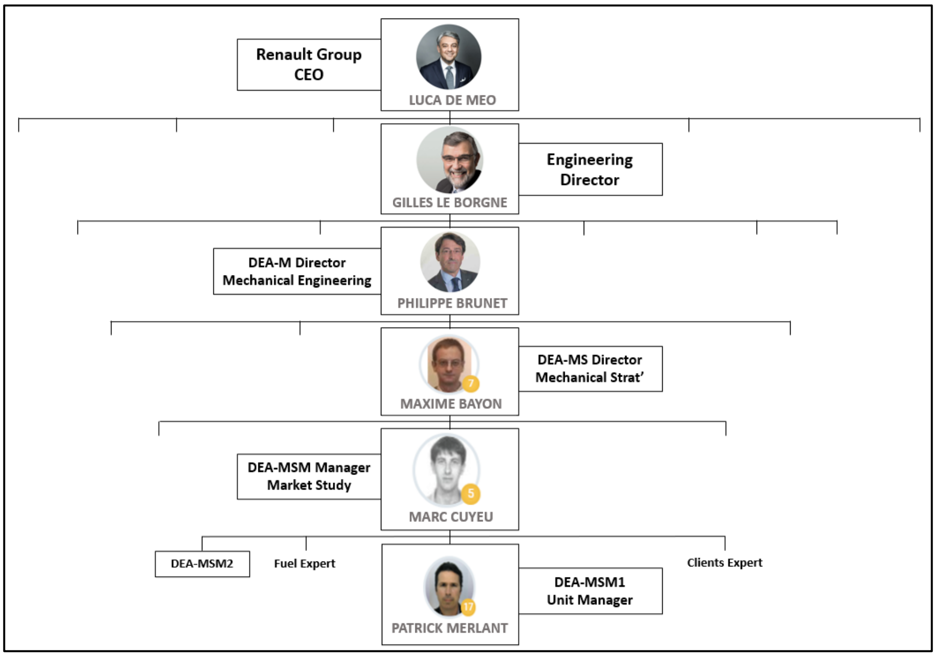

Figure 31 : Renault Group Organization Chart from DEA-MSM1 to CEO

Historically, the team was located at Lardy Technical Center (CTL) because of the proximity with the tracks and test-benches. Nowadays, half of the team is still located over there, but the other half works at the Technocentre (stands for "Technical Center") (*fig. 32*), Renault's R&D headquarters. Both centers are 40 minutes apart by car.

Figure 32 : Renault Biggest R&D center : Le Technocentre, in Guyancourt, near Paris

The team is composed of :

- Patrick MERLANT : Product Knowledge Chief Unit
- Isabelle BONFAND : EV Competitors powertrain Project Leader
- Érick NICOULEAU-BOURLES : HEV and PHEV Competitors powertrain Project Leader
- Samuel DESSEAUX : SI Competitors powertrain Project Leader and powertrain Specialist
- Isabelle LOUIS-ROSE : Powertrain valorization and competition Project Leader
- Benoit BRION : Market specifications Specialist
- Érick FAUVEL : Competitors strategies Project Leader
- Frederique PRAT : Communication Project Leader
- Julien AVI : Powertrain Static Analysis Project Leader
- Michele BIANCHINI : Powertrain Static Analysis Strategy
- Patrick MADELAINE : Powertrain Static Analysis Specialist
- LAURENT BARRE : Powertrain Static Analysis Specialist
- Mohamed Achref OUERTATANI : Érick FAUVEL's apprentice until 2022
- Diego VASQUEZ : Isabelle BONFAND's apprentice until the 31st of July 2021
- Reda BOUMAYLA : Isabelle LOUIS-ROSE's apprentice until the 31st of July 2021
- Fabian MOUTAULT : Isabelle BONFAND's apprentice until 2022
- Thibault-Pierre BOULENGER (me) : Isabelle BONFAND's trainee

(Apprentices are long term interns doing half their time at school and the other half in the company whereas trainees are working full-time in the company)

Vehicle Project leaders (whether BEV, HEV, PHEV or SI engines) are responsible for several cars during their test sessions. However, they do not lead these tests by themselves. Many actors from different working units take part in the process (*fig. 33*), and project leaders have to coordinate these actions, to gather all results and to present them with precise conclusions at the end of the process. During this process, many other tasks are to be done in order to collect information regarding tested vehicles, are new coming ones that are not yet being tested but that will be on the schedule shortly.

Figure 33 : Several competition project leaders (finance, electronics, ...) analyzing the power box of the MY2021 Fiat 500e

5.2.2. Powertrain specifications

Powertrain specifications sheet is a simple Excel document presenting the most important information regarding the powertrain of the car we are studying.
The goal is to have a clear document that is available for anyone who can get close to the car, during dynamic or static tests, but also during driving test, whether it is for technicians or directors when they are driving the car.

On this document, we can find several information such as (*Table 6 and 7*) :

<table>
<tr><th colspan="3">General information</th></tr>
<tr><td colspan="3">Brand / Model / Model year
Market and segment
Type of energy
Version
Picture of the vehicle
Picture of the powertrain
Serial number</td></tr>
<tr><th>Engine and battery specifications</th><th>Power transmission and consumptions</th><th>External specifications</th></tr>
<tr><td>Type of engine or EM
Position
Maximum power (hp/kW)
Maximum torque (N.m)
Battery parameters
Battery cooling
Heating system
Braking system

Details (Driving modes, charging time, regenerating modes, smartphone application functions, …)</td><td>Autonomy
Maximum speed
Gear ratio
Type of propulsion

Consumption regarding situations :
WLTC 23°C
WLTC summer/winter
(several sources)</td><td>Dimensions
Tires
Mass
(several sources)</td></tr>
</table>

Table 6 : Information in the powertrain specifications sheet

During my internship, I did several powertrain specifications sheets for electric cars in the 2021 schedule, but also some Renault cars for the test days so testers can have clear comparisons between Renault and competitors' vehicles, but this topic will be discussed during 5.2.7. part.

Vehicles studied :

Competitor's vehicles	***Renault's vehicles***
DEA-MSM1 Test Vehicle 1 (B-Segment) DEA-MSM1 Test Vehicle 2 (C-Segment) Fiat 500e Icône Plus (Test Vehicle 3) DEA-MSM1 Test Vehicle 4 (C-Segment)	Dacia Spring MY2021 Renault Twingo EV Renault Zoe MY2021

Table 7 : Powertrain specifications sheets realized

Powertrain specifications sheet is a document that will be useful any many other situations. This document will be used again in the press review of the studied vehicle. As followed (*fig. 24*), we can see that we are adding other interesting visuals in order to have a better understanding of the vehicle.

Caractéristiques techniques e-PWT

Fiat 500e – 87 kW – 220 N.m

Marque	Fiat	
Véhicule	500 electric	
Année Modèle / Segment de gamme - Marché	2021	A-Segment - France
Motorisation	**Electrique**	
Version	Icône Plus 118 cv - coloris Onyx Black	
CARACTERISTIQUES MOTEUR ET BATTERIE		
Type de moteur	Moteur synchrone à aimants permanents	
Implantation sur véhicule	Essieu avant / Traction	
Puissance maxi	**87 kW / 118 Ch**	
Puissance continue en 30 min	*43 kW*	
Couple max	220 N.m	
Batterie	42 kWh Lithium-Ion NCM622 / 37,3 kWh Utile (96 cells dans 8 modules) - 294 kg annoncés	
Implantation sur véhicule	Sous plancher (et arriére)	
Tension batterie	400 V	
Puissance en sortie	-	
Refroidissement batterie	Par eau	
Pompe à chaleur	Non (Résistances chauffantes pour l'habitacle)	
Système de freinage découplé	Oui	
Points remarquables :	1er véhicule électrique de Fiat, basé sur une nouvelle plateforme dédiée (plateforme 332). Présence d'un Park Lock. **2 lois de récupératif sur levier :** Range et Sherpa Le mode Range permet de moins utiliser le frein et de conduire à une pédale ou presque. Le mode Sherpa déconnecte en plus tous les systèmes consommant trop d'énergie. **3 modes de conduite :** Normal / Range / Sherpa. **Chargeur :** Adaptatif mono-triphasé de 2 kW à 11 kW et DC jusqu'à 85 kW. **Temps de charge :** - DC 85 kW charge rapide (15-80%) : 30min - AC 11 kW borne publique (15-100%) : 3h20 - AC 2 kW prise domestique (15-100%) : 18h30	
TRANSMISSION		
Marque - Désignation boîte / Type de propulsion		4x2 - FWD
Type de boite - Nbre de Rapports - Ratio réducteur	**Boîte de vitesses avec réducteur à un seul rapport - Ratio 9,559**	
PERFORMANCES		
Vitesse maxi	**150 km/h**	
Autonomie en tout électrique	314 km (WLTC - données constructeur)	

CONSOMMATION		
Emissions CO_2 sur cycle WLTC	**0 g CO_2/km**	
Consommation cycle mixte	14,3 kWh/100 km (données COC)	
DIMENSIONS extérieures - MASSE		
Longueur / Largeur / Hauteur	3632 / 1683 / 1529	
Type Pneumatique - Développée roue calculée	205/45 R17 88V	1,879 m
PTAC	1690 kg	
M_{VODM}	1290 kg (catalogue) - 1356 kg (mesure A2MAC1) - 1365 kg avec conducteur (COC)	

La Fiat 500 est le premier véhicule de série dédié à l'électrique de la marque italienne, avec une toute nouvelle plateforme. Elle dispose d'une **batterie de 42 kWh refroidie par eau**, promettant une **autonomie de 320 km en cycle mixte** et autorisant la **recharge DC jusqu'à 85 kW.** La batterie placée sous le plancher rend le comportement routier bon malgré le poids, qui permet quant à lui un freinage régénératif efficace.

Figure 34 : Fiat 500e powertrain specifications page in the press review

5.2.3. Press review

As we just discussed, press reviews ("Revues de presse") are a hot topic in the team as it is necessary to present these vehicles which are uncommon for Renault employees (*fig. 35*).

Figure 35 : Fiat 500e press review front page

When a vehicle is bought and about to arrive, DEA-MSM1 project leaders write press reviews in order to present the vehicle, to collect data and opinions from several respected medias. Thanks to this document, it is easier to have a first opinion on the vehicle, but also to start thinking on what will be interesting to study.

The Press Review document is organized as following :
- Front page (with some powerful visuals) (*fig. 35*)
- Summary
- Video presentation of the vehicle (coming from TV or from respected medias on Youtube)
- Powertrain specifications (*fig. 34*)
- Models available and specifications (dimensions, autonomy, power, …)
- Press review, gathering interesting parts of respected medias regarding the positive and negative points of the powertrain studied in the document. Highlighted in red if considered as negative, or in green if considered as positive (*fig. 36*)
- Conclusion (*fig. 37*)
- Back page with a link leading to DEA-MSM1 Yammer page

Figure 36 : Fiat 500e press review section

Press review (*fig. 36*) section can last approximatively 10 pages, but more articles are gathered. In general, articles agreeing each other or telling the same things are displayed only once. As we said earlier, the only parts copy-pasted are the ones talking about powertrain related topics. Comfort or infotainment systems are not discussed in DEA-MSM1 press reviews but by the CAC team.

Conclusion section (*fig. 37*) is quite important as many people will only check this very last page in order to get a fast opinion on the studied vehicle (for example directors before taking the car for the weekend in order to drive it by themselves and make their own opinion about it).
Here are gathered the most interesting points of the vehicle, whether they are good are bad, they can lead awareness on parameters to study during the several planned tests. For example for the Fiat 500e received in March 2021 and currently being tested, articles agree on the fact that the vehicle is quite dynamic despite its weight, that its autonomy and charging phase are correct and that the regenerative braking is efficient. On the negative aspects, it is pointed that there is a unique

A simple sentence is also added in order to have a simple conclusion on the car, for example for the Fiat 500e : "Fiat modernizes its emblematic model with a dynamic and hardy vehicle. Its unique regenerative mode, even if it is efficient, seems to have some issues at low speed" (*fig. 37*).

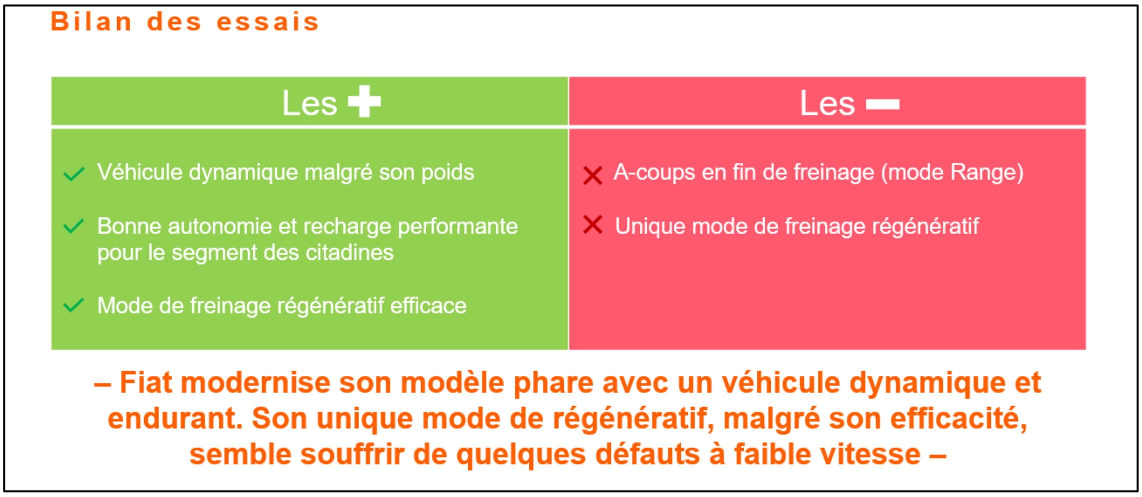

Figure 37 : Fiat 500e press review conclusion

However, it is sometimes interesting to add other parts in order to highlight a specific point whether it is positive or negative.

Here (*fig. 38*) is displayed a page of the DEA-MSM1 Test Vehicle 4 press review. There is a CO_2 emissions comparison we other European vehicles from the same segment (DEA-MSM1 Test Vehicle 4, TV5, TV6 and TV7).
This graph is quite interesting because it highlights several things :

- Current TV5 is not ready for 2022 malus change.
- DEA-MSM1 Test Vehicle 4 is ready for this change.
- TV6 with mechanical gearbox rejects way less CO_2 than the same vehicle but equipped with automatic gearbox.

Such a simple graph can be very useful for developing teams as they have clear numbers to aim in order to be at least as good as competitors.

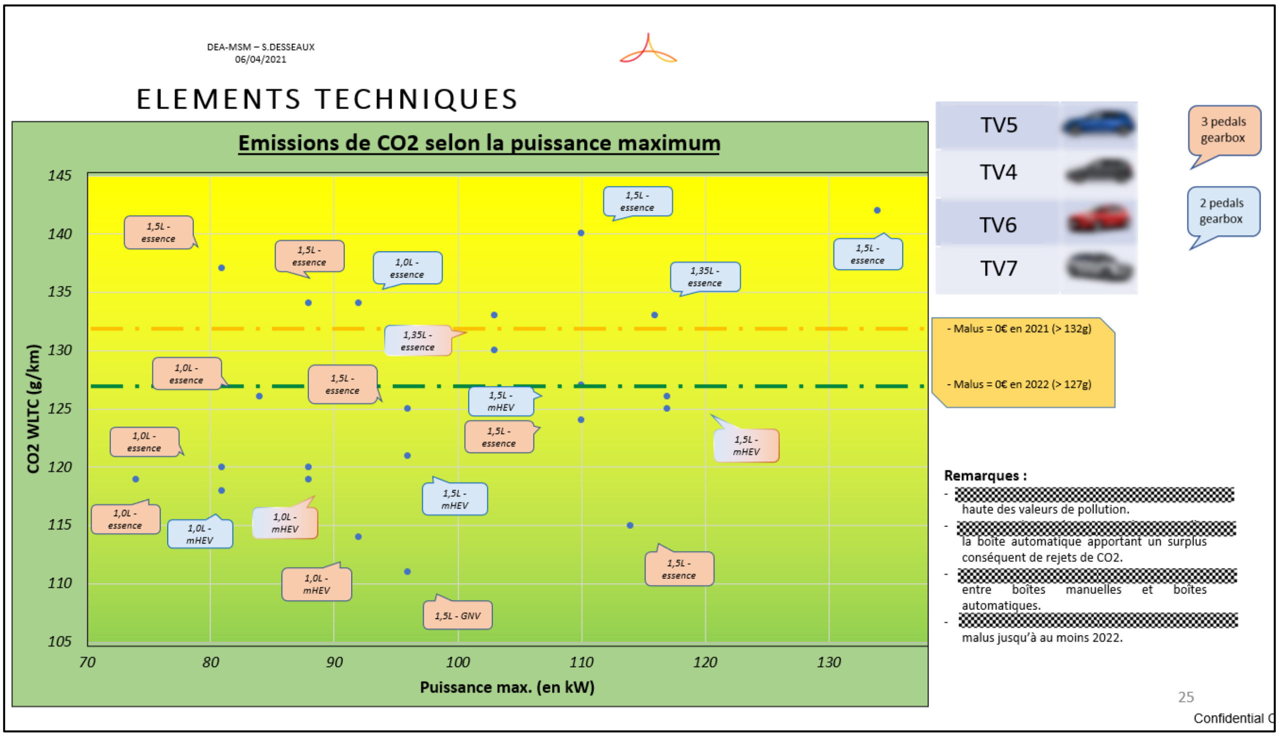

Figure 38 : DEA-MSM1 Test Vehicle 4 press review - CO_2 emissions comparisons

Even if vehicles are studied at the same time by DEA-MSM1 and CAC teams, press review documents are written separately. It is because the two teams are totally separated in Renault's organization. DEA-MSM1 depends on the engineering sector whereas CAC depends on the "vehicle" sector.
Nevertheless, both teams of currently merging their work in order to reduce costs : Fiat 500e and DEA-MSM1 Test Vehicle 2 are the first vehicles studied mutually by both teams, which means that they have the same vehicle and will present their results during the same meeting.

5.2.4. Trimestral top sells and scatter-bands

One of the new missions of the project leaders for 2021 is to raise trimestral top sells and scatter-bands in order to have a better overview of the current European market.
In order to have serious numbers, DEA-MSM1 is working with Schmidt Automotive Research, a German company specialized in registration calculations, exploiting them in order to have clear numbers for European countries, for BE vehicles but also PHEV or fuel vehicles.

DEA-MSM1 received the Q1 report at the end of march and I worked on the results during May and June (*fig. 39*).

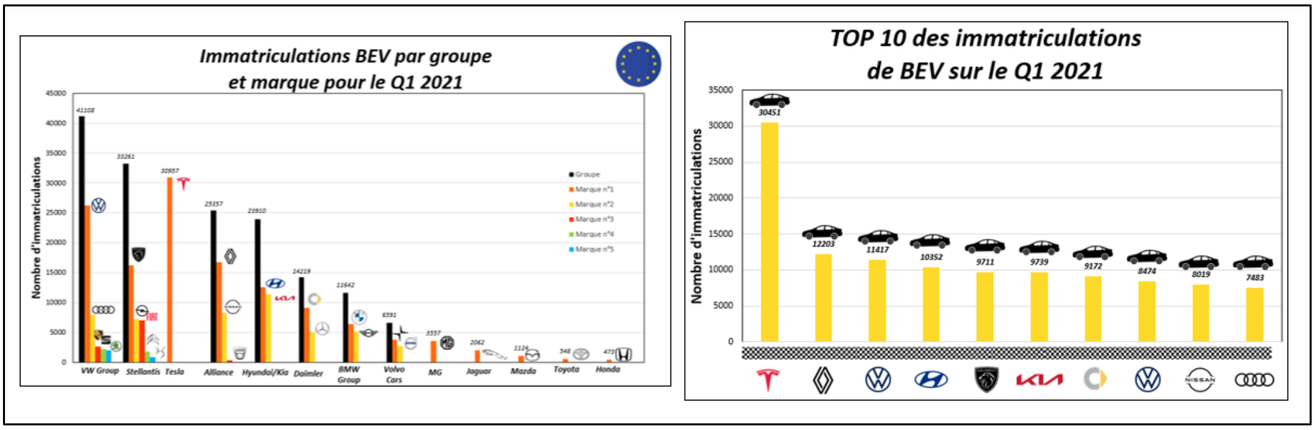

Figure 39 : Q1 2021 BEV top-sells - top brands and top 10 vehicle registrations in Europe

The document is structured as following :

- Front page
- Summary
- Top sells and details (*fig. 39*)
- Scatter-bands (the definitive graphs are still being discussed)
- Global table summing up specifications of the vehicles presented
- A more precise presentation of each vehicle studied, similar as in press reviews
- Back page with a link leading to DEA-MSM1 Yammer page

As it is the first time the project leaders are requested to do such a document, project leaders discussed a long time about the graphs to showcase depending on how relevant they are.
Moreover, sources regarding these vehicles' specifications are a hot topic as it is complicated to have all the interesting values from a same, trustful source.

Regarding charging time for example, Renault teams are working with specific settings to evaluate charging performances of the studied vehicle : 15-100% for AC charging and 15-80% for DC charging, with stable summer weather.
The internet website Automobile-Propre.com (standing for "Clean automotive") can be really interesting for this type of requests. There is a charging simulator displaying charging times depending on the battery SOC at the beginning and the ending of charge, but also external weather (winter or summer), and type of charge, going from low AC charging to high DC charging (*fig. 40*).

Figure 40 : Fiat 500e Automobile-Propre.com charging simulator UI

Even if this simulator is not perfect, it allows us to have homogenous data for all the vehicles tested and to draw charging scatter-bands (*fig. 41*).

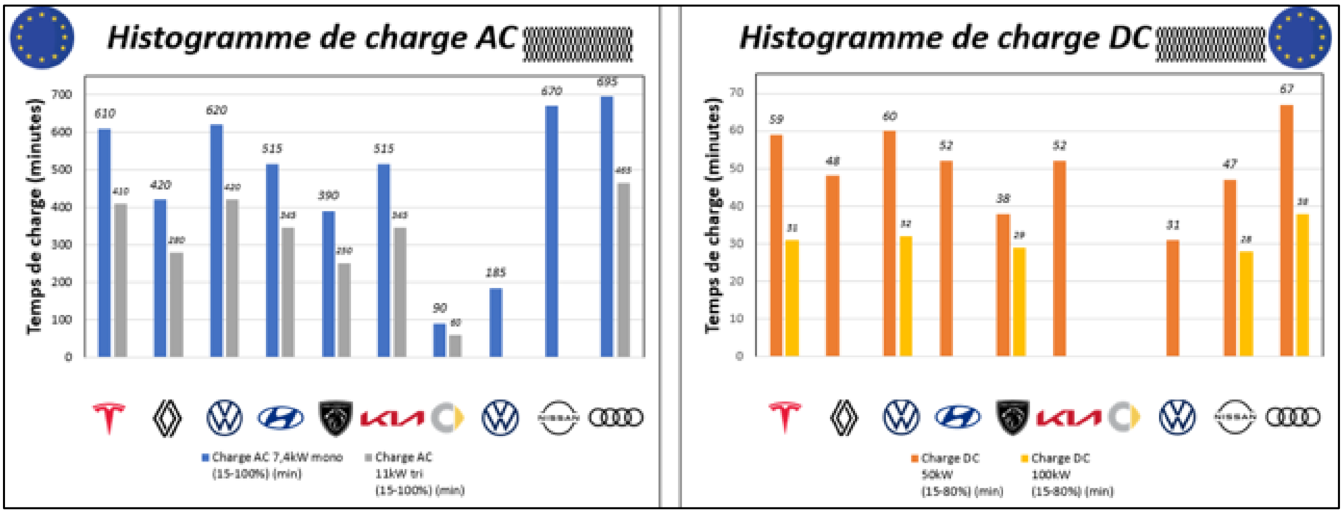

Figure 41 : Charging scatter-bands for Q1 top 10 EV vehicles

At the moment, the final shape of the document is still being discussed by the project leaders, but many graphs have been realized :

- Autonomy depending on usable battery capacity
- Energy consumption depending on SCx
- Energy consumption for high-speed depending on SCx
- Energy consumption depending on vehicle mass (*fig. 42*)
- Energy consumption for high-speed depending on vehicle mass
- AC and DC charging time (*fig. 41*)
- AC 11kW charging time depending on usable battery capacity
- AC 11kW charging time depending on usable battery capacity
- AC 11kW charging time depending on usable battery capacity
- AC 11kW charging time depending on usable battery capacity
- Vmax depending on maximum power
- 0-50 km/h acceleration depending on maximum power
- 0-100 km/h acceleration depending on maximum power

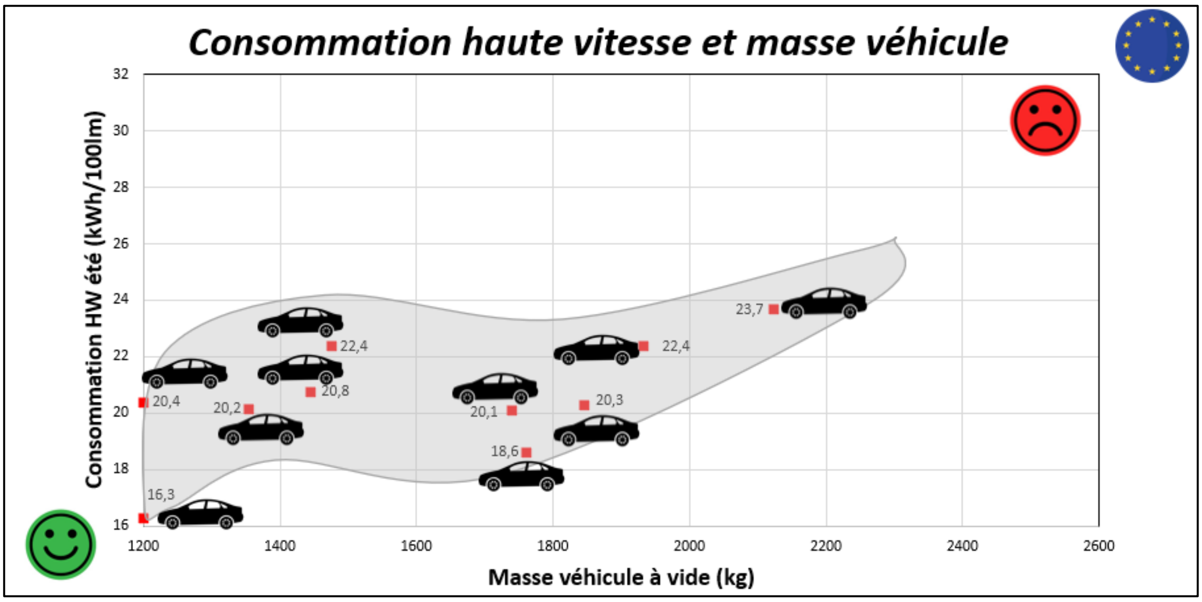

Figure 42 : Example of a graph – High Speed Consumption and vehicle weight

The goal of this document is not to draw conclusions thanks to the graphs or data that is showcased, but to display comparisons between these vehicles so the reader can have a better point of view of the market at the moment.
It is then up to the reader to conclude if vehicle #1 is performing better than vehicle #3 and why.

To be noted : The specifications of the vehicle showcased are the specifications of the vehicle with the biggest autonomy. For example, Tesla Model 3 has 3 versions currently in Europe : Standard Plus Autonomy, High Autonomy and Performances. High autonomy version is the model with the highest autonomy, so all the specifications showcased in the scatter-bands will be based on this vehicle. This choice has been done by the project leaders in order to have the same way of results display through the documents.

5.2.5. Future vehicle and platform presentation

During a 6-month internship, news can happen, especially in the high-tech world.
Already presented a while ago (as a prototype), some news was published at the end of the first trimester 2021. As Car Manufacturer Z is an international brand, Renault International agency published a short document with the specifications presented earlier. DEA-MSM1 then had the mission to present an updated version of this document to the strategical director Axel PLASSE in order to have a better overview of the vehicle, but also the intents it has on the market.

The goal was to understand Car Manufacturer Z strategy regarding their new electric platform (GMP-Z) but also to present the technologies included in the first vehicle with this platform : Competitor Vehicle Z

The document is structured as following :

- Front Page
- Introduction
- Summary
- Competitor Vehicle Z presentation
- GMP-Z modularity
- Car Manufacturer Z roadmaps (roadmaps by brands, by models, and for the future GMP-Z2) (*fig. 43 and 44*)
- GMP-Z presentation with several pages discussing new technologies included
- Specifications table Competitor Vehicle Z, Renault Test Vehicle A and competitors (*fig. 45*)
- Conclusion

Renault International agency compiled some information regarding new technologies in the powertrain but it was necessary to study Car Manufacturer Z group strategy for this new full electric platform.

IHS Markit is a company specialized in this type of information : it compiles production numbers of almost every factory around the world and displays many of the specifications of the vehicle. Thanks to this database, it is possible to do an Excel extract and then to study the numbers with Spotfire.
Then it is necessary to analyze the numbers in order to get clearer ideas of what will Car Manufacturer Z strategy will be with this GMP-Z (*fig. 43*) : it is visible that around 7 vehicles will be produced with the GMP-Z platform, 3 for sub-brand Z1 and 4 for sub-brand Z2. Competitor Vehicle Z and Competitor Vehicle Z' will be the only vehicles produced in Europe, others will be imported. Thanks to IHS Markit

database, we can also see approximative numbers of productions : almost 2M5 vehicles for sub-brand Z1 and around 3M units for sub-brand Z2, with important shares for Competitor Vehicles Z and Z' (*fig. 43*).

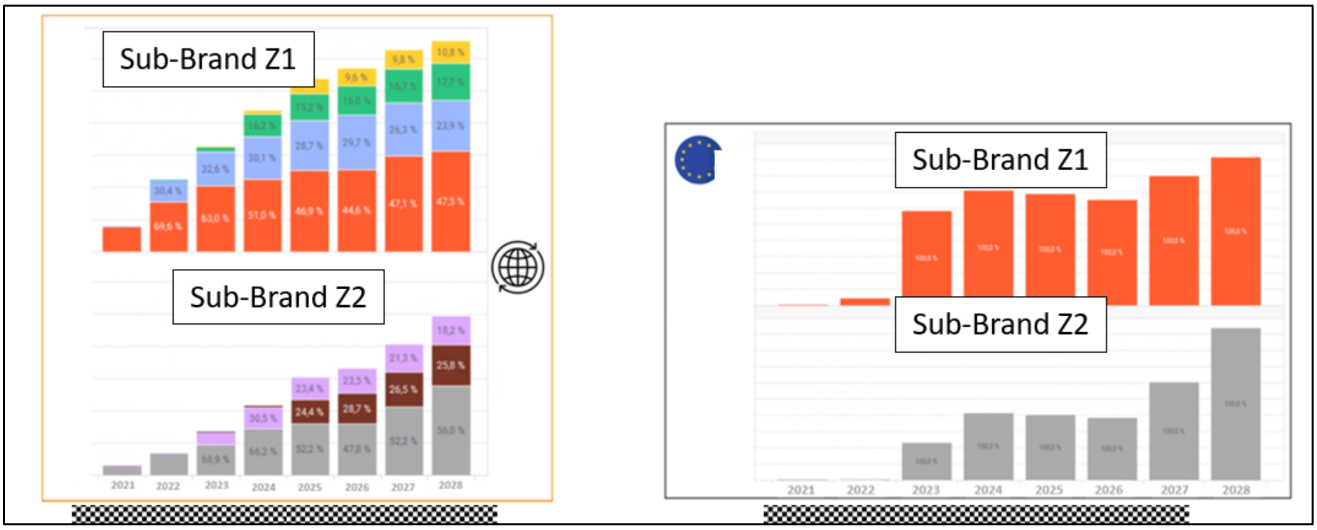

Figure 43 : GMP-Z vehicles worldwide and European production schedule

But if we dig a bit more, we can spot several starts of production (SOP) dates, meaning that the start of delivery will follow. But even more, we can spot possible facelifts dates, as shown below (*fig. 43*) with minor updates of competitor vehicles. At the middle of their career, the cars will be a bit updated to match its future competitors which will be more recent.

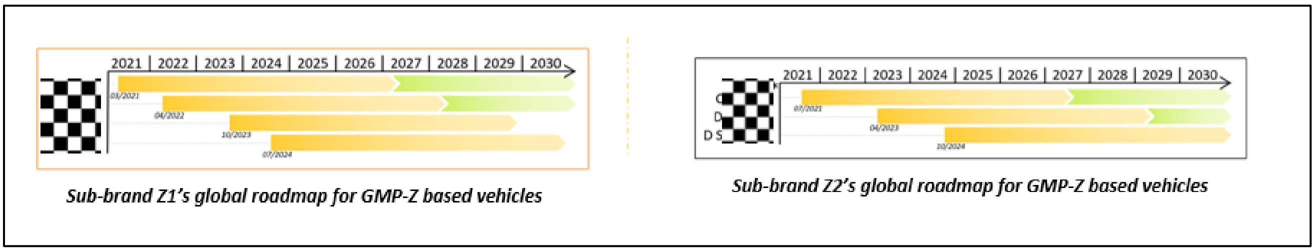

Figure 44 : Car Manufacturer Z roadmaps

In order to have a fast comparison with other vehicles that will directly compete with the Competitor Vehicle Z, there also is a table showcasing important parameters of these vehicles (fig. 34). These vehicles can be brand new, like the new Competitor Vehicle Z or the DEA-MSM1 Test Vehicle 2, or they can be the current market leader, like the Tesla Model 3, or the future Renault full electric vehicle.

Thanks to this table, it is easier to see that these vehicles will be in the same segment, with similar performances and prices. But their differences are also eye-catching : Competitor Vehicle Z will be the only one to have some types of feature and such a big wheelbase regarding its dimensions.

Vehicle		Competitor Vehicle Z	Renault Test Vehicle A	Renault Test Vehicle A'	DEA-MSM1 Test Vehicle 2+	Competitor Vehicle 1'
Dimension [mm]	Length	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Width	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Height	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Wheelbase	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Powertrain	Power [kW]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Torque [Nm]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	0 to 100 kph [sec]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Max. Speed [kph]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Battery Capacity (usable) [kWh]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
DC Charging (0-80%)	*350kW (800V)	[illegible]				
	250kW (400V) – by Tesla					[illegible]
	150kW (400V) – by Tesla					[illegible]
	100kW (400V)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	50kW (400V)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Autonomy [km] (WLTP 23)		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Energy consumption [kWh/100km] (WLTP 23)		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Tire [inch]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Weight [kg]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Expected price (excluding option, subsidy)		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Figure 45 : Specifications table with Competitor Vehicle Z, Renault Test A and competitors

To be noted : This document has been written in English as it comes from Renault International agency, and that it will be useful for other teams, not necessarily in French speaking countries (Romania, Korea, Brazil, …)

5.2.6. MS Project and schedules

Because of the COVID-19 sanitary crisis, most of the team members were working from home on a regular basis. For this simple reason, communication and relationships between team members were harder, but moreover, organization and planification was getting really complicated.
To handle this issue, one of the 2021 project leaders' objectives was to work on a global common planification sheet.
Using Microsoft MS Project software, the goal was to set precise schedules for each vehicle the team was working with.

	B	Fiat 500e 87kW CAC2216 DEA-MSM1	Date réception véh	Réception	0 jr	Lun 08/03/21	Lun 08/03/21	
	B	Fiat 500e 87kW CAC2216 DEA-MSM1	Rodage	Rodage	5 jrs	Lun 15/03/21	Ven 19/03/21	693
	B	Fiat 500e 87kW CAC2216 DEA-MSM1	Rédaction Fiche technique et diffusi	Rédaction fiche technique et diffusion VIN	3 jrs	Lun 22/03/21	Mer 24/03/21	694
	B	Fiat 500e 87kW CAC2216 DEA-MSM1	Expo	Prépa véh pour expo0	2 jrs	Jeu 25/03/21	Ven 26/03/21	695
	B	Fiat 500e 87kW CAC2216 DEA-MSM1	Expo	Expo 0 : véh décaréné sur le pont	5 jrs	Lun 29/03/21	Ven 02/04/21	696
	B	Fiat 500e 87kW CAC2216 DEA-MSM1	Logistique	Transfert CTL > soufflerie S2A (Montigny)	5 jrs	Lun 05/04/21	Ven 09/04/21	697
	B	Fiat 500e 87kW CAC2216 DEA-MSM1	Soufflerie véh	Passage en soufflerie (détermination SCx)	4 jrs	Lun 12/04/21	Jeu 15/04/21	698
	B	Fiat 500e 87kW CAC2216 DEA-MSM1	Logistique	Transfert soufflerie S2A (Montigny) > TCR	1 jr	Ven 16/04/21	Ven 16/04/21	699
	B	Fiat 500e 87kW CAC2216 DEA-MSM1	Logisitque	Transfert TCR > CTL	5 jrs	Lun 19/04/21	Ven 23/04/21	700
	B	Fiat 500e 87kW CAC2216 DEA-MSM1	Agrément	Agrément	29 jrs	Lun 26/04/21	Jeu 03/06/21	701
	B	Fiat 500e 87kW CAC2216 DEA-MSM1	Synthèse Métier	Synthèse agrément	15 jrs	Ven 04/06/21	Jeu 24/06/21	702
	B	Fiat 500e 87kW CAC2216 DEA-MSM1	Logistique	Transfert CTL > TCR	1 jr	Ven 04/06/21	Ven 04/06/21	702
	B	Fiat 500e 87kW CAC2216 DEA-MSM1	Analyse fonctionnelle	DEA-MUA : DC-DC / CEM / SDF / EVSE	15 jrs	Lun 07/06/21	Ven 25/06/21	704
	B	Fiat 500e 87kW CAC2216 DEA-MSM1	Synthèse Métier	Synthèse DEA-MUA	15 jrs	Lun 28/06/21	Ven 16/07/21	705
	B	Fiat 500e 87kW CAC2216 DEA-MSM1	Logistique	Transfert TCR > CTL	1 jr?	Lun 28/06/21	Lun 28/06/21	705
	B	Fiat 500e 87kW CAC2216 DEA-MSM1	Essai	Essais découvertes CTL	5 jrs	Mar 29/06/21	Lun 05/07/21	707
	B	Fiat 500e 87kW CAC2216 DEA-MSM1	Logistique	Transfert CTL > TCR	4 jrs	Mar 06/07/21	Ven 09/07/21	708
	B	Fiat 500e 87kW CAC2216 DEA-MSM1	Prêt CAC	Prêt véh au CAC (Caroline Garie)	10 jrs	Lun 12/07/21	Ven 23/07/21	709
	B	Fiat 500e 87kW CAC2216 DEA-MSM1	Logistique	Transfert TCR > CTL	2 jrs	Lun 26/07/21	Mar 27/07/21	710
	B	Fiat 500e 87kW CAC2216 DEA-MSM1	NVH	NVH CTL	30 jrs	Mer 28/07/21	Mar 07/09/21	711
	B	Fiat 500e 87kW CAC2216 DEA-MSM1	Logistique	Transfert CTL > TCR	2 jrs	Mer 08/09/21	Jeu 09/09/21	712
	B	Fiat 500e 87kW CAC2216 DEA-MSM1	Prêt CAC	Prêt véh au CAC	16 jrs	Ven 10/09/21	Ven 01/10/21	713
	B	Fiat 500e 87kW CAC2216 DEA-MSM1	Logistique	Transfert TCR > CTA	5 jrs	Lun 11/10/21	Ven 15/10/21	714
	B	Fiat 500e 87kW CAC2216 DEA-MSM1	Perfo	Perfo-conso DEA-TP	45 jrs	Lun 18/10/21	Ven 17/12/21	715
	B	Fiat 500e 87kW CAC2216 DEA-MSM1	Logistique	Transfert CTA > CTL	5 jrs	Lun 20/12/21	Ven 24/12/21	716
	B	Fiat 500e 87kW CAC2216 DEA-MSM1	Synthèse Métier	Synthèse perfo-conso	15 jrs	Lun 20/12/21	Ven 07/01/22	716

Figure 46 : Fiat 500e timetable, from reception to synthesis report

This document is common for the whole team, therefore many cars are represented (*fig. 46*) :

- Gasoline (SI) vehicles (project leader : Samuel DESSEAUX)
- HEV and PHEV vehicles (project leader : Érick NICOULEAU-BOURLES)
- BEV vehicles (project leader : Isabelle BONFAND)

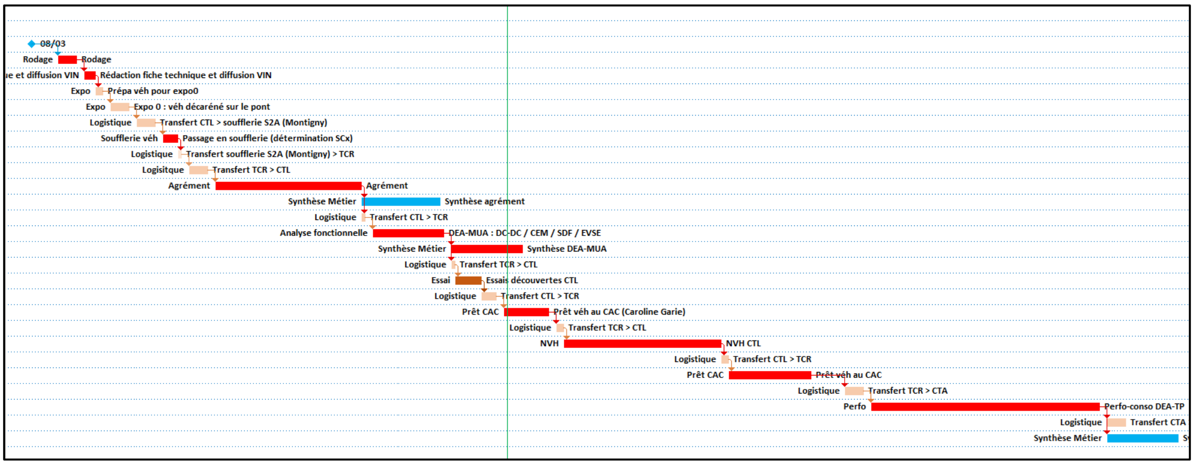

Figure 47 : Fiat 500e schedule diagram, with tasks represented over time

On my side, I worked on BEV schedule from mid-2020 to the end of 2022 for some models arrived during 2021 :

- DEA-MSM1 Test Vehicle 1
- DEA-MSM1 Test Vehicle 2
- Fiat 500e La Prima
- DEA-MSM1 Test Vehicle 5

For each model DEA-MSM1 team is working with several vehicles.
Indeed, during a full vehicle test process, up to 4 cars can be needed to complete all the requested activities. DEA-MSM1 is a team focused on motorization and powertrain systems, so it does not need anything in the passenger compartment, whereas CAC team is actually focused on these parts (passenger compartment, materials, infotainment solutions, …). For this reason and in order to reduce costs, it has been decided that both teams had now to work together, and so to buy cars together.
Before, both teams could be 4 times the same car. For the Fiat 500e (*fig. 47)* for example, they now have 3 vehicles, so they have to arrange schedules. So, it is very important to know at any time where the studied vehicle is, at which Renault center (there are 4 Renault centers in "Ile-de-France", the region around Paris, main city of France).

To be noted : learning how to work with this software has been really interesting because I have been able to see all the test process a car is passing in the DEA-MSM1 team, even if during my internship the vehicles tested did not pass them all because of the schedule.
Also, working on MS Project is quite good for my personal knowledge as many French companies are also using this software and therefore requesting applicants to already have basis with it.

5.2.7. Test days

As DEA-MSM service is split between Lardy and Guyancourt (Technocentre), it is quite rare that everyone is gathered around a common activity, even more during the COVID-19 pandemic.
But its mission is quite unique in the company, as members mostly work on non-Renault cars. For this reason, it is really interesting to organize directors' driving tests and test sessions for team members but also for Renault workers. Directors' driving tests are organized regularly when the vehicles are between two phases, during the weekend mostly. Test sessions are one-time events organized once or twice a year on a regular basis. Because of the COVID-19 pandemic, there has been none in 2020 and the team feared none would be organized in 2021 either.

Hopefully, June month was pretty calm sanitary speaking and the team had the possibility to organize a test day on Thursday the 10^{th}.
This session was centered on two topics :
- HEV and PHEV vehicles competing with new Renault's E-Tech technologies
- BEV vehicles competing with Renault Zoe, Dacia Spring and Renault Test Vehicle A

In order to do these comparisons, many vehicles have been gathered (*fig. 48*) :
- Toyota Yaris HEV MY2021
- Honda Jazz HEV MY2020
- Peugeot 3008 PHEV MY2020
- Volvo XC40 PHEV MY2020

- Hyundai IONIQ MY2018
- DEA-MSM1 Test Vehicle 1
- Fiat 500e La Prima MY2021
- Renault Captur E-Tech PHEV MY2021
- Renault Clio E-Tech HEV MY2021
- Renault Zoe R135 MY2021
- Dacia Spring MY2021
- Renault Test Vehicle A

Figure 48 : BEV line-up for June test day : Spring / Renault Test Vehicle A / Twingo EV / Zoe / IONIQ / 500e / DEA-MSM1 Test Vehicle 1

The event was organized on Lardy dedicated track, and multiple activities were planned to test these vehicles. A slow-speed phase was set in the middle area with zigzags, braking phases, parking phases, roundabout, cobbled surface driving, but there was also an acceleration track and a whole circle to do at high-speed. This part of the track was restricted for any other activity during the session, so testers were free to stop at any time in order to check whatever they needed to (*fig. 49*).

Figure 49 : Lardy Renault Center test track

This event was really interesting because I had the possibility to drive many vehicles, but also because I had the opportunity to meet many members of the team I had only talked to through Teams or during meetings before. Furthermore, we were all reunited around the same interest (*fig. 50*).

Figure 50 : Team photography during June test day

6. Conclusion and discussion

The aim of this master's thesis was to study how thermal-management impact global performances of a Battery Electric Vehicle (BEV) and how to evaluate it.

6.1. Conclusion

Through the scientific research and thesis work I did about thermal-management, DEA-MSM1 now has a clear view on how this topic will be important in the upcoming years. Through cycles study of prototypes and current technologies evaluation, some cycles have been highlighted as interesting for evaluating thermal-management during cooling or heating phases. Moreover, some technologies have been studied and they could improve thermal-management if they were integrated in future BEV.
Since the need was defined and clear, it was easier to work on cycles to choose in order to evaluate thermal-management the best way it is possible. Many teams are involved in the process, therefore many cycles have been considered in the first place.
Now that cycles are precisely defined and that teams have agreed on what to measure during these cycles, the hard part is to deal with subcontractors in order to have the results without losing too much time or too much money.
Unfortunately, external situations caused the process to be slower than planned and denied the final results I aimed to get.

6.2. Discussion

Thermal-management definitely is an important topic and will become a key factor in the upcoming years. But as it is a new system, progress can still be done, especially regarding its evaluation :

- 15 thermal-management evaluating cycles is the goal, but 20 currently studied cycles are interesting and should be considered.

- Instrumentation is such a hot topic as data can be very hard to collect, clear definition of the needs is important and first results will help to define what truly matters.

- CAN network complicates instrumentation and study results as they encrypt all the information Renault engineers would like to collect, a Translation File is required but is it cost efficient to subcontract it for every vehicle DEA-MSM1 is testing ?

- Working with many teams is quite difficult and time-costly, decisions are long to be taken, even if there is a dedicated team working on communication between Renault teams.

7. Personal thoughts

Renault 6-month internship and master's thesis redaction was an interesting experience. In the first place, I was supposed to fully help Miss Bonfand in her project leader tasks but we agreed to divide my work : half my time was dedicated to project leader tasks and the other half was dedicated to thermal-management evaluation. The goal of the second task was to highlight interesting cycles and then to think on what to measure during these cycles in order to interpret how the vehicle reacts during the cycle.

Both parts were interesting as I had the opportunity to work on many things a French engineer will have to do in his career : to deal with scientific data and to work on it, but also to deal with management tasks, schedules and people.
Moreover, working in one of the biggest French automotive company was an incredible opportunity, I met people driven by their passion for automotive, taking part in this industrial process. But I also discovered car companies are not only about building a car but that there are plenty of other missions. Mechanical strategy fascinating sector as people can work on Renault vehicles but also on competitor vehicles.

Master's thesis redaction has been really interesting as it the biggest and most complex document I have done yet, even more in a foreign language. Dealing with scientific data is interesting and educative as I will likely deal with this type of tasks during my career.

From a more global point of view, working on Battery Electric Vehicles (BEV) probably is the best opportunity I could have as a 6-month internship. Even if I studied BEV during my 3 engineering years, working on this technology in a professional environment is totally different and allowed me to discover many things.
It is a nice bonus for my career, and many opportunities I had came from the fact that I worked on BEV, and moreover in such an international company as Renault.

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