STUDY INTO THE ELECTRIFICATION NEEDS OF MOBILITY IN BELGIUM AND THE RELATED IMPACTS

Final Report

This study was conducted by CLIMACT on behalf of the FCSD between February and November 2021.
The opinions expressed in this report are those of CLIMACT, and do not necessarily reflect those of the members of the FCSD.
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Content

Note

This study was funded by the Federal Council for Sustainable Development (FCSD), a council of members incorporated by the Law on Sustainable Development of 5 May 1997. The Council acts as a forum for discussion on sustainable development and also aims (among other things) to raise awareness among public and private organisations, as well as among the public, and to propose studies on sustainable development. For more information: https://www.frdo-cfdd.be/en/the-council

The Council drafted and published a set of terms of reference that led to this study being conducted by CLIMACT. A Support Committee, made up of members of the FCSD and experts from various administrations, monitored the study. Various meetings were held to support the research team, share the expertise of the various participants and provide scope for the study.

Glossary

BEV: Battery Electric Vehicle.

EOL: End of Life.

EV: Electric Vehicle, including BEV and PHEV.

GHG: Greenhouse Gas.

AI: Artificial Intelligence.

ICEV: Internal Combustion Engine Vehicle, including conventional diesel and petrol powered vehicles.

LCA: Life Cycle Assessment.

LDV: Light Duty Vehicle.

MaaS: Mobility as a Service: the service consists of offering an alternative to individual car ownership.

SDG: Sustainable Development Goal.

PHEV: Plug-in Hybrid Electric Vehicle.

PLV: Powered Light Vehicles[1].

TOD: Transit-Oriented Development.

TTW: Tank-to-Wheel. This is the energy consumption from the car's tank to the wheels, and the related emissions.

V2G: Vehicle-to-Grid.

VOC: Volatile Organic Compounds.

WTW: Well-To-Wheel. The WTW carbon footprint, in the case of a BEV, includes emissions from the generation of electricity, its distribution, and the extraction and refining of the fossil fuels used in the generation of this electricity. This measure is included in the LCA carbon footprint, which includes all GHG emissions related to the car (including vehicle production in the case of the LCA, for example).

[1] This includes class L vehicles (motorised 2-4 wheel vehicles with a mass and power not exceeding 400 kg (without battery) and 15 kW.

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1 Executive Summary

1.1 Background and aims of the study

Decarbonising the transport sector is one of the priorities of the European Union, in particular in the context of the commitments made in the Paris Agreement and, more recently, in the Green Pact for Europe and the European Commission's Fit for 55 strategy.

The challenge is twofold: on the one hand, the sector accounts for ~16% of global annual GHG emissions[2] (and 22% of Belgian territorial emissions[3]) and on the other hand, it is the only sector whose emissions increased in Belgium between 1990 and 2019[4]. [23]

The European plans call for the replacement of traditional ICE vehicles with battery electric vehicles; the Commission's proposed targets are moving towards a ban on sales of fossil fuel cars and vans by 2035. [103]

While these developments make it possible to significantly reduce the GHG emissions of the sector, they also raise various questions about their environmental, social and economic impacts.

It is in this context that the Federal Council for Sustainable Development (FCSD), at the request of its members, commissioned a study to be conducted into the needs for electrification of mobility in Belgium and the related environmental, economic and social impacts[5].

This document summarises all the findings of the research conducted. It aims to answer the following questions:

- What are the possible scenarios for battery demand for a decarbonised Belgium in 2050?
- What are the (positive and negative) economic, environmental and social impacts of these scenarios?
- What policy measures are crucial for decarbonising rapidly, without compromising other sustainable development goals?

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[2] In 2016, based on estimates from Climate Watch and The World Resource Institute, https://ourworldindata.org/emissions-by-sector [43].
[3] See (French only) https://climat.be/en-belgique/climat-et-emissions/emissions-des-gaz-a-effet-de-serre/emissions-par-secteur.
[4] If we consider tertiary and secondary heating as one sector (see link in footnote 3).
[5] The technical requirements are set out in the Special Specifications CFDD2021/01 and were clarified at the information session on Monday 14 December 2020.

1.2 Electromobility scenarios for a decarbonised Belgium

The scenarios presented in this study are the result of several months of collaboration with industrial experts, academic experts, the climate change department of the FPS Public Health, Food Chain Safety and the Environment (hereinafter FPS Health) and members of the FCSD.

The analyses and conclusions presented in this section take as their starting point the exploratory scenarios for a carbon-neutral Belgium developed by the FPS Health in collaboration with CLIMACT. These scenarios are based on a modelling tool called "2050 Pathways Explorer", developed by CLIMACT. Passenger and freight transport, as well as road, sea, rail and air transport, are included in the scope of the study.

Three key scenarios aiming at the complete decarbonisation of the transport sector in Belgium in 2050 are used:

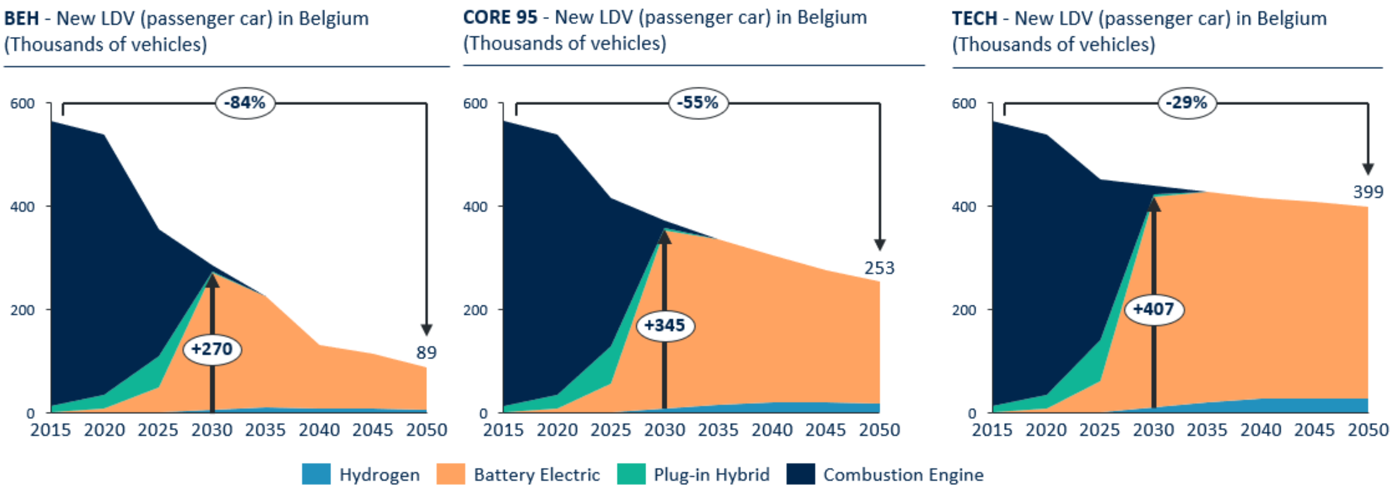
- The Technological (TECH) scenario, which prioritises technological change (e.g. new engines) to decarbonise the economy,
- The Behaviour scenario (BEH), which focuses on behavioural change (e.g. a modal shift to public transport),
- The CORE 95 scenario, which is ambitious but more balanced as regards the two approaches mentioned above.

No scenario can exclude behavioural or technological changes; a combination of both is necessary to achieve carbon neutrality.

Among the key assumptions detailed in the table in Annex 2, we can highlight the fact that the evolution between 2015 and 2050 of kilometres travelled by car stabilises in the TECH scenario, whereas it decreases by 22% and 51% respectively in the CORE 95 and BEH scenarios. We can also observe a decrease in the modal share of the car in passenger transport: from 62% in 2015 to 33% in 2050 for the BEH scenario, to 45% for the CORE 95 scenario and to 51% for the TECH scenario. The other decarbonisation levers (penetration of electric vehicles, rate of use, etc.) are detailed in Annex 2.

The analysis shows that the decarbonisation scenarios modelled all imply a reduction in the annual volumes of cars sold, and, in parallel, a rise in the share of electric vehicles. This objective corresponds proportionally to the objectives currently proposed by the European Commission for 2035 [103]: the end of sales of ICEV in 2035 throughout the European Union[6]. In absolute terms, the quantities are contrasted from one scenario to another, as highlighted in Figure 1.

Figure 1: Sales of LDVs in Belgium according to 3 main scenarios in the analysis



Beyond behavioural changes to reduce overall demand for vehicles, the choice of batteries as the core technology for new light duty vehicles is justified in various ways:

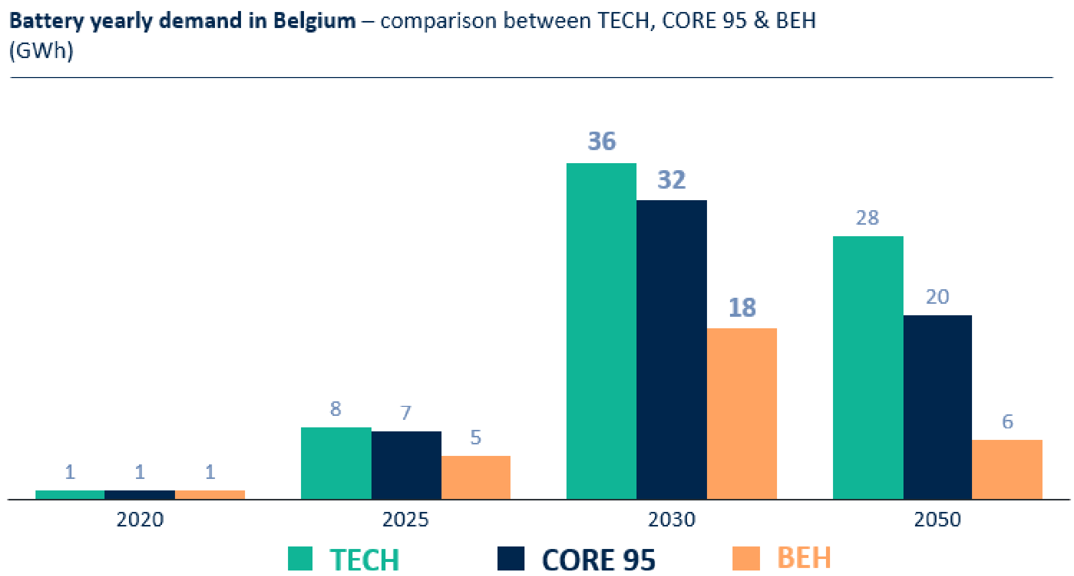
- The alternative of synthetic fuels (such as synthetic diesel ("e-diesel") or hydrogen) is a useful but not very energy-efficient option. Various studies recommend reserving the use of synthetic fuels for heavy duty vehicles, shipping and aviation [120], modes of transport for which batteries are not considered a viable alternative,
- Biofuels are also seen as a possible solution for decarbonisation. Several studies have pointed out that sustainable, low-emission quantities of these energies are limited. This underpins the importance of using possible alternatives (such as batteries) to minimise the use of these fuels while reducing greenhouse gas emissions. [120]

[6] The linear evolution of the growth in sales of BEV was also analysed and is discussed in this study. This sensitivity analysis de facto reduces the demand for batteries and materials, but does not meet the "zero emissions" objectives proposed by the European Commission (and strongly reduces the sector's emission reduction potential). For this reason, it is not mentioned in the summary of the study.

- It is useful to recall that the European objectives described in the previous paragraph only relate to sales of new vehicles: without additional measures, the fleet will still be made up of "traditional" vehicles until it is completely renewed, which disproportionately increases the use of synthetic fuels or biofuels if they are made possible for light duty vehicles [85].

Volumes of electric cars directly influence the demand for batteries. Estimates for the growth in battery volumes between 2020 and 2030 underscore the need to limit the use of cars if the target of ending sales of ICEV by 2030-2035 is to be realistic. The TECH and CORE 95 scenarios, which nevertheless decrease the number of cars sold, seem particularly ambitious: they multiply the number of batteries produced between 2020 and 2030 for electromobility in Belgium by 36 and 32 respectively. These multiples would imply a distribution of new batteries in favour of Belgium rather than other European countries. Growth close to BEH levels seems more realistic, as shown in the Figure below (see section 4.3.2 for more details).

Figure 2: Battery demand in Belgium (GWh) according to the 3 main scenarios in the analysis



1.3 The challenges arising from the electromobility scenarios

Reducing the demand for transport, producing such a quantity of batteries, transforming the automotive industry, all these changes underscore the fact that decarbonising the transportation sector will have major social, economic and environmental consequences.

This study analyses these from four angles: first, through a summary of the positive and negative externalities linked to this transition (chapter 3 and Annex 1); second, through a more detailed qualitative analysis of specific major consequences (chapter 5); third, by quantifying the pressure on the resources of six critical metals (section 4.3.3); and fourth, by quantifying the improvement in air quality (section 5.3).

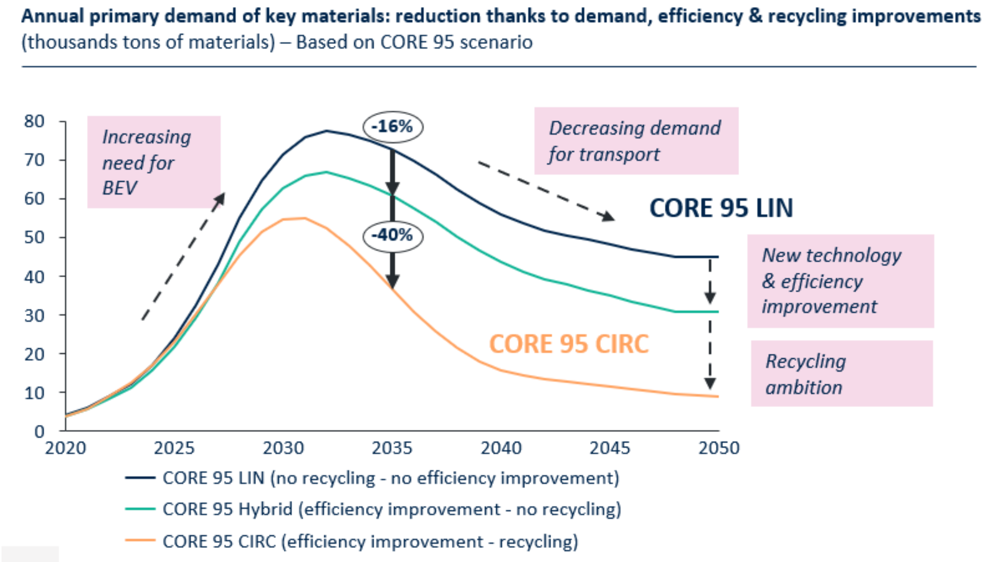
1.3.1 Pressure on resources

In all the scenarios, there is an urgent need to develop standards, infrastructure, incentives and technological innovations that reduce the primary need for cobalt and lithium on the one hand, and allow for the collection and recycling of mined volumes on the other, in order to keep the quantities of primary materials within orders of magnitude that are compatible with the estimates of mineral reserves and resources. These conclusions apply to all the materials studied, and should be addressed as a priority for cobalt, given the estimated quantities available. It is crucial to ensure the rapid industrial development of new technologies and in particular technologies that make it possible to wean ourselves off cobalt.

The scenarios that emphasise behavioural changes have a significant impact on the needs for primary materials (these changes lower the “bell-shape" in Figure 3 below). Reducing demand in the short term is all the more important because the technologies that limit cobalt demand are marginal at the time of writing. That being said, reducing demand does not make using technological innovations and standards or incentives that maximise their potential (e.g., a target recycling rate) any less important.

Continued geological exploration appears to be unavoidable to meet demand and ensure rapid decarbonisation of transport: strong accompanying measures are necessary to minimise the social and environmental externalities of this exploration.

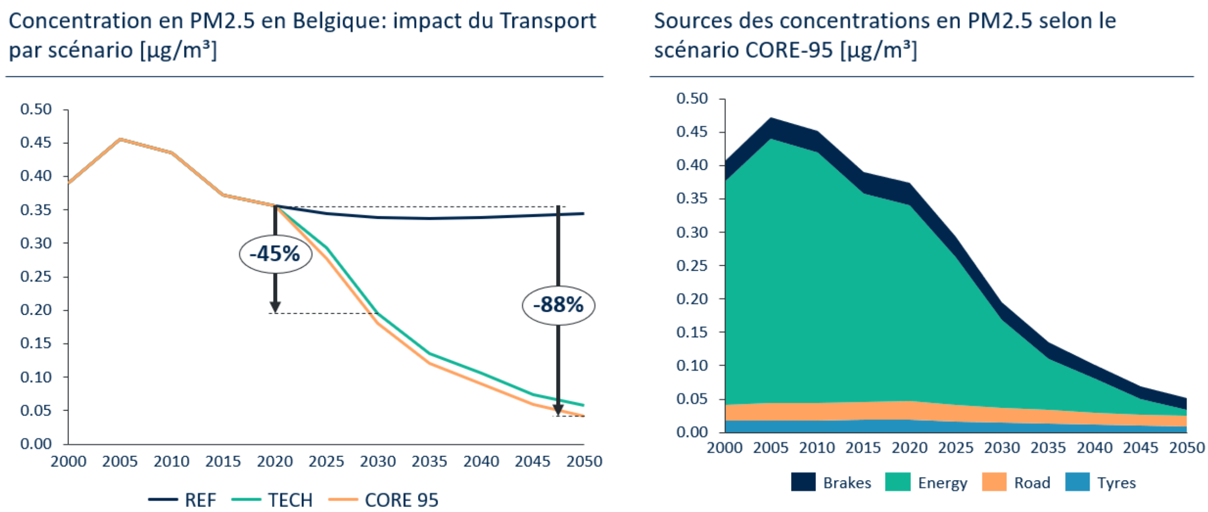
Figure 3: Belgian annual demand for primary materials according to various sensitivity analyses around CORE 95 - sum of the volumes of the materials analysed (thousand tonnes)



1.3.2 Improvement of the air quality

The emissions and concentrations of the air pollutants studied (NH_3, PM2.5, VOC) decrease in all the scenarios for decarbonisation by electromobility, given that the main source of these is the combustion of fossil fuels. The model predicts residual PM2.5 emissions in 2050 from wear and tear of tyres, brakes and asphalt. Innovations (emerging but not modelled) will be necessary in order to completely remove this particulate matter.

Figure 4: Concentrations of PM2.5 - comparison of the REF, CORE 95 and TECH scenarios



1.3.3 Other environmental externalities

Greenhouse gas emissions across the value chain (section 5.2). Most of the studies indicate that electric vehicles emit less greenhouse gases than ICE vehicles over the entire life cycle. It should be noted, however, that battery production technologies are still currently dependent on electric and fossil fuels: in a carbon-neutral world, it is therefore essential to decarbonise this production and promote the most efficient technologies.

Decarbonisation of the electricity grid (section 5.2.3). Decarbonising electricity generation in parallel with the development of electromobility is essential. It is useful to recall here also the importance of reducing upstream demand, for decarbonisation to occur rapidly, since the transition of various sectors will happen via the electrification of technologies.

Biodiversity (section 3.2). Various studies document the damage inflicted on natural ecosystems by current mining operations (not just related to electromobility). Future mining (including deep-sea mining) is also subject to much criticism in this regard.

1.3.4 Social externalities

Violations of human rights in mining regions (section 5.4). Major problems are regularly reported in the mining regions from which the key materials for electromobility are sourced. It is inaccurate to attribute all of these negative externalities (impact on the health of miners and neighbouring populations, violence, land grabbing, working conditions and child labour) solely to electric car batteries: these are nonetheless recurrent phenomena in the mining industry, regardless of the use of the materials downstream. Taking action on the battery value chain is urgent but not sufficient: while this may be an entry point for more standards, it is also essential to improve mining practices in general (see policy recommendations).

Employment (section 5.5). It is difficult to qualify with certainty the net impact of the arrival of electric vehicles on employment in Europe, and by extension in Belgium. There are still many uncertainties regarding the parameters used and, to our knowledge, there is no precise study on the Belgian case. However, there will be a profound change in the types of skills needed and a significant portion of the workforce currently employed in the automotive sector will have to be retrained. Moreover, new services (outside the vehicle production value chain) will emerge in the decarbonisation scenarios (such as the development of car-sharing technologies), which could be the source of new jobs.

1.4 Recommendation for policy measures

1.4.1 The European Commission's proposal for a regulation

In the context of the European Green Deal, under the new "Circular Economy Action Plan", in December 2020 the European Commission published an important proposal for a regulation that covers the entire battery value chain: "Regulation [...] concerning batteries and waste batteries". The proposal aims to introduce minimum environmental and social criteria for all types of batteries placed on the European market. Throughout the value chain, it promotes environmental and social due diligence. Upstream of use, it requires a calculation of the carbon footprint of production and pushes for the creation of a "passport" to facilitate transparency regarding key information for the consumer and for the actors involved in the repair, reuse or recycling of batteries. Downstream, it lays down collection and recycling targets for materials.

1.4.2 Recommendations on the proposal for a regulation

Most Member States, NGOs and stakeholders welcomed this proposal, while insisting on maintaining a sufficient level of ambition in the final text and suggesting a series of improvements to it [77, 74, 99, 112]. This section draws on the positions taken by these stakeholders in an attempt to identify the shortcomings in the current proposal for a regulation and to suggest corrective recommendations or essential points to be included in the final text (the text still needs to be amended and validated by the Parliament and the Council). These recommendations (listed below and detailed in Chapter 6) are not intended to be exhaustive, but rather to address the major impacts identified above.

a) **Recommendations 1 to 2 relate to the collection and recycling targets**: the collection rate should be as ambitious as possible and recycling rates should be aligned (at a minimum) with current best practice for critical materials. The regulation must be able to easily cover other resources that will become crucial as technologies evolve.
b) **Recommendations 3 to 6 concern the due diligence obligations in the value chain**: the criteria should be based on the broadest texts in terms of risks and geographical areas covered (not limited to armed conflict zones) and cover more materials than those listed at present**.**
c) **Recommendation 7 concerns deep-sea mining**. The deep-seabed appears to have vast potential, but the unknowns and risks for biodiversity are still significant. Supply chain due diligence should be extended to explicitly cover the seabed, and include all potential environmental and social impacts of deep-sea mining.

1.4.3 Other recommendations related to the challenges identified

The above-mentioned proposal for a regulation does not cover all the major challenges studied. The ambitious decarbonisation targets for 2030, reduction of car use, support for innovation, jobs, etc. are several examples of elements that are outside the scope of this proposal. The recommendations below therefore relate either to other European policies or to measures that could be taken at federal (or regional) level.

Furthermore, these recommendations draw on other studies, reiterating the importance and urgency of the climate issue. The decarbonisation of transport is a key assumption in the analyses carried out, and is considered essential for the advent of a truly sustainable society. It is useful to recall that the negative consequences of the development of batteries presented in this study do not in any way justify scaling back the necessary decarbonisation ambitions. Identifying these negative consequences makes it possible to add markers, which are also essential for the sustainable development of electric mobility.

a) **Recommendations 8 and 9 concern the decarbonisation targets for all sales of new cars (LDV) and vans**: the targets (existing or proposed) for 2025 and 2030 need to be increased to ensure effective decarbonisation by 2035. Belgium should aim for more ambitious targets.
b) **Recommendations 10 and 11 concern the need to reduce the weight and power of cars**. At the European level, it is necessary to remove the weight parameter from the formula for calculating CO_2 targets. At the Belgian level, the public needs to be encouraged to purchase lighter vehicles, and taxes on heavier vehicles should be increased. Raising public awareness of the issue also has a role to play. Further adaptation of the reform of the legal framework for company cars to accelerate this change is recommended.
c) **Recommendation 12 proposes setting up an international cooperative agency** with a mandate to oversee and promote the sharing and improvement of human rights and environmental due diligence criteria.
d) **Recommendations 13 and 14 concern the acceleration of investments and incentives to reduce transport demand and promote active and shared mobility.**
e) **Recommendations 15 to 17 concern the need to support employment, innovation and the industrial deployment of technologies that are essential to the transition**: reorientation programmes must be prepared to guide people towards the sectors of the future, and to support innovation and the deployment of recycling technologies for key materials.

2 Introduction

The Federal Council for Sustainable Development (FCSD), at the request of its members, commissioned CLIMACT to conduct a study into the evolutions of electrification of mobility in Belgium and the related environmental, economic and social impacts[7]. This study is based on the work carried out by the FPS Health on the elaboration of scenarios that aim at climate neutrality in Belgium by 2050.

In agreement with the FCSD and the FPS Health, links have been established with the study conducted by the FPS Health to determine the environmental impacts linked to battery developments up to 2050 and to ensure that the studies complement and reinforce each other.

The study, in the context of the envisaged resources, identifies the main challenges relevant to Belgium in the development of electromobility, drawing on the extensive literature. It is based on an analysis of contrasting scenarios, in conjunction with the work of the FPS Health. The study also builds on other work of the FCSD and has benefited from discussions with members of the latter. The study is a useful contribution to the debate on the electrification of mobility in Belgium and could be supplemented by specific analyses, in particular concerning the role of other energy vectors such as renewable gas or hydrogen.

This report details the work conducted between February and November 2021:

- Chapter 3 illustrates, based on the literature review, the main environmental, economic and social issues,
- Chapter 4 explores, with the help of the model developed for elaborating the Belgian scenarios and sensitivity analyses, the implications in terms of number of vehicles, batteries and mining resources of the development of electromobility in Belgium,
- Chapter 5 analyses the key impacts of ambitious electromobility scenarios on GHG reduction, air quality, health, human rights and employment,
- Chapter 6 develops several recommendations for policy measures to support the development of electromobility in Belgium,
- The annexes contain the bibliography and details of the analyses.

[7] The technical requirements are set out in the Special Specifications CFDD2021/01 and were clarified at the information session on Monday 14 December 2020.

3 Context and challenges of electromobility

3.1 Electromobility is developing rapidly

Decarbonising transport is crucial in reducing GHG emissions. Indeed, the urgency is twofold: on the one hand, the sector accounts for ~16% of global annual GHG emissions[8] (and 22% of Belgian territorial emissions[9]) and on the other hand, it is the only sector that saw its emissions increase in Belgium between 1990 and 2019[10]. [23]

Decarbonising transport is complex: the vehicle fleet and infrastructure to be developed are huge, and the economic, social and technological challenges related to the automotive industry are considerable.

Decarbonising transport is one of the priorities of the Member States of the European Union, in particular in the context of the commitments made in the Paris Agreement and, more recently, in the European Commission's Green Pact for Europe. These commitments are translated into a range of objectives and measures for all sectors of economic activity, including transport.

The transition to electromobility and battery electric vehicles are at the heart of these measures and at this stage primarily concern so-called light duty vehicles (i.e. passenger cars and vans).

The year 2020, despite the pandemic, marked a turning point in the evolution of electric vehicle sales: they represented about 10% of annual new vehicle sales in Europe, which overtook China in terms of absolute sales[11]. Globally, sales of electric vehicles have grown by an average of 30% per year since 2016. The penetration of electric vehicles in the total vehicle fleet is still low and was ~2% in Belgium in 2020. [16,17,24]

The prospective scenarios of various international organisations [9, 116, 117] confirm the upward trend of electric vehicle sales by 2030. They expect the demand for batteries to rise from 8 to 30 times the current demand between 2020 and 2030.

[8] In 2016, based on estimates from Climate Watch and The World Resource Institute, summarised at https://ourworldindata.org/emissions-by-sector [43].
[9] See (French only) https://climat.be/en-belgique/climat-et-emissions/emissions-des-gaz-a-effet-de-serre/emissions-par-secteur.
[10] If we consider tertiary and secondary heating as one sector (see link in footnote 9).
[11] PHEV included.

These developments are accompanied by economic, environmental and social challenges. The increase in battery production to a high level in a short period of time puts great pressure on all levels of the battery supply chain.

Annex 1 shows the main environmental, economic and social challenges, extracted from an extensive literature review and categorised into risks and opportunities. The following section summarises these issues.

3.2 Challenges related to the development of electromobility and the sustainable development goals

The table below groups the challenges identified in the summary (in Annex 1) and indicates the link with the SDGs. A general description of the challenge in relation to the transport sector and the corresponding SDGs is given. A full description of the risks and opportunities for each of the SDGs is also available in Annex 1.

Table 1: Summary of the challenges and link to the SDGs

Challenge	SDG	Description
Environmental challenges		
GHG emissions	13	The transport sector emits a significant portion of GHG emissions at the global level, and even more so at the Belgian level. Alignment with the SDGs and the Paris Agreement implies a sharp reduction in these emissions.
Energy consumption and efficiency	11,12	Transport is an integral part of the energy-intensive aspect of today's society. This is due to the high demand for mobility and vehicles and the low efficiency of internal combustion engines. Electric motors are more efficient than internal combustion engines.
Air quality	3,11	Air pollution from transport is associated with hazards to human health and biodiversity. This pollution is related to vehicle demand, the type of fuel and driving style.
Destruction of biodiversity	12,14,15	Protecting biodiversity is essential for a sustainable society. However, the processes for mining metals or fossil fuels can cause the destruction of ecosystems.
Scarcity of resources	12	Producing batteries requires large quantities of metals. Some of these resources have significant potential for becoming scarce in the coming years. However, electromobility makes it possible to reduce the risk of oil scarcity.
Waste production/responsible consumption	11,12	Responsible/sustainable consumption in transport finds its meaning in the circularity of the goods used. Any car component that is not recycled results in a lot of waste going to landfill. In particular, waste from batteries can be particularly hazardous.

Development of renewable energies	7,13	On the one hand, electromobility, which requires significant amounts of electricity, must be accompanied by the use of clean energy, where progress still needs to be made in Europe and in Belgium. On the other hand, batteries can be reused as storage units for the electricity grid.
Economic challenges		
Economic development	8	The automotive sector is currently an economic powerhouse in the EU. Electromobility, accompanied by falling demand, could lead to the economic decline of the sector; it also brings opportunities for new markets (shared cars, recycling, shared mobility management, etc.).
Economic dependence	8,9	The EU is currently economically dependent on foreign countries for its supply of materials and fossil fuels, as well as for the production of batteries.
Charging infrastructure	8,9	There is a need for massive investment in an efficient charging station network with adequate capacity. This network is currently very underdeveloped.
Sustainable industrialisation	9	The mining of materials and battery production mainly take place outside the EU, in a less strict regulatory framework.
Human and social challenges		
Employment	8	At the European level, electromobility could, in the medium term, reduce the supply of jobs in the automotive sector. However, some markets (recycling/reuse, management and maintenance of shared mobility) could create new jobs.
Social inequalities	10	Providing access to transport for all is a goal of social sustainability. Today, electromobility is seen as an elitist pursuit, with access limited to the well-off. The development of shared mobility (electric or fossil) could facilitate access to transport for people on low incomes.
Urban convenience	3,11	Transport based on private vehicles causes a range of inconveniences, including traffic congestion, noise pollution, road insecurity and parking difficulties.
Infringements of fundamental rights	3,16	This challenge aims to address the overall human impacts associated with the mining sector. Mining is currently associated with conditions that often violate human rights (impact on the health of miners and neighbouring populations, violence, land grabbing, working conditions and child labour).
Decent and skilled work	8	The European automotive industry is overwhelmingly associated with a skilled workforce and decent working conditions.

4 Prospects for the development of electromobility in Belgium

4.1 Introduction

The development of electromobility in Europe and Belgium will lead to significantly higher needs for batteries and the materials required for their production.

This chapter examines the possible evolution of the demand for batteries in Belgium and the related need for critical mining resources. The analysis makes it possible to study the scale of the challenges concerning the pressure on resources and to establish the conditions and policy measures that will allow the smooth and sustainable development of electromobility.

The main assumption for determining the demand for batteries is the complete decarbonisation of the transport sector by 2050, modelled through the work conducted by the FPS Health and CLIMACT.

The present study is based on the scenarios resulting from this work[12]. Three contrasting scenarios are used and sensitivity analyses are performed on various key parameters[13]. The three scenarios are the following:

- The TECH scenario, which aims for decarbonisation by 2050 by emphasizing technological improvements and deployments more than behavioural changes, implies a higher growth in the supply of electric vehicles,
- The BEH scenario, which focuses more on behavioural changes (although technological improvements remain important),
- The CORE 95 scenario, balanced on the behavioural and technological approaches,
- These scenarios are compared with the REF scenario, based on unchanged trends.

The pressure on six materials is then analysed. These are cobalt, lithium, graphite, nickel, manganese and aluminium. The model makes it possible to include improved battery technologies, reducing the demand for some of these materials, either through new battery technologies or by improving the efficiency of existing technologies and recycling.

4.2 Methodology

[12] https://climat.be/2050-fr/analyse-de-scenarios.
[13] See section 4.2.3.

The scenarios presented in this study are the result of several months of collaboration with industrial experts, academic experts, the FPS Health, members of the FCSD, various non-governmental associations and consultancies (including TDI-Sustainability[14]).

The following elements are discussed in this chapter: a summary description of the scope, the underlying assumptions and the functioning of the model used.

4.2.1 Scope

The study focuses on quantifying the battery needs in relation to the evolution of electromobility in road transport (passenger and freight) in Belgium. In the following sections, there is a specific focus on road passenger transport: this is the transport category that generates the highest demand for batteries by 2030-2035 [9, 116, 117]. This is due to the fact that present and future technologies appear to be less suited to the needs of heavier vehicles, such as trucks, buses, ships or aeroplanes. Although they are not illustrated in this section, it should be remembered that in the scenarios and tools used, these modes of transport (and their specific decarbonisation technologies) are also studied and the demand for batteries that they generate is included in the quantities calculated.

Once these battery requirements have been determined, the quantities are converted into materials requirements, which makes it possible to assess the pressure on the available reserves and resources. We focus on the six most critical materials in terms of supply in sufficient quantities: cobalt, lithium, graphite, nickel, manganese and aluminium.

4.2.2 The Pathways Explorer

The Pathways Explorer is a simulation model of energy consumption and greenhouse gas emissions that makes it possible to analyse the implications of implementing ambitious scenarios for the transition to a decarbonised economy. The tool, developed by CLIMACT, is based on EUCalc, GlobalCalc and other existing calculator models. These tools make it possible to study the full range of solutions for reducing GHG emissions, test a wide range of potential measures, including emerging trends in mobility, housing or food habits, as well as the full range of underlying technology options. A more complete description of the model is given in Annex 2.

4.2.3 Key assumptions

[14] https://tdi-sustainability.com/.

Various categories of parameters are modelled in the BE2050 project developed by CLIMACT for the FPS Health to assess the demand for batteries and the pressure on critical materials. These categories are:

- Evolutions within the Transport sector (demand, modal shift, vehicle utilisation rates, etc.),
- Technological improvements in batteries,
- The degree of recycling of batteries and their components,
- The availability of materials and resources.

These categories are briefly described below, along with the key assumptions made for each one.

- **The evolution of the Belgian transport sector in the different scenarios**

Several possible scenarios for achieving carbon neutrality in Belgium by 2050 are explored in the study of the FPS Health[15]. Among the key assumptions detailed in the three scenarios used (TECH, BEH and CORE), detailed in the table in Annex 2, we can highlight the fact that the evolution between 2015 and 2050 of kilometres travelled by car stabilises in the TECH scenario, and decreases in the CORE 95 and BEH scenarios by 22% and 51% respectively. We can also observe a decrease in the modal share of the car in passenger transport: from 62% in 2015 to 33% in 2050 for the BEH scenario, to 45% for the CORE 95 scenario and to 51% for the TECH scenario. The other decarbonisation levers (penetration of electric vehicles, rate of use, etc.) are found in Annex 2.

When the scenarios for this study were devised, the shape of the evolution curve between 2020 and 2050 was discussed at length. A sensitivity analysis was performed to assess the impact of a linear evolution of these curves, rather than the S-shapes used in the initial BEH, TECH, and CORE 95 scenarios. This results in scenarios of **rapid decarbonisation ("FAST")** in the case of S-shapes (an S-shape achieves most of the electrification ambitions more quickly) and **slower decarbonisation** ("SLOW") in the case of linear projections. This sensitivity analysis is discussed in the following sections.

Priority was given to batteries for sales of new light duty vehicles, as explained in Section 1.2 and in a study by Transport & Environment [120].

- **Evolutions in the demand for materials for the construction of batteries: new technologies and recycling**

Two sets of contrasting assumptions were used within the resource consumption model developed for this project. They make it possible to assess the impact of circularity in the battery value chain, by contrasting

[15] https://climat.be/doc/climate-neutral-belgium-by-2050-report.pdf.

two variants: the LINEAR variant (LIN) and the CIRCULAR variant (CIRC). These assumptions are detailed in Annex 2.

Two types of levers are used:

- Circularity levers, which determine the proportion of recycling of different materials. They include the battery recycling rate (the percentage of end-of-life batteries that are recycled) and the recycling efficiency of each material (the proportion of this material that is actually recovered during recycling). The LINEAR (LIN) scenarios push these levers to a very limited extent, while the CIRCULAR (CIRC) scenarios correspond to a high level of these levers, reflecting greater circularity.
  In a CIRC scenario, we suppose that close to 100% of batteries are recycled by 2050, with a recycling efficiency close to 100% for all materials, except for lithium and graphite for which only a recycling efficiency of around 20% is achieved.
  In a LIN scenario, we suppose that 10% of batteries are recycled by 2050, and the materials recycling efficiency is close to 100%, except for lithium and graphite for which only a recycling efficiency of around 10% is achieved.
- The levers of material efficiency, which make it possible to determine, for each material studied, the material intensity per unit of energy storage (kg/kWh). They represent on the one hand the improvements made in optimising current batteries, and on the other hand, the new battery technologies with a different materials mix (see below). The LIN scenarios are not very ambitious in terms of material efficiency, the CIRC scenarios correspond to the gradual penetration of new, more resource-efficient technologies. As such, in a CIRC scenario, cobalt and nickel will be completely eliminated from battery components by 2050, and the need for lithium will be greatly reduced (-60%).

The combination of the assumptions regarding circularity (LIN and CIRC) and the REF, CORE 95 and TECH scenarios, results in six different scenarios (one CIRC and one LIN for each of the three basic scenarios).

The assumptions regarding technological improvements (mentioned above and detailed in Annex 2) were established through interactions with battery experts at the VUB (MOBI).

There are three key developments to bear in mind in this context. Firstly, various technological improvements (both in battery management systems and in the materials used) will reduce the need for critical resources in the short and medium term by optimising the Lithium-Ion technologies already in use today. Secondly, new Lithium-Ion technologies are currently in the research and development stage. We should see the appearance of new cathodes replacing cobalt (e.g. via HVS ("high voltage spinel") technology) and then solid state batteries, which will also reduce material requirements per kWh. Thirdly, and in the longer term (post-2030), new technologies without Lithium-Ion could develop. The experts are therefore banking on cathode technologies that use oxygen rather than primary resources (such as cobalt at present or the materials found in HVS in a few years' time).

- **The mismatch between battery demand and the available resources**

Two approaches can be used to compare the demand for batteries and the resources available.

The first approach compares the allocation of resources to Belgium according to the distribution of new cars: to assess the short-term feasibility of Belgian needs in relation to the available resources and reserves, the Belgian share was calculated on the basis of the % of new cars sold in Belgium in relation to new cars sold worldwide. This approach is useful for studying the short-term feasibility.

The second approach allocates resources to Belgium on the basis of population. To compare the Belgian needs with the available resources and reserves, Belgium's "fair" share has been calculated on the basis of the relative size of the Belgian population compared to the world population. This approach is more suitable for studying the long-term feasibility, as it illustrates a fairer distribution.

The estimates of reserves and resources come from the U.S. Geological Survey [113] and their definition is explained in Annex 2. Estimates of cars produced come from the OICA [114].

4.3 Main results

4.3.1 Evolutions in road transport

*The decarbonisation scenarios modelled all imply a reduction in the annual volumes of cars sold, and a rise in the share of electric cars and vehicles (*Figure 5*).*

The annual demand for batteries for electromobility depends on the demand for new electric means of transport. New vehicles depend on the evolution of various factors within the sector (the initial demand for transport, the rate of use of these vehicles, the rate of sharing, the percentage of this demand by mode of transport, technological developments, etc.).

The decarbonisation scenarios TECH, BEH and CORE 95 test the implications of the different scenarios, focusing on specific factors over others: these are detailed in the previous section and more information is available on the website of the FPS Health[16]. This section details the total transport demand, the breakdown of this demand by mode of transport, and the annual need for electric cars to meet the demand.

[16] https://climat.be/2050-fr/analyse-de-scenarios.

Main observations related to transport demand

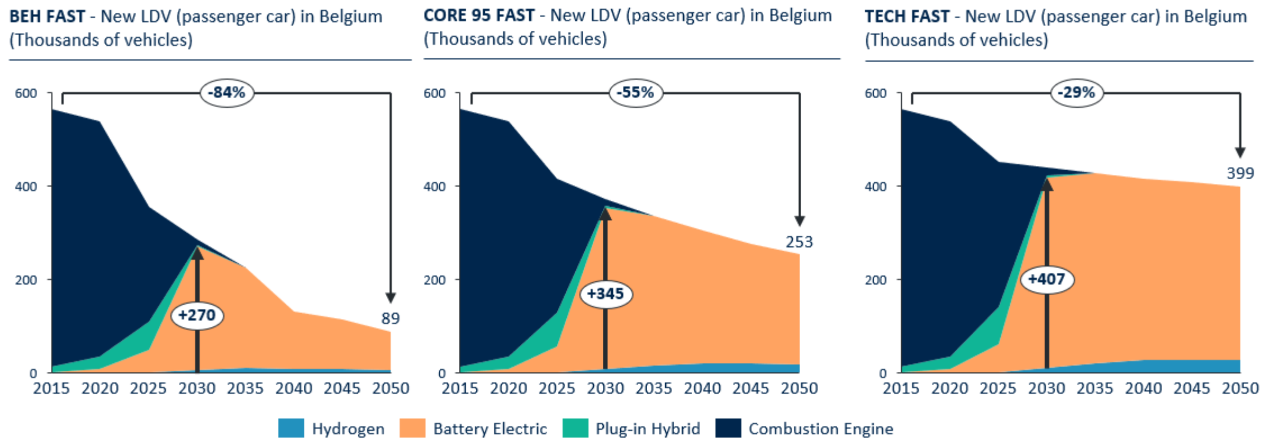
a) In addition to the evolutions in demand detailed in the previous section, it is primarily the evolution of modal shares that impacts the demand for cars and batteries. In all scenarios, the proportion of cars decreases in relation to the other modes of transport. In absolute terms, it decreases in BEH and CORE 95 and stabilises in TECH.

b) Other assumptions are obviously important, such as the rate of car use or car sharing, which tends to increase and therefore decrease the need for the quantity of cars (see Annex 2 for more details).

Main observations related to the impact on annual vehicle demand

a) Combining the assumptions detailed above results in a decrease in annual car demand in the different scenarios, this decrease being less marked for the TECH scenario (-29% between 2015 and 2050) than for the BEH (-84%) or CORE 95 (-55%) scenarios.
The ambitions for a rapid transition to electric vehicles are shown in Figure 5, TECH, CORE 95 and BEH use low-carbon technologies, mainly battery electric vehicles (BEV/EV), the transition to hybrid cars (PHEV) and to hydrogen vehicles (FCEV). We can observe the evolution from ~8,000 electric cars in 2020 to ~270,000 for the BEH scenario (x34), ~407,000 for the TECH scenario (x50) and ~345,000 for the CORE 95 scenario (x43) in 2030. These volumes will have a direct impact on battery needs.

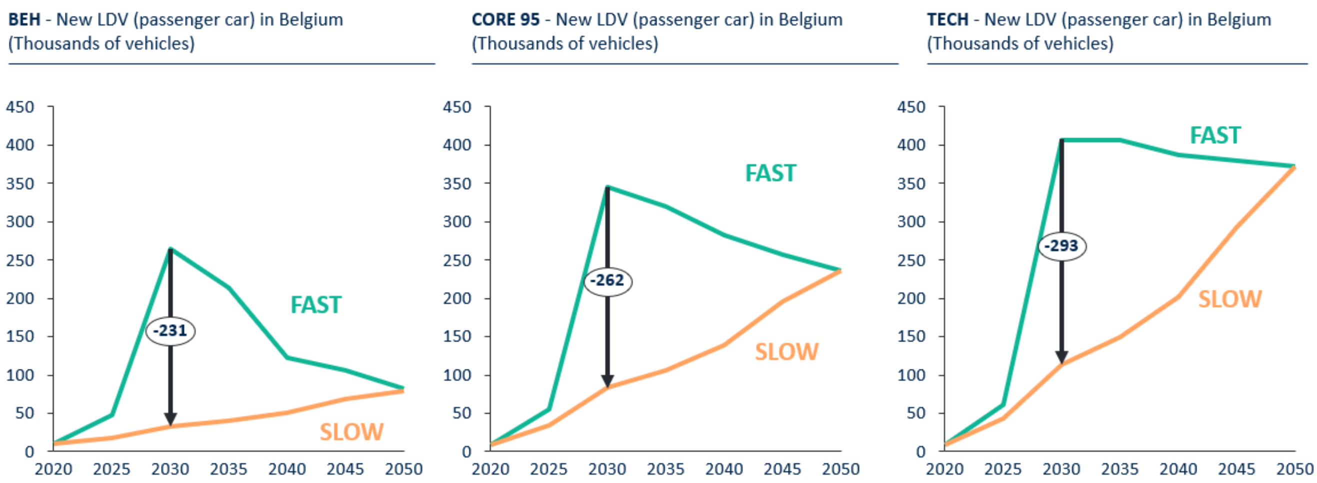
Figure 5: Sales of LDVs in Belgium according to 3 main scenarios in the analysis and rapid decarbonisation (FAST)



b) In the case of slower decarbonisation (Figure 6), the necessary volumes of new electric cars are lower than in the previous case in 2030: ~20,000 for the BEH scenario (x2.5 compared to 2020), 80,000 for CORE 95 (x10 compared to 2020) and 110,000 for TECH (x14 compared to 2020). Of course, this will have repercussions in terms of battery needs, as we will see in the next section. Note that this difference is compensated by sales of ICE vehicles extended beyond 2035, which implies (i) de facto a higher amount of emissions than the rapid decarbonisation scenarios, (ii) a deviation from the European Commission's proposals for -100% emissions from new sales of ICE cars and vans by 2035.

c) The evolutions for buses, trucks and other means of transport are similar, but staggered in time for heavier duty vehicles.

Figure 6: Sales of electric LDVs in Belgium according to 3 main scenarios in the comparative analysis and slow decarbonisation (SLOW) and rapid decarbonisation (FAST)



4.3.2 Evolutions in demand for batteries

Rapidly decarbonising emissions from cars and vans (end of sales of new ICE vehicles between 2030 and 2035) implies significant behavioural changes (reducing demand, modal shift, vehicle utilisation rates) in order to reduce the demand for new electric cars. Without this, the increase in battery volumes (x36 between 2020 and 2030 for the TECH scenario) is possible (given the announcements of production capacity in Europe by 2030) but would imply that the volumes produced in Europe would be distributed in favour of Belgium over the other countries of the continent. The industrial challenge, if these scenarios are emulated throughout Europe, remains significant for CORE 95 (x32) and BEH (x18).

Main observations related to battery demand

a) Significant growth in annual battery demand is expected by 2030-2035 in all three scenarios; it is proportional to the growth in the need for electric cars to decarbonise the transport sector by 2050 (seeFigure 7).
b) The demand for electric vehicles and batteries is linked. In the cases with rapid decarbonisation, we observe a multiplication between 2020 and 2030 of the demand for batteries ranging from a factor of 18 for the BEH scenario to a factor of 36 for the TECH scenario (and a factor of 32 for the CORE 95 scenario). This is a formidable challenge from an industrial perspective, but it corresponds to the estimates of the various scenarios of international organisations (ranging from 8 to 30) [9, 116, 117] and is not too far from the growth levels linked to the recent announcements of production capacity in Europe ("gigafactories"). Indeed, these evolutions should be seen in the context of announcements of future production capacities for batteries for electric vehicles. Estimates differ from one institute to another, but the total annual production is expected to be between 500 and 730 GWh in Europe in 2030 (compared to 25 GWh of production in 2020, i.e. a multiplication of 20 to 30 in 10 years). [124, 125]
c) Beyond the unprecedented industrial challenge, these factors multiply the risks in the battery value chain (listed in section 3.2). They validate the importance of measures to reduce upstream transport demand and strict due diligence criteria (see chapter 6).
d) In the case of slower decarbonisation, the growth rates are lower (x10 between 2020 and 2030 for the TECH scenario, x8 for CORE 95 and x6 for BEH). Although they seem more easily achievable from an industrial perspective, this is at the expense of greenhouse gas emissions, since the difference will have to be made up by sales of ICE vehicles. While these could make carbon neutrality possible by 2050, it does not seem wise to use them, for several reasons:

- They do not allow for decarbonisation through a natural renewal of the fleet: it will be necessary (between 2035 and 2050) to ban ICE vehicles from circulation that are still in good working order,
- They imply sales targets well below the current proposals of the European Commission (-100% of emissions from new sales in 2035) [103] and the recommendations of NGOs specialising in this area [105, 106],
- They do not safeguard the carbon budget as effectively, as sales of ICEV continue to make up the vehicle fleet after 2035.[17]

[17] A counter-argument would be the use of synthetic fuels created from renewable electricity. Various studies suggest that it is unwise to use these future innovations for light duty road transport (cars and vans) due to their low energy efficiency. [85]

Figure 7: Annual battery demand in Belgium - comparison of scenarios in the case of rapid decarbonisation

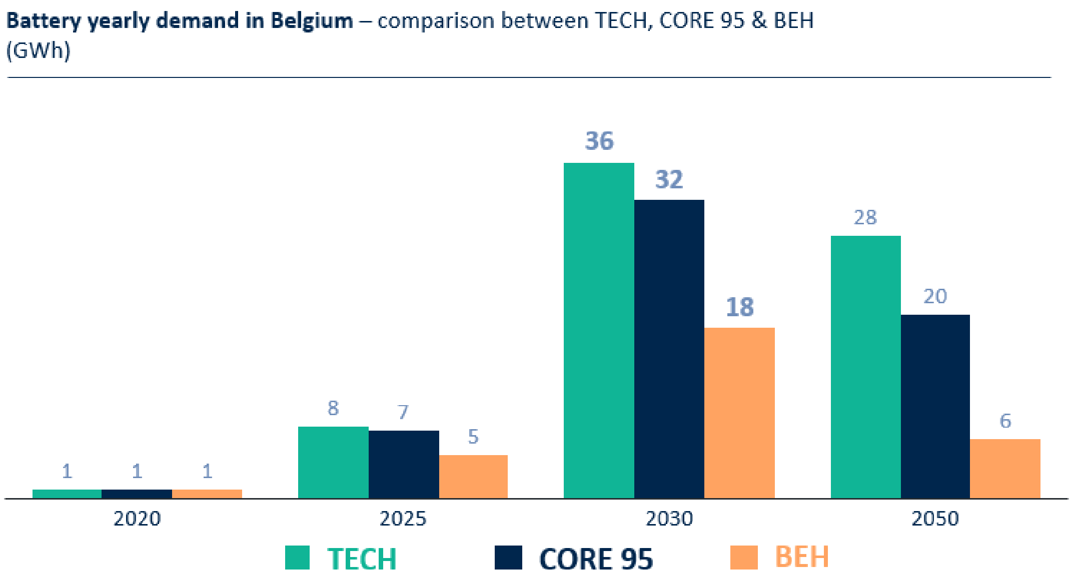
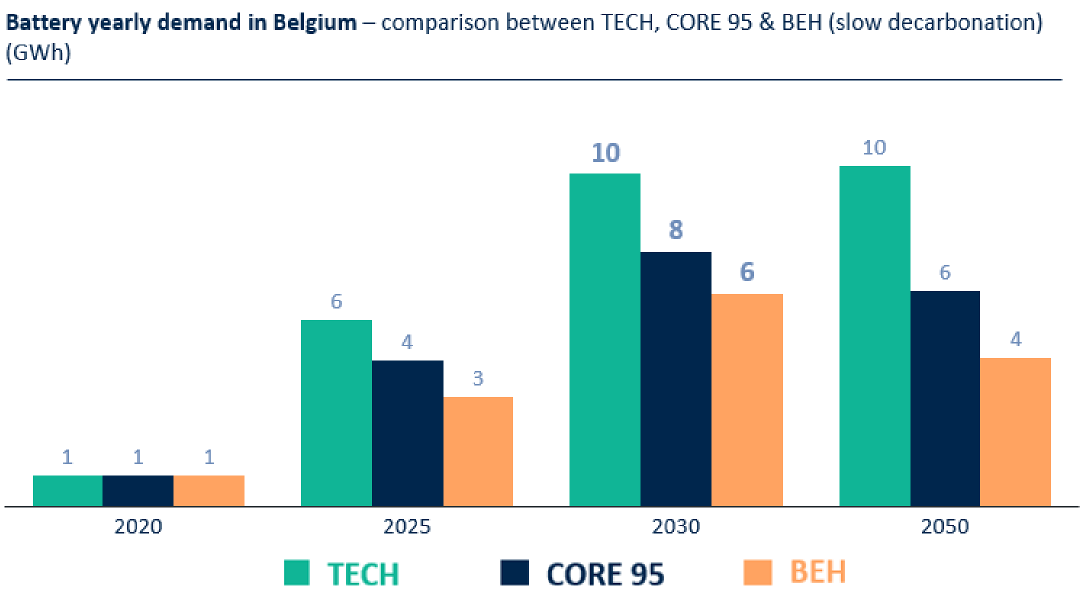


Figure 8: Annual battery demand in Belgium - comparison of scenarios in the case of slow decarbonisation



4.3.3 The pressure on resources

In all the scenarios studied, there is an urgent need to develop infrastructure, standards, incentives and technologies that (i) reduce the primary need for cobalt and lithium, (ii) allow for the collection and recycling of mined volumes, in order to keep the quantities of primary materials within orders of magnitude that are compatible with the estimates of mineral reserves and resources. These conclusions apply to all the materials studied, but are more urgent for cobalt, given the estimated quantities available.

The scenarios that emphasise behavioural changes have a significant impact on the needs for primary materials (these changes lower the "bell curve" in Figure 3 below). Reducing demand in the short term is all the more important because the technologies that limit cobalt demand are not yet mature at the time of writing. That being said, reducing demand does not make using standards and technological innovations and standards or incentives that maximise their potential (e.g., a target recycling rate - see chapter on the political recommendations) any less important.

Continued geological exploration appears to be unavoidable to meet demand and ensure rapid decarbonisation of the vehicle fleet: strong accompanying measures are necessary to minimise their social and environmental externalities, as listed in chapter 3.

As a reminder, reducing demand for materials, for the same battery demand, can be achieved through:

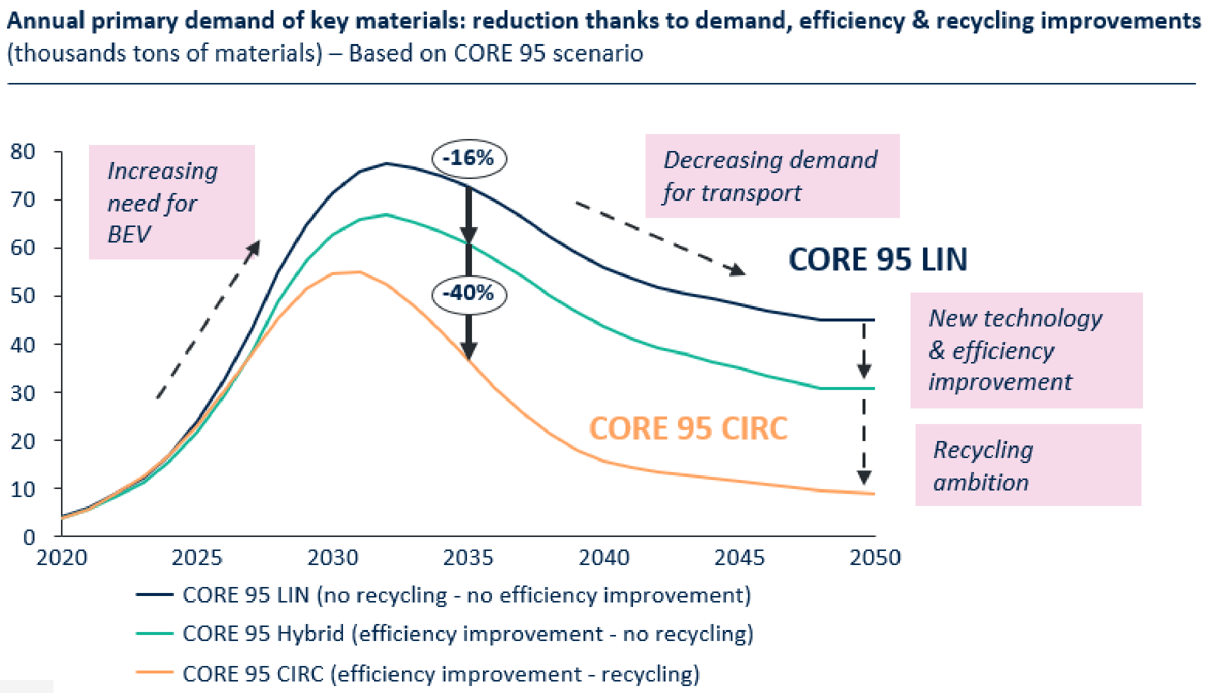
- Increasing the material efficiency of existing technologies (e.g. having less kg of cobalt per kWh of battery, for the same technology),
- The technology shift to battery technologies that no longer use certain critical materials (which corresponds to a 100% improvement in material efficiency),
- Increasing the recycling and recyclability of materials.

Main observations related to the pressure on resources

a) A comparison of the needs in terms of materials with the current reserves and resources shows that even in the scenarios where demand is reduced, technological improvements are essential for the sustainable development of electromobility. This observation applies to both battery technologies and recycling techniques.

Based on the assumptions presented in section 4.2.3, Figure 9 illustrates the impact of new technology & efficiency improvement and recycling ambition. In the CORE 95 scenario, by 2035, these technologies reduce the demand for primary resources for batteries by over 55%. Recycling efficiency is particularly important, accounting for more than three-quarters of this reduction. The levers for behavioural change are also shown in Figure 9: reducing the demand for vehicles reduces the demand for primary materials. They also make it possible to lower the bell curve.

Figure 9: Annual demand for primary materials according to various sensitivity analyses around CORE 95 - sum of the volumes of the materials analysed (thousand tonnes)



b) Despite these improvements, the model confirms strong pressure especially on cobalt and to a lesser extent lithium (see following sections). This reinforces the need to pull the behavioural and technological levers mentioned above, in order to:
   - Ensure security of supply of these critical materials (both in quantity and price) without compromising the need to reduce greenhouse gas emissions rapidly,
   - Allow just as ambitious development in other regions of the world.

4.3.4 Cobalt

Methodological note: Annex 2 defines reserves and resources and the limitations of current estimates. Section 4.2.3 explains the methodology used to compare Belgian demand and world reserves/resources.[18] The figures below show only the key elements that make it possible to support the conclusions and main observations described below. For an exhaustive review of the different indicators studied, see Annex 3.

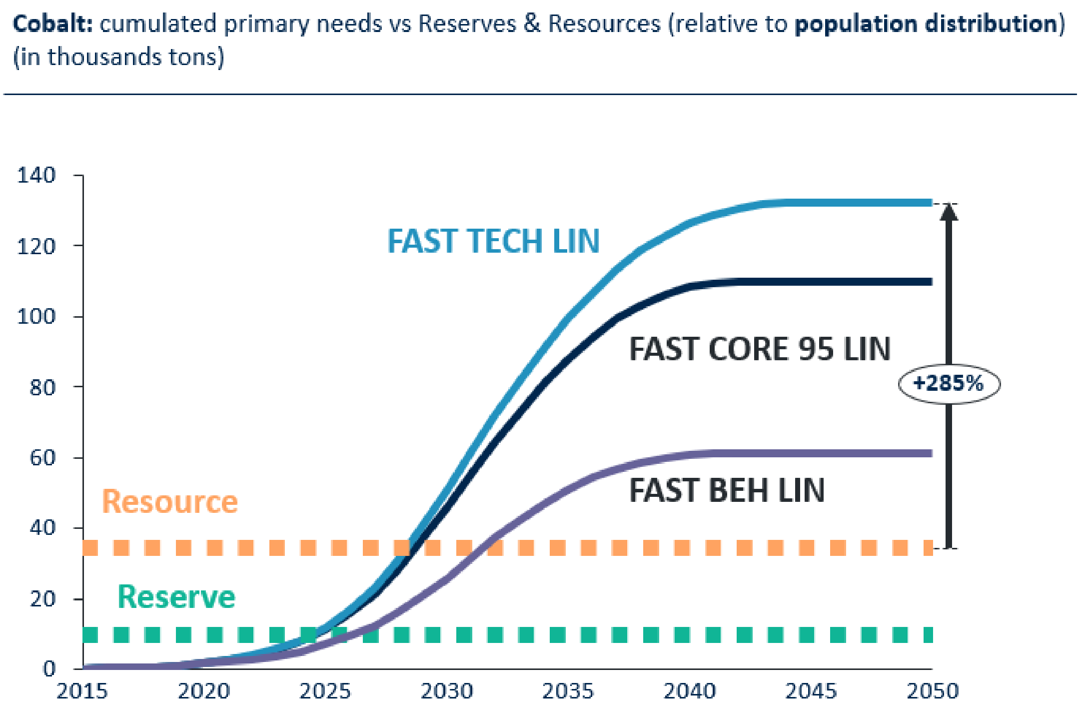
Main observations:

To decarbonise transport rapidly (no more sales of ICE vehicles between 2030 and 2035):

a) Technical improvements in recycling and new cobalt-free battery technologies are essential. Indeed, the "LIN" scenarios (and primarily the TECH and CORE 95) without technological improvements (in batteries and recycling techniques) deviate significantly not only from the levels of resources considered as available for Belgium in the long term, but also from the levels of reserves available in the short term (Figure 10). Only the behavioural scenario approximates the short-term reserves.

[18] Allocating the estimated global reserves and resources to Belgium according to the distribution of new car sales in the world and in Belgium reflects the short-term availability of a raw material for Belgium. We will use this indicator and ratio to assess short-term pressure. At the same time, using the population distribution as an allocation factor tends to reflect the long-term availability of a raw material for Belgium. In this case, the resources associated with the population distribution are used to assess long-term pressure and complement the previous indicator.

Figure 10: Primary cobalt needs versus reserve and resource estimates (availability relative to population in Belgium and worldwide (explanation in the methodology section))[19]



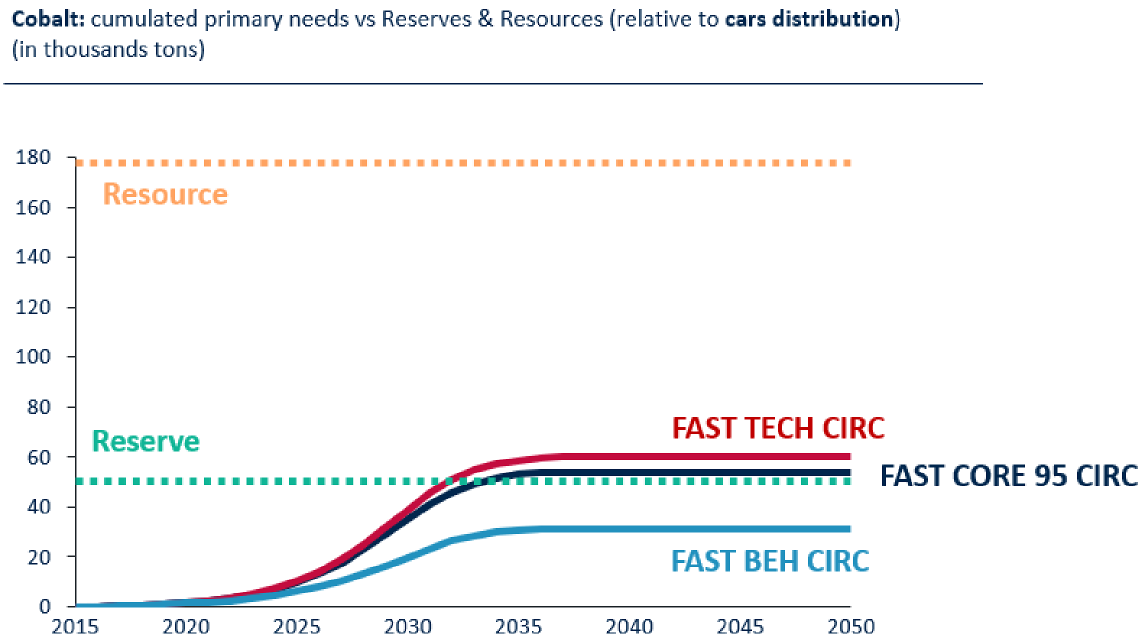
b) In a "CIRC" scenario (with technological improvements), TECH and CORE 95 indicate a rapid and significant pressure, but quite close to the levels of reserves available in the short term (see Figure 11). However, the fact that these reserves are fully exploited between 2030 and 2035 leaves little room for deployment and mineral exploration if technological improvements are slow to roll out.

c) The BEH CIRC scenario (combining behavioural changes and innovations in battery and recycling technologies), greatly reduces the risk of supply problems by limiting the need for electrification. It reduces the volumes of critical materials that need to be mined and allows time for new cobalt-free technologies, for example, to emerge. At the same time, greenhouse gas emissions are reduced, which is not the case for the scenarios with slower decarbonisation. This is the only scenario that remains below the reserve and resource curves.

d) If these new battery technologies do not emerge in time, it is essential to continue mining exploration to increase the size of the reserves, as well as to invest in efficient recycling technologies.

[19] The full graph (LIN and CIRC available for each comparison) is available in Annex 3.

Figure 11: Primary cobalt needs versus reserve and resource estimates (availability relative to the distribution of new cars in Belgium and worldwide (explanation in the methodology section))[20]



4.3.5 Lithium

Main observations:

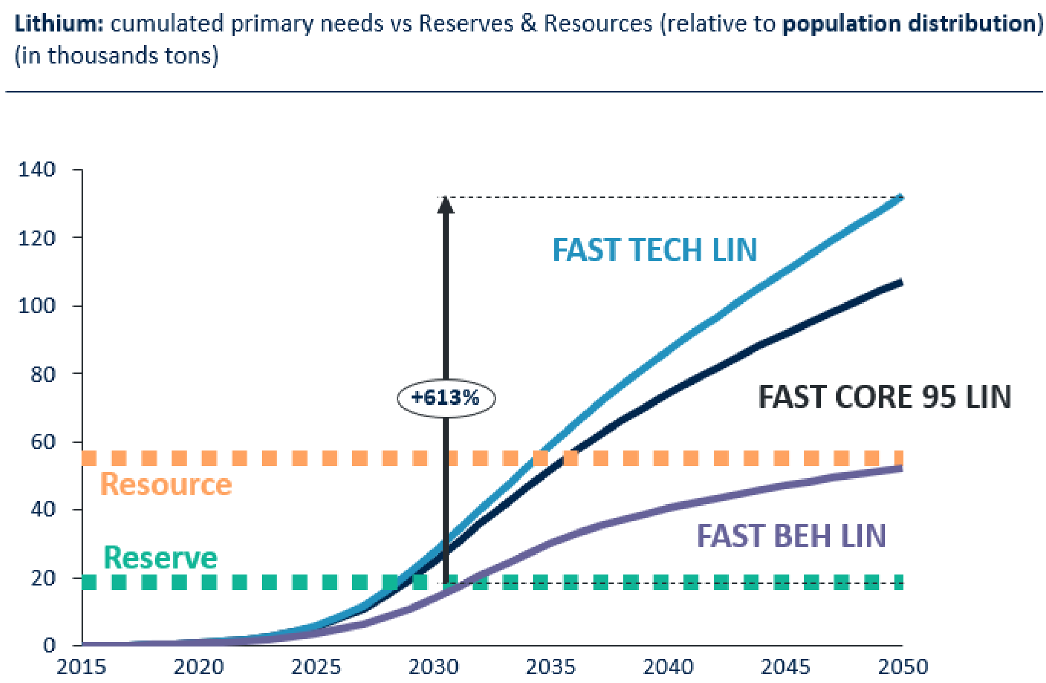
If we decarbonise transportation rapidly (phasing out of sales of ICEV between 2030 and 2035), the conclusions are similar to those for cobalt. However, the estimates of resources and reserves evolve positively and tend to decrease the urgency compared to the latter.[21]

a) Technical improvements that recycle lithium and more efficient alternative technologies are essential. Indeed, the TECH and CORE 95 scenarios, without technological improvements (in batteries and recycling techniques) deviate significantly and rapidly (from 2035) from the levels of resources considered as available for Belgium in the long term. This is less the case for BEH LIN, even though the reserve levels available for Belgium are quickly exceeded. This would imply: (i) that the rest of the world cannot keep up with this rate (ii) and that it is necessary to mine most of the estimated lithium resources

[20] The full graph (LIN and CIRC available for each comparison) is available in Annex 3.
[21] We can see that the estimates of lithium resources have increased from 53 million tonnes in 2018 to 86 million tonnes in 2021 (and lithium production almost doubled between 2017 and 2020). For cobalt, these same estimates remain stable between 2018 and 2021. [122, 123]

by 2050. These two arguments come on top of those relating to cobalt, underscoring the importance of continuing to develop new battery and recycling technologies.

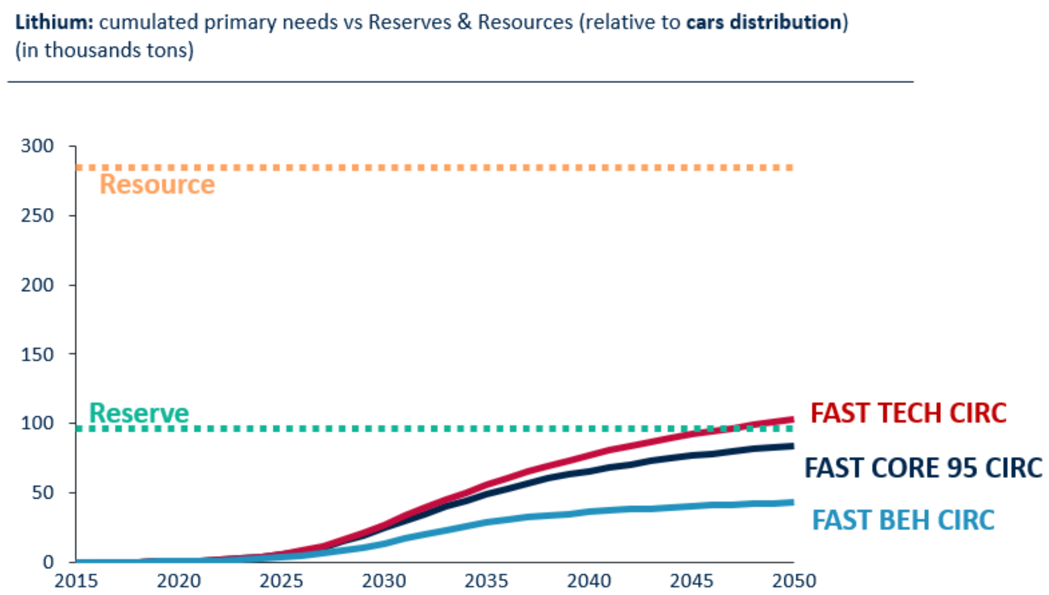
Figure 12: Primary lithium needs versus reserve and resource estimates (availability relative to population in Belgium and worldwide (explanation in the methodology section))[22]



[22] The full graph (LIN and CIRC available for each comparison) is available in Annex 3.

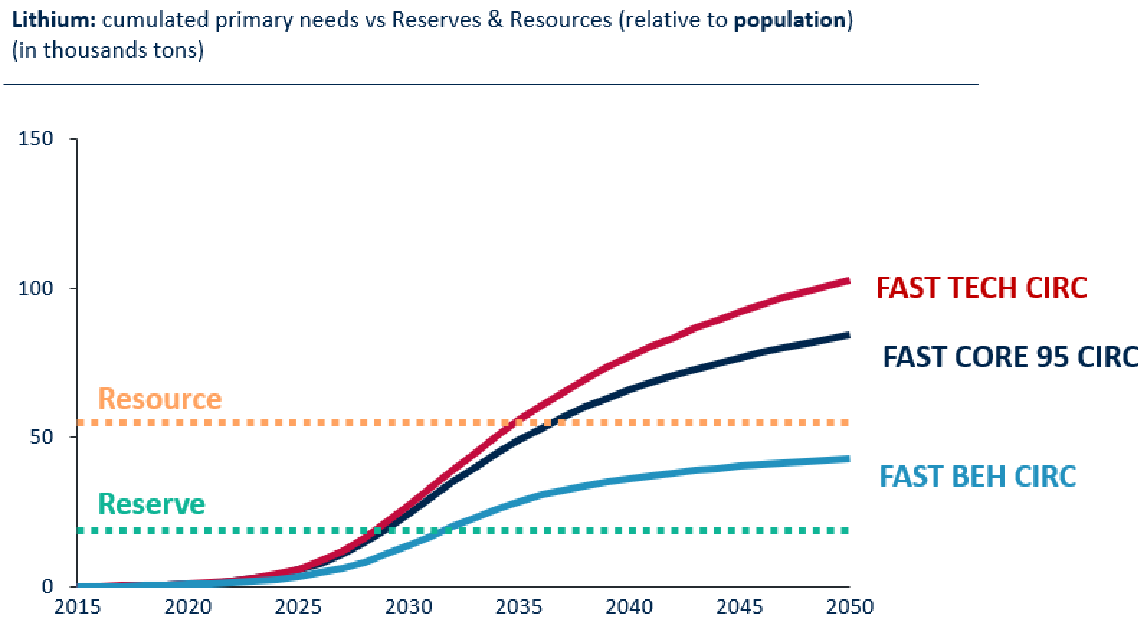
b) This last point is validated by the analysis of the CIRC scenarios, which tend not to exceed the levels of reserves available in the short term for Belgium (Figure 13) - in contrast to the curves for cobalt which see TECH and CORE 95 reaching these same levels as early as 2030-2035. This implies, however, that long-term resource levels are exceeded by TECH and CORE 95 (see Figure 14) - which tends to favour the BEH CIRC scenario, combining significant behavioural change and large-scale technological innovation, and to support mining exploration under a legal framework that strictly limits the externalities.

Figure 13: Primary lithium needs versus reserve and resource estimates (availability relative to the distribution of new cars in Belgium and worldwide (explanation in the methodology section))[23]



[23] The full graph (LIN and CIRC available for each comparison) is available in Annex 3.

Figure 14: Primary lithium needs versus reserve and resource estimates (availability relative to population in Belgium and worldwide (explanation in the methodology section))[24]



[24] The full graph (LIN and CIRC available for each comparison) is available in Annex 3.

4.3.6 Other materials analysed

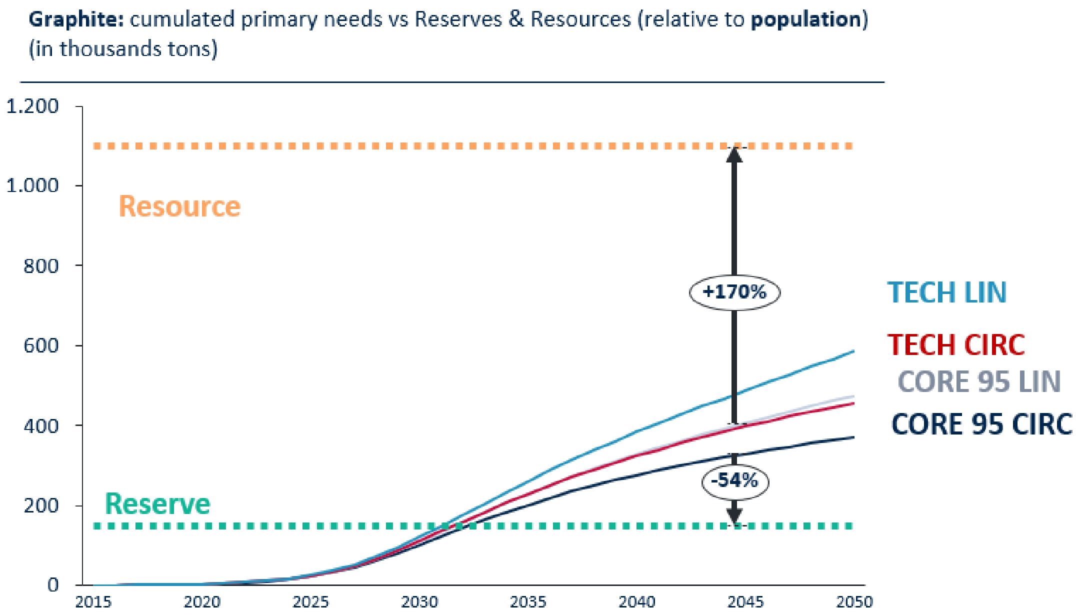
a) For graphite, in the TECH and CORE 95 scenarios, electromobility as such does not pose a major problem in the long term if the estimated resources become economically viable. New battery and recycling technologies are having an impact but the question of the availability of materials is not problematic, unlike the environmental and social challenges already raised. For the entire vehicle fleet to be electrified, it will be essential to make the resources exploitable (or to identify new reserves, see Figure 15). Electromobility is not the only sector that needs these resources: these conclusions need to be put in perspective, by adding the other sectors. The situation is less critical than for cobalt or lithium, for which only the demand for batteries is already problematic in view of the estimated reserves available in the short term.

b) For nickel, the conclusions are similar. Nevertheless, new battery and recycling technologies make it possible to avoid mining exploration in the long term.

c) As regards aluminium and manganese, both the efforts to reduce demand and the technological improvements in batteries do not change the fact that, a priori, current resources are sufficient to meet Belgian and global needs. Electromobility is not the only sector that needs these resources: these conclusions need to be put in perspective, by adding the other sectors.

d) One of the major limitations of the study is of course that it only assesses the impact of electromobility on these materials. However, demand for these is obviously dependent on other evolutions. These evolutions also need to be considered, to measure more precisely the potential mismatch between needs and availability of resources.

Figure 15: Primary graphite needs versus reserve and resource estimates (availability relative to population in Belgium and worldwide (explanation in the methodology section))[25]



[25] The evolutions and comparisons of other materials can be found in Annex 3.

5 Analysis of key impacts

5.1 Introduction

This chapter details the main risks and opportunities associated with the large-scale development of electromobility. The previous chapter described various scenarios based around the need to decarbonise the entire transport sector in Belgium by 2050. The analysis shows that it is essential to combine both behavioural and technological levers. At the technological level, decarbonisation implies a shift from internal combustion engines to electric engines[26] - which is reflected in the various European policies.) This transition is an unprecedented transformation. Choosing the battery option for transport brings with it a range of opportunities and risks, with significant environmental, social and economic consequences - identified in chapter 3. The table below, based on the summary in Chapter 3, ranks the main potential costs and benefits of the scenarios discussed above.

Expected benefits	• Strong reduction of GHG emissions (SDG 13) • Improvement of air quality (SDGs 3 and 11) • Circularity of materials (SDGs 11 & 12) and greater economic independence over time (SDGs 8 & 9) • Contributes to the development of sustainable cities (SDGs 3 and 11), in particular through the improvement of air quality and active and shared modal shift (SDGs 3 and 11)
Potential risks/costs	• Impact on biodiversity (SDGs 12, 14, 15) • Mineral resource scarcity (SDG 12) • A brake on the economic power of the sector (SDG 8) • Potential fall in employment (SDG 8) • Infringements of basic human rights (SDGs 3, 8, 9, 16)

In this section, only four of these potential consequences are analysed:

[26] As a reminder, this study focuses on the impact of the development of batteries that make electrification possible - other technologies are also possible (indirect electrification via hydrogen for example): although used in setting up the scenarios mentioned above (to a lesser extent and not for cars and vans), their impacts are not addressed here.

- **GHG emissions reduction and life cycle analysis:** the previous chapter deals with direct emissions and energy consumption (TTW). What is the situation as regards life cycle emissions compared to conventional vehicles? What are the energy needs for recycling the batteries? What about the changes as regards upstream power generation?
- **Air quality:** what does the switch to electric power make possible in terms of improving air quality in Belgium?
- **Infringements of fundamental rights:** the main social and health challenges identified in the mining regions have been studied: health, violence, working conditions, land grabbing.
- **Jobs:** what is the risk/opportunity trade-off in terms of net jobs? How many new positions would there be and what skills are needed? How to facilitate the transition from ICE skills to electric motor skills?

5.2 Reduction of GHG emissions

5.2.1 Greenhouse gas emissions

Various analyses of the entire life cycle show that electric vehicles emit less greenhouse gases than ICE vehicles (see Figure 16).

Several literature reviews [44][45] have listed and summarised the results of the life cycle assessments (e.g. [1][72][73]). They conclude that, based on the European electricity mix (EU28), the impact of electric cars is 55% lower than that of ICEVs powered by unleaded petrol[27]. The conclusions vary from country to country (or from one state to another in the US [73]), but in Europe only an electric vehicle running on electricity in Estonia performs worse than conventional cars[28]. Even in Poland, often cited as a counter-example, electric vehicles perform better than ICEV (15% less CO_2e/km) [46].

The work of Professor Auke Hoekstra [69] in particular concludes that life cycle assessments of vehicles tend to overestimate the emissions of electric vehicles, for several reasons, including an overestimate of emissions related to battery production, an underestimate of battery life, a failure to take into account positive developments in the electrical system and an underestimate of emissions from conventional vehicles.

5.2.2 Energy consumption and recycling

The quantity of batteries that have reached the end of their life is currently relatively low; while data on consumption linked to recycling exist, they are likely to evolve as scale effects and technological improvements develop along with the growth of the volumes to be recycled.

The data on the energy consumption of battery recycling presented in various identified studies [66][67][68] confirm the conclusions of the life cycle assessments: when applying this specific consumption to the results of the transition scenarios from the previous chapter, it can be seen that the energy needs for recycling are not expected to exceed 3% of the total needs in the CORE 95, TECH or BEH scenarios - while these needs for transport are already lower in the transition scenarios (~70% reduction in total by 2050 when comparing REF and CORE 95), as illustrated in Figure 17.

[27] The impact of diesel engines is 15% lower than that of petrol engines.
[28] Estonia uses coal for 70% of its electricity generation [46].

Figure 16: Comparison of global warming power over the life cycle of cars [44] [45]

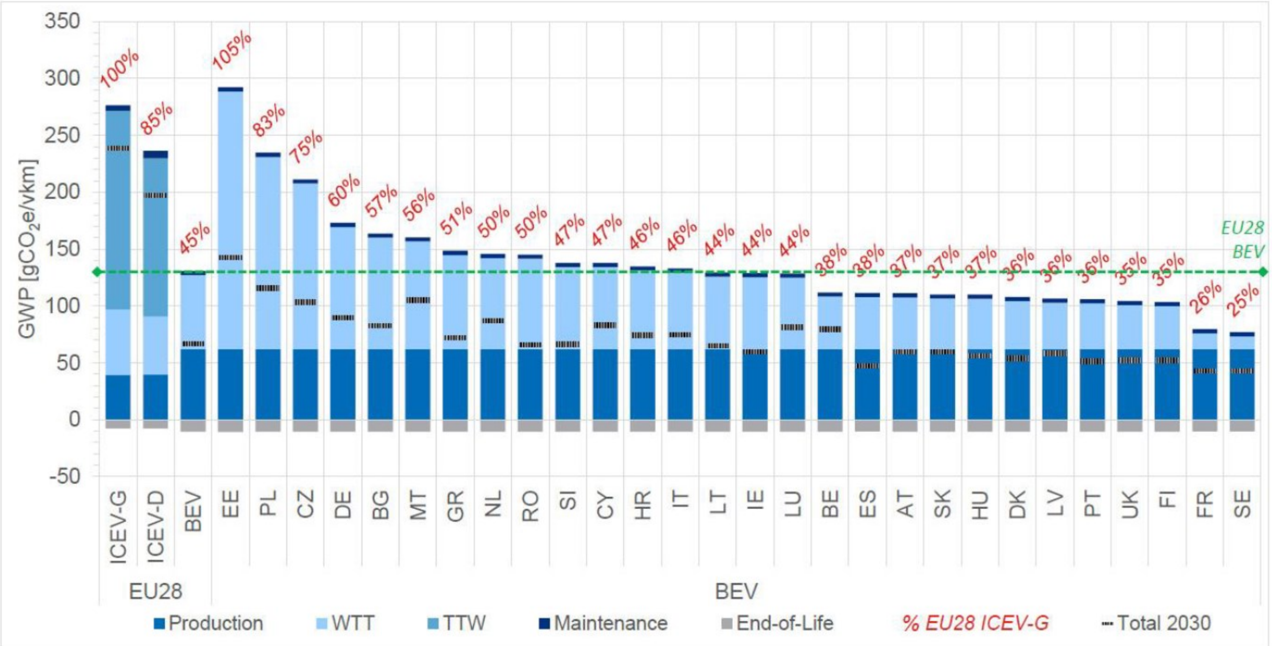
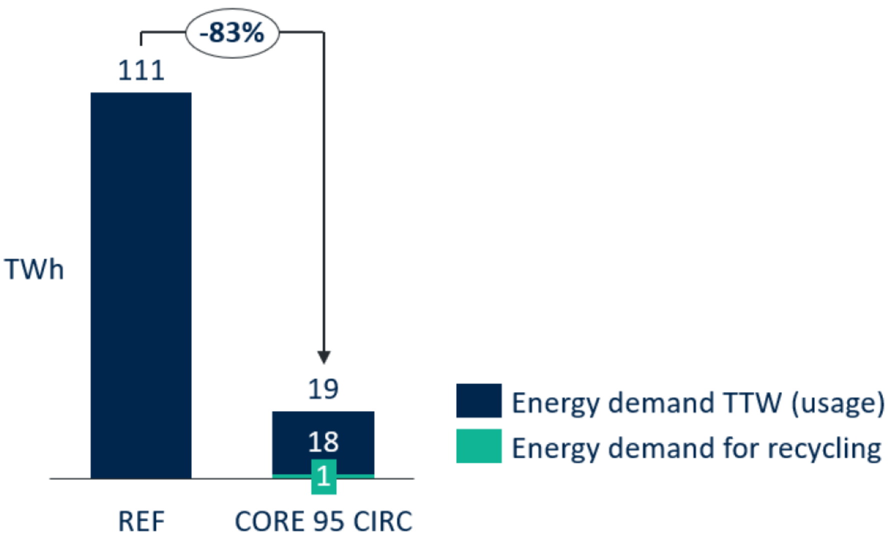


Figure 17: Primary energy consumption in 2050 for transport - selection of specific items



5.2.3 Energy consumption and electric system

Decarbonising electricity generation in parallel with the development of electromobility is essential. While the solutions to decarbonise the generation of electricity already exist, the complexity of the transition lies in the volumes required, which will likely increase, since the decarbonisation of a range of sectors (such as construction and industry, for example) relies (at least in part) on them being electrified. The scale of the challenge in ambitious decarbonisation scenarios is detailed in various studies [70, 71] which:

- Encourage improvements to the journeys we make, for example: switching to more active modes, increasing car sharing, looking again at urban planning policy, to reduce the amount and length of necessary journeys, encouraging shorter commutes,
- Encourage more rapid deployment of decarbonised electricity sources,
- Discourage the use of synthetic fuels (such as, if we use a broad definition of the concept, synthetic diesel, synthetic ammonia or hydrogen) for passenger transport, as these are much less energy efficient than batteries, requiring clean electricity themselves to be produced.

Decarbonising electricity generation also improves air quality in areas close to power plants and reduces exposure to pollutants in coal mines (which is less relevant in Belgium) [110, 111].

5.3 Impacts on air quality

5.3.1 Methodology

Air quality related to the use of vehicles is assessed in this chapter. The following sources of pollution are identified: brake wear (labelled "brake" in the figures below), tyre wear ("tyres"), road wear ("road") and energy ("energy").

The "Pathways Explorer" model [53] presented above makes it possible to quantify air pollutant emissions and link them to direct impacts on human health. The following analysis was made by CLIMACT, based on the assumptions and sources used in the EuCalc project [54], primarily based on the analyses of the consultancy firm IIASA. [55] The pollutants studied are the following: NH_3, SO_2, PM2.5, VOC[29]. PM2.5 is the most problematic pollutant for health in Belgium and Europe (7,400 and 379,000 deaths in 2018, respectively) [118], and transport is a significant source of emissions (~20% of all PM2.5 emissions in 2017) [119].

The results of the REF, CORE-95 and TECH scenarios[30] are used to show the evolution of emissions of these pollutants.

The information is available for all the following modes of transport: buses, cars, heavy trucks, light trucks (<3.5t), two-wheelers, aeroplanes, trains, coastal and river traffic.

It is relevant to note that driving behaviour is considered similar between the ICEV and electric cars, as well as the tyre rubber. New technologies that capture brake-related emissions [115] are emerging, but are not taken into consideration either.

5.3.2 Results

Emissions and concentrations of air pollutants decrease in the decarbonisation scenarios for electromobility.

The reason is simple: these emissions and concentrations are mainly related to the combustion of fossil fuels and the number of vehicle kilometres travelled; two indicators that are significantly modified in TECH and CORE 95.

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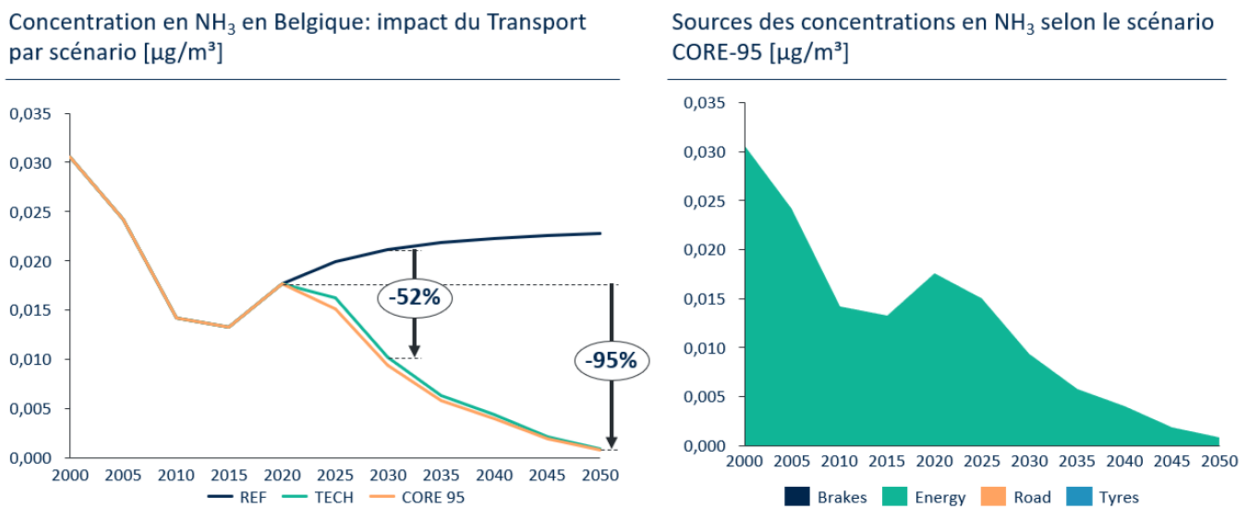
[29] NO_x is not taken into account as the model considers a dilution of the emissions over the whole Belgian territory (source: IIASA [55] - this results in a dispersion factor = 0).

[30] See section 4.2 for the definition of these scenarios.

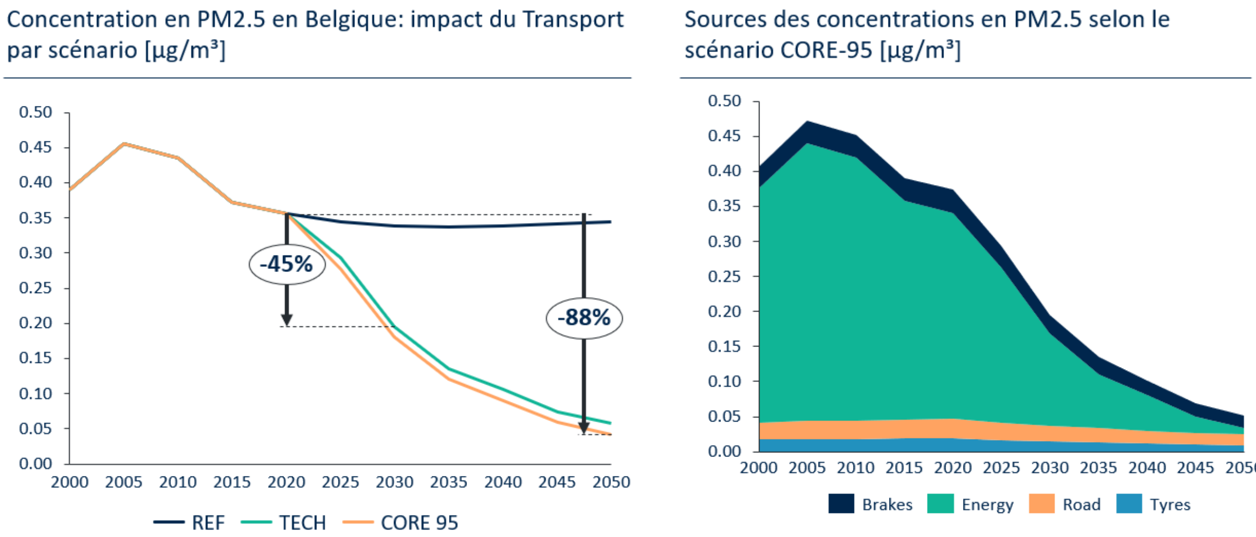
As NH_3 and VOCs are entirely due to combustion, it is possible to reduce these both by the technology shift and the gradual reduction of vehicle kilometres (also possible in TECH given the growth of vehicle sharing technologies). This is illustrated in Figure 18 for NH_3.

Figure 18: NH_3 emissions in Belgium according to REF, CORE 95 and TECH



The conclusion is the same for PM2.5, except that emissions from brakes, tyres and roads decrease less sharply. Capture technologies will be necessary to eliminate these emissions (they are currently under development [115]).[31]

Figure 19: PM2.5 emissions in Belgium according to REF, CORE 95 and TECH



As regards SO_2 emissions, the standards of previous years have been beneficial, as no emissions have been measured since 2010.

[31] Certain technological improvements in fossil fuels have not been taken into account (e.g. the introduction of Euro 7 fuels). The decrease that they would allow in REF is not quantified in this study.

5.4 Infringements of fundamental rights

Major problems are regularly reported in the mining regions from which the necessary materials for electromobility are sourced. Attributing all of these negative externalities to new car batteries is inaccurate: these recurring phenomena concern a number of mining practices (and have for decades), regardless of the use of the materials downstream. Taking action on the battery value chain is urgent but not sufficient: while this may be an entry point for more standards, it is also essential and urgent to improve mining practices in general.

The externalities described in this section relate to the mining of materials necessary for the manufacture of batteries according to current technologies. It is useful to recall that these materials are currently also used for applications other than electromobility. Given the scale of the growth prospects for batteries, these applications could become the main market for these materials, so it is important to identify current negative impacts in order to define timely remedial measures.

It is useful to refer to the work of organisations such as Amnesty International, Business Human Rights, and Human Rights Watch for more details (this list is not exhaustive). The following paragraphs primarily focus on the problems in the Democratic Republic of Congo (DRC), but it soon becomes clear that similar phenomena take place all over the world, even if most of it is listed first in South America, Africa, Asia and then in Central America [100] [107] [108].

5.4.1 Health

Various studies show significant concentrations of toxic metals in the urine of populations living near cobalt mines in Katanga [63]. As such: "previous research has shown that people living close to DRC's mines had forty three times the level of cobalt, five times the level of lead, and four times the level of cadmium and uranium in their urine than is considered normal. Visitors to the area witness ore concentrates falling off open dump trucks, creating dangerous dust in the streets."

While the impact of certain metals such as lead on human health is an established fact, it would appear that only one study, from a collaboration between Belgian and Congolese universities, has attempted to demonstrate the link between the concentration of cobalt and the potential impacts on human health, in this case congenital malformations. Published in The Lancet, it also notes that "women in southern Congo had metal concentrations that are among the highest ever reported for pregnant women." While the study could not establish a statistical link between these concentrations and congenital malformations, it did show a clear link between the fact that the father works in the mine, and the likelihood of congenital malformations. [61] [64]

There are many causes of toxic concentrations, and they can come from both direct exposure in the mines and impacts on air quality related to the transportation of metals or metal processing. In Katanga, a report explains: "Thousands of trucks travel to and from the mines and related operations all day and through the night, exposing resident in the cities of Lubumbashi and Likasi to heightened air pollution and leaving them rightfully afraid of contracting lung diseases. Chronic exposure to such dust can lead to potentially fatal hard-metal lung disease. It can also lead to a variety of other pulmonary problems, including asthma, decreased lung function, and pneumonia." [60]

Katanga is not the only region at risk and cobalt is not the only mineral concerned. Similar problems are reported in other parts of the world [107]. We can cite an example from Indonesia, where toxic fumes have been observed coming from factories that process minerals mined nearby: "Dwi Sawung from the non-profit Indonesian Forum for the Environment (Walhi) said that most of the smelters built by China in Indonesia used old, highly polluting technology, and most Chinese-funded projects lacked environmental safeguards. [...] Yose said to prevent environmental problems in the future, the Indonesian government should strictly enforce its environmental protection regulations." [65]

5.4.2 Child labour and working conditions in general

An Amnesty International investigation from 2016 [56] showed that some cobalt mines in the DRC employ children in conditions described as "the worst forms of child labour". The same report describes the working conditions in certain mines where miners are exposed to significant risks of fatal accidents (tunnel collapses, fires, etc.). Although, according to several observers [57], this work is apparently only limited to artisanal exploitation (which would correspond to 10-20% of cobalt production in the DRC [57]), in 2014 UNICEF estimated that there were 40,000 children working in the mines at Katanga [58].

Among the causes or factors aggravating these situations, Amnesty International lists loopholes in laws and standards or, where these do exist, in the capacity of government agencies to monitor and enforce them. Amnesty International also points to a lack of due diligence by companies as recommended by the OECD's Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High Risk Areas. [59]

5.4.3 Violence

Amnesty International and the study centre SOMO [60] also report various cases of violence observed in 2016. Police and military personnel have been seen firing shots at illegal miners who have entered copper and cobalt mines without permission.

5.4.4 Land grabbing and unbalanced compensation

Various cases falling into this category were described in the above-mentioned study [60]: (i) the relocation of communities to land with poor soil, (ii) land grabbing without alternative land being offered and without adequate compensation, (iii) the relocation of communities to land without access to clean water or basic infrastructure, and (iv) clearing of forests that serve as livelihoods for the surrounding communities, without alternative solutions. These actions are all the more problematic as they affect groups who are already in a precarious situation, making them even more vulnerable.

Once again, the DRC and cobalt are not isolated examples. Aluminium, for example, (produced from bauxite) also suffers from similar problems in the Solomon Islands [100, 101].

5.5 Impact on employment in Europe

It is difficult to qualify with certainty the net impact of the arrival of electric vehicles on employment in Europe, and by extension in Belgium. There are still too many uncertainties regarding the parameters used and, to our knowledge, there is no precise study on the Belgian case. One thing is certain, there will be a profound change in the types of skills needed, and the need to re-orient a significant portion of the workforce currently employed in the automotive sector.

Several prospective studies measuring the economic impact of the development of electric cars (in terms of jobs and GDP) have been carried out since 2010 by various consultancies. The identified studies primarily focus on the German labour market, although some extend their findings to the European level. Their methodology and assumptions differ, as do their conclusions: some are positive, others negative. The following paragraphs summarise, qualify and cross-reference the conclusions of the work that we found most relevant.

In a recent study [47], conducted by the German Federal Employment Agency, which focuses on Germany between 2020 and 2035, the central scenario suggests an increase in employment and GDP in the short term (2025), linked to the significant amount of investment, and a net decline in both indicators in the medium term (2035). They forecast a net loss of 114,000 jobs by 2035, i.e. a 10% increase in current unemployment in Germany.

This study draws conclusions by qualifying these results. Firstly, the scenario for the evolution of the penetration of electric vehicles in annual sales is centred on an ambition of 23% by 2030. A higher penetration of electric vehicles - increasingly realistic given recent evolutions - would boost the employment balance by 2035. Secondly, relocating as many activities as possible in the value chain would also improve the suggested forecasts.

Conversely, another study co-authored by Transport & Environment and commissioned by the IEA ("The European Association of Electrical Contractors") in 2018 concludes that at the European level in 2030 the number of jobs created by the transition to electric will be twice the number of jobs lost [48]. In its communication on the study, Transport & Environment also qualifies the conclusions of the study by the Fraunhofer Institute for Industrial Engineering, commissioned by Volkswagen [51], in which the results are also rather negative for German jobs (see below): according to Transport & Environment, the Fraunhofer Institute attributes 83% of the losses to productivity improvements and not to the growth of electromobility.

The need to relocate jobs and integrate the value chain is a message that seems to have been followed by some German manufacturers[32]. Indeed, the need to cover a wider range of their value chain appears to be central to their growth plan in view of the partnerships listed: the production of batteries and construction of "gigafactories", recycling plant and objectives, setting up charging stations, etc.

In a November 2020 publication produced in partnership with the Fraunhofer Institute for Industrial Engineering, it is mentioned that "the study relativises the occasionally alarming findings of previous publications and refutes common scenarios describing exclusively negative employment effects. Using the example of Volkswagen, the study shows there is no uniform employment trend in the "transformation corridor" over the coming decade". [51]

The authors of the recent report for the "Platform for electromobility" [52] seem to agree, adding that: "In total, the number of jobs across the eight investigated industries will remain nearly constant until 2030. However, there will be significant shifts. [...] In consequence, strong temporal, industry and job-related as well as regional transitions will occur in the labor market". They therefore insist on the need to anticipate training to facilitate professional reorientations.

It should be noted that these studies generally focus on light vehicles, which of course is the majority, but fail to quantify the additional opportunities and risks that other modes of transport could represent.

In conclusion, it is difficult to qualify with certainty and precision the impact of the advent of electric vehicles on employment. There are risks and opportunities, and the forecasts vary significantly from one study to another. The margin of error regarding quantifications of jobs is non-negligible given the uncertain nature of the assumptions and the amount of parameters involved. As such, parameters such as the rate of development of recycling or relocation of the production of high value-added components appear to be crucial for maintaining a stable employment rate - or at least reducing the risks of job losses.

Despite the scale of the uncertainties and given the necessity of making this transition, two conclusions emerge from the literature review:

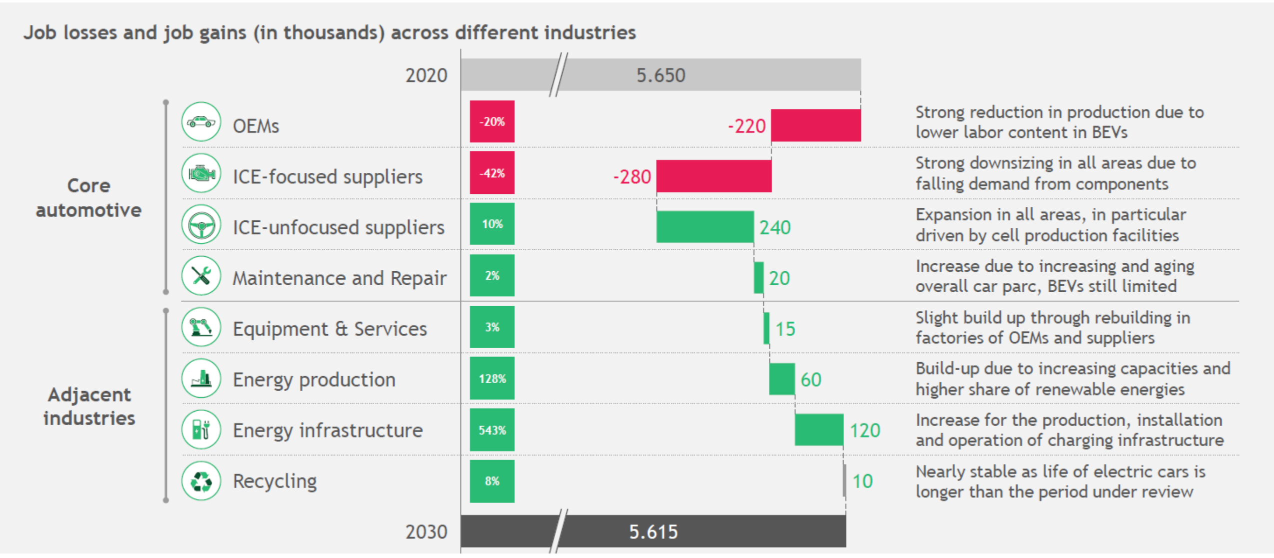
- The development of electric vehicles and the end of ICEs must be accompanied by the local development of ancillary sectors in the value chain in order to be considered "sustainable" in terms of employment. Indeed, as highlighted by each of these studies, there will be a shift in useful skills,

[32] VW, for example, in their recent communication [49] on their strategic reorientation towards "all-electric" - which contrasts with the historically rather conservative positioning of the German automotive lobby VDA [50].

- It is essential to have decent programmes (both at the policy and industry levels) in terms of support and training to be put in place to reorient people working in these industries.

Finally, in connection with the previous point, these notions of diversification and development of related sectors are all the more crucial as none of the studies seem to suggest a reduction in demand and a decline in the car market, contrary to what is stated in the CORE-95 and BEHAVIOUR scenarios. If such paths are chosen, the net employment balance of the car manufacturers is likely to be negative. In this case, the reorientation programmes will have to prioritise a switch to other industries in need of manpower, if necessary in other sectors, such as the energy renovation of buildings or industry, or the development of renewable energy. At the same time, new services (outside the vehicle production value chain) will emerge in these decarbonisation scenarios (such as the development of car-sharing technologies), which could also be the source of new jobs.

Figure 20: BCG study [52] - balance of jobs related to the automotive industry in Europe



6 Recommendations for policy measures

6.1 Introduction

This chapter proposes a range of measures based on the qualitative and quantitative analyses carried out. These measures will either promote the decarbonisation scenarios studied in chapter 4, or prevent (or mitigate) the negative externalities listed above and analysed in chapters 3 and 5. This chapter echoes various legal texts, interviews with experts, articles, studies and position papers of several environmental organisations (for more details, see [74, 76, 77, 78, 82, 85, 99, 102]).

6.2 A central text: the proposal for a regulation on batteries published by the European Commission [76].

In the context of the European Green Deal, under the new "Circular Economy Action Plan", in December 2020 the European Commission published an important proposal for a regulation that covers the entire battery value chain: "Regulation [...] concerning batteries and waste batteries". It aims to replace a previous directive ("concerning batteries and accumulators and waste batteries and accumulators"), which is not only becoming obsolete in view of future developments but is also problematic on several levels (e.g. lack of framework conditions to encourage investment, sub-optimal functioning of recycling markets and insufficiently closed material management, social and environmental risks).

The proposal for a regulation aims to introduce minimum environmental and social criteria for all types of batteries placed on the European market. It promotes environmental and social due diligence throughout the value chain. Upstream of use, it requires a calculation of the carbon footprint of production and pushes for the creation of a "passport" to facilitate transparency regarding key information for the consumer and for the actors involved in the repair, reuse or recycling of batteries. Downstream, it lays down collection and recycling targets for materials.

At the time of publication of this study, the text is being reviewed by several committees of the Parliament as well as by the Council of Europe, represented by the Ministers of the Environment of each Member State, and is expected to be voted on around February 2022 [77].

6.3 Recommendations for improvements to the current proposal

Most Member States, NGOs and stakeholders welcomed this proposal, while suggesting a series of improvements to the final text [77, 74, 99, 112]. This section draws on the positions taken by these stakeholders to identify shortcomings in the current proposal for a regulation, and suggest remedial recommendations. Moreover, as the text is under revision, some of these recommendations insist that specific ambitions remain high in the final text. The points raised are not intended to be exhaustive, but rather to address the major issues raised in Chapters 4 and 5.

6.3.1 Ensuring ambitious collection and recycling targets

Chapters 4 and 5of this study emphasise the need to prioritise the recycling of materials. It is crucial to have robust targets for the initial collection of end-of-life batteries and for the recycling rate of the components of these batteries. Article 47, 48, 55 and 57 of the European Commission's proposal for a regulation These recommendations are in line with those of a consortium of NGOs [74].

Recommendation 1: Prohibit the disposal and destruction of batteries via landfill or incinerators. This applies to both automotive and industrial batteries.

Recommendation 2: The recycling targets for critical materials must be aligned with current best practices. The table below summarises the minimum recommendations (linked to the scenarios in Chapter 4). An opening to other materials in the event that new technologies are developed must be made possible.

Critical materials	Recommended objectives for 2030
Cobalt	98%
Lithium	90%
Copper	98%
Nickel	98%

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6.3.2 Compulsory due diligence on the value chain upstream of production

This section primarily takes inspiration from [74] and [99], selecting and adapting some of their recommendations. Readers are advised to refer to these documents for a more complete and detailed listing of the selected items summarised below.

The aim of this section is to cover the themes related to social risks (in the broad sense of fundamental rights) and environmental risks covered in Chapter 5. In the proposal for a regulation, this is Article 39.

Recommendation 3: Include all categories of batteries in due diligence obligations, not just industrial and electric vehicle batteries.

Recommendation 4: Use the criteria in the texts that include all human and environmental risks, and not just the "OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas", which is too restrictive geographically and thematically. It is recommended to refer instead to the following texts: "UN Guiding Principles" and the "OECD Guidelines for Multinational Enterprises" [83, 84]).

Recommendation 5: Expand the spectrum of materials covered to include at least copper, bauxite and iron (not covered in this study but recommended by Amnesty International). Eventually, the obligation should become "material agnostic" so that all mining activity is subject to the same obligations. [112]

Recommendation 6: Develop ambitious environmental due diligence criteria with reference to key principles of European environmental laws, international agreements and a non-exhaustive list of negative environmental impacts. This is necessary because there are no international standards that list these criteria, as is the case for human rights, for example. It is important to include a non-exhaustive list of negative environmental consequences (similar to the European taxonomy regulation or the Corporate Sustainability Reporting Directive)[33] to give substance to this obligation.

6.3.3 Include provisions for potential deep-sea mining

[33] The list of environmental impacts should include, without being limited to, direct and indirect impacts related to climate change (including greenhouse gas emissions), air, soil, water and noise pollution (including through the disposal of chemicals), hazardous substances and waste generation, loss and damage to forests and natural ecosystems, loss of biodiversity and loss of habitats and species.

The deep-seabed contains globally important mineral deposits, including copper, cobalt, lithium, nickel, [86] manganese, silver, zinc, and many rare earth elements and metals [87]. The potential of the deep-seabed for battery supply chains is widely acknowledged. One mining company, for example, describes polymetallic nodules on the deep-seabed, which contain cobalt, nickel, copper and manganese, as "a battery in a rock" [88].

The International Seabed Authority (ISA) is currently drafting regulations to authorise and govern mining in the international seabed area, which could be finalised within two years. Some countries, including the Cook Islands [90], Japan [91] [92] and Norway [93], provide for mining in their national jurisdictions.

Potential deep-sea mining is controversial. Groups of scientists and marine conservationists [94] [95] [96], as well as the European Parliament [97], are calling for a moratorium on deep-sea mining until more is known about the potential environmental, social and economic effects and until impact management techniques are proven effective. Certain major manufacturers have endorsed this call [98], although the wider manufacturing community is concerned about how future demand for battery resources will be met, and see deep-seabed resources as part of the solution. Due to the controversy surrounding potential deep-sea mining, strong responsible sourcing requirements must be drawn up and adhered to.

Belgium has a significant interest in the management, exploration and exploitation of deep-seabed resources. GSR, a subsidiary of the Belgian dredging company DEME, is one of the leading deep-sea mining exploration companies. The Belgian government sponsors GSR's exploration contract with the International Seabed Authority and GSR also has a contract with the Cook Islands. Belgium also has a permanent mission to the ISA in Jamaica.

Recommendation 7: Extend due diligence for the supply chain to explicitly cover the seabed, and include all potential environmental and social impacts of deep-sea mining. Until a credible due diligence framework is in place, European companies in the battery supply chain (above a certain size) should help draft one. This can be done by participating in appropriate forums such as the World Economic Forum Deep-Sea Minerals Dialogue.

6.4 Other recommendations at European and Belgian level

The Commission's proposal for a regulation only pertains to the management of batteries. It does not cover various items mentioned in the previous chapters, including:

- The measures specific to the Transport sector that define emission reduction targets that are up to the climate challenge,
- The Transport sector measures to limit the pressure on natural resources and primary energy demand,
- The measures that allow a more realistic industrial transition (given the growth in volumes required) without compromising the climate ambitions,
- The measures that support the large-scale development of charging infrastructure, sustainable battery production capacity (including innovation targeting less material-intensive batteries) and recycling,
- The measures to support and facilitate professional re-orientation.

The list is non-exhaustive, but these points are crucial and will need the support of the legislator.

The following recommendations attempt both to identify shortcomings in other texts published by the European Commission in the context of the Green Deal [103] and suggest other measures not directly related to the latter. Moreover, each recommendation also specifies whether or not their scope can be applied to the Belgian national framework.

6.4.1 Decarbonisation of all new car (LDV) and light truck sales

In this study, the decarbonisation of transport is considered essential for the advent of a truly sustainable society. The analyses primarily focus on the consequences of electromobility and the induced production of batteries, according to several decarbonisation scenarios. The basic assumption for measuring this impact is a ban on the sale of new light-duty ICE vehicles between 2030 and 2035 (as suggested, at least, by various studies [85, 120] in order to achieve the necessary reductions by 2050). This is in line with the target recently proposed by the Commission in the Fit for 55 package (end of sales of LDVs (i.e. cars) and ICE vans by 2035, and a reduction in average emissions from vehicles sold in 2030 of -55% (vs 2021)) [103].

According to various studies, while this is an improvement on the current target (-37% by 2030), it is not ambitious enough in view of the climate-related [85] and economic [104] challenges. These same studies suggest a revision of the objectives leading up to 2025 and 2030, to enable decarbonisation by 2035. It is also useful to scrutinise the national efforts and in particular the need for developed countries, including Belgium, to set more ambitious targets than 2035 in order to give poorer regions more time [104].

Given the importance and urgency of the climate challenge, it is useful to recall that the negative consequences of the development of batteries presented in this study do not in any way justify scaling back the necessary decarbonisation ambitions. These make it possible to add markers, which are also essential for the sustainable development of the electric sector. The recommendations below echo the above-mentioned studies to recall the importance of the challenge while reiterating that (i) the other recommendations (behavioural change and technological advances) in this section are essential to ensure sustainable development and (ii) that recommendations 8 and 9 need to be studied in greater depth in order to validate the above-mentioned objectives and to adapt the support to industry.

Recommendation 8: Set 2030 as the target for ending sales of new LDVs and ICE vans in Belgium.

Recommendation 9: Support the proposed ban for 2035 and follow the recommendations of [105] that the current European targets for 2025 and 2030 should be increased.

6.4.2 Setting stricter standards and targets for the weight and power of cars

It is crucial to reverse the trends of recent years regarding the average weight of vehicles; in Europe, this weight grew by almost 10% between 2001 and 2016 [80], while SUVs went from 10% of sales in 2010 to almost 42% in 2020 [104]. Four elements back up this claim [102]:

- There is a need to reduce the energy consumption in use and manufacture - the direct and indirect emissions - of new vehicles,
- There is a need to reduce the size of the average battery of future electric vehicles, to limit mining and its potential negative consequences,
- There is a need to reduce emissions of particulate matter, which are larger for heavy duty vehicles,
- There is a need to improve safety on the roads by reducing the hazards of heavy duty vehicles for weaker road users[34].

One of the many benefits of reduced weight and power is the reduction in material requirements, which was shown to be essential in Chapter 4. To bring this about would require additional standards at European (and Belgian) level. The policy recommendations issued by the "Lisacar"[35] initiative, the NGO Transport & Environment ([104] and [106]), the scientific journal Nature [102] and the director of the International Energy Agency (IEA) [109] all point in this direction.

Recommendation 10: Modify the suggested formula for CO_2e/km targets by 2025 and 2030 by removing vehicle mass from the equation (see [106] for details).

Recommendation 11: Set standards and targets for weight and power of cars, with a view to reducing them. At the same time, encourage purchases of lighter vehicles, discourage purchases of heavy vehicles (SUVs) and raise awareness on the subject. In Belgium, in the absence of broader regulation, such provisions should be added to the recently enacted reform of company cars.

6.4.3 Setting up an international agency for cooperation in the mining of critical materials

[34] There are various studies on the subject, with divergent conclusions. The fact they are dangerous has been retained as an argument against SUVs because (i) mass and speed are directly related to the kinetic energy of a vehicle and (ii) the bulky profile of some of these vehicles has more serious consequences than a conventional car shape for weaker road users in the event of a collision.

[35] See all the suggestions (in French) at: https://www.lisacar.eu/.

This proposal echoes the article by Marc-Antoine Eyl-Mazzega in Le Monde [75]. It would facilitate both the sharing of certain practices and the coordination of supply chain audits.

Recommendation 12: set up an international cooperative agency with a mandate to oversee and promote the sharing and improvement of human rights and environmental due diligence criteria developed in the previous section.

6.4.4 Reduce the use of cars

It is essential that strong investment programmes are made long term at European level, to reduce initial demand and encourage the modal shift. Without going into detail, the recommendations set out in [85] summarise the elements to be implemented at European or national level.

Recommendation 13: Invest in active and shared mobility - accelerate investment in walking, cycling and public transport infrastructure and associated rolling stock. Involve organisations that support persons with reduced mobility in these transformations, to make these new practices accessible to all. Invest in behavioural change technologies such as "Mobility as a Service".

Recommendation 14: Reform the tax system to accelerate the modal shift.

6.4.5 Jobs, innovation and industries of the transition

A European economic and industrial strategy - more comprehensive than the following recommendations - is clearly necessary to bring about the energy transition rapidly and smoothly. The aim of this section is to provide several elements that appear important in light of the above conclusions.

Section 5.4 showed the risks for jobs directly or indirectly linked to the traditional European automotive industry; the workers concerned must be supported, retraining must be facilitated and the development of future sectors must be accelerated.

Recommendation 15: Supervise and support assistance and reorientation programmes for workers affected by the transition.

Recommendation 16: Support investments in the industries of the battery value chain to control the long-term employment rate (see recycling and new technologies below, and also target charging infrastructure) and avoid dependence on foreign industries with lower social and environmental standards.

Chapter 4 showed how the principles of the circular economy become self-evident in view of the mismatch between resource estimates and the growth of future needs. It is imperative to accelerate the development of battery component recycling industries - both in innovation and industrial development. This chapter has highlighted the importance of accelerating the development of less resource-intensive battery technologies.

Recommendation 17: Support innovations in recycling techniques and new battery technologies, as well as the industrial development of the latter. Also prioritise the sharing of knowledge of cutting-edge technologies to ensure a match between recycling capacity and future annual volumes.

7 Annex 1: Summary of environmental, social and economic challenges

7.1 The main environmental challenges

Activities in the value chain	Risks	Opportunities
Mining of materials	• **The growth in EV demand could lead to resource shortages in the short term.** These are mainly cobalt, nickel, lithium. [10, 13] • **Mining materials generates environmental impacts,** including toxicity, ecotoxicity, destruction of biotopes and eutrophication of fresh water. As regards land use and water consumption, BEVs perform worse than ICEVs. [1, 26]	• **The development of electromobility will slow down the depletion of fossil fuels.** With the electrification of transport, the depletion of fossil fuels is reduced, as are the environmental risks associated with extracting the latter.
Vehicle and battery manufacturing	• **The carbon footprint of battery production is significant**. The carbon footprint of battery production is about half of the total footprint of EV production [3, 19]. The manufacture of an EV is more carbon intensive than the manufacture of an ICEV - although a full LCA is necessary to properly compare the footprint of the technologies. • **The location of the industry is part of the impact.** The current battery industry is primarily located in China, where the electricity sector is highly carbon-intensive. [25]	• **Battery technology is new and technological advances could potentially reduce their environmental footprint.** These include in particular solid-state batteries, expected after 2030; improved electronic interface; the use of AI. [3, 18, 19]

Use and indirect emissions	• **Electricity generation can be carbon- and air pollutant intensive**. The emissions from driving a BEV are mainly associated with the generation of electricity, which depends on the regional mix. Whatever the mix, even in the case of a nuclear phase-out in Belgium or high coal-fired power generation in Poland, the associated GHG emissions are lower than those of an ICEV [19]. • **The impact on air quality is still (potentially) significant**. Driving on the road emits local pollutants (airborne particles) from the road, brakes and tyres. This is a newly studied aspect that affects any type of vehicle and for which there are various uncertainties. [1, 2, 26]	• **WTW emissions are reduced by increasing renewable energy** in the European energy mix. • **The BEV** ○ **is more efficient:** energy yields (kWh/km), BEVs are two to four times better than ICEVs, resulting in a lower WTW even with grey electricity. [17] ○ **allows for higher mileage**, which creates an opportunity for MaaS [19] ○ **improves air quality**, as there are no exhaust emissions (SOx, NOx, PM). • **The use of fossil fuels is falling**. With electric vehicles and the increase in renewable energy, there is a reduction in the environmental and health risks associated with the extraction and combustion of fossil fuels. [36]
End-of-life management	• **Recycling capacity is uncertain:** there is uncertainty regarding. As batteries are an evolving technology, it is not certain that we will have the technology and industrial capacity to recycle them effectively. • **Hazardous battery waste will accumulate, representing a significant volume**. A large volume of hazardous waste can be expected around 2030 if the recycling sector does not develop rapidly enough.	• **Efficient recycling means less extraction, which means that fewer resources are extracted**. Improved and more widespread management of end-of-life battery processing will lead to a reduction in raw material extraction and associated environmental risks. • **Electromobility may facilitate the transition to "functional" mobility**. This includes reduced demand for vehicle and vehicle fleet usage (MaaS), and reduced quantities of materials per car[ab] [14, 22, 27, 28].
Carbon footprint in life cycle assessment	• **There are still conflicting claims, given the recent development of electromobility**. Given that electric vehicles are an emerging technology, there are still conflicting claims, although more and more studies appear to confirm the fact that electric vehicles have a significantly lower carbon footprint than ICEV. [3, 19]	• **The full carbon footprint (LCA) of a BEV is three times lower than that of an ICEV**. [3, 19, 45][c] • **The carbon footprint of the future BEV will be four times smaller than that of ICEVs**, mainly due to the decarbonisation of electricity in the EU. [d] [19]

7.2 The main economic challenges

Activities in the value chain	Risks	Opportunities
Mining of materials	• **Europe is dependent on other countries for the supply of materials.** These materials are mainly produced outside Europe. A growing demand for batteries could weaken the European economy if the EU remains dependent on the supply of materials.	• **Recycling mitigates the EU's dependence on foreign supplies.** This would ensure economic independence and security of supply. Recycling has the potential to develop a European materials recovery market. [18, 21] • **Electromobility is an emerging market and provides opportunities for relocating the materials industry**. As the market is emerging, Europe can relocate this production on its territory and develop the domestic metallurgical industry in particular. • **PLVs are an opportunity to reduce the demand for materials**. PLVs are lightweight (less than 400 kg) and can reduce the need for materials and dependence on other countries. This is an opportunity to develop a new market in the European automotive sector. [13, 27] • **The development of electromobility reduces Europe's dependence on imported fuel.**
Vehicle and battery manufacturing	• **BEVs use simplified manufacturing processes**. It is likely that in the long term, the manufacturing sector will decline (see impact on employment in the "Social" section). [12] • **Europe is currently heavily dependent on foreign production**, especially from Asia. [35]	• **Recycling makes it possible to raise domestic battery production**. Relocating battery production to Europe is an opportunity for more independence (especially in the long term when combined with the recycling of raw materials), more added value and more jobs (see next section). [35]
Use: consumer adoption	• **The vehicle's range, charging infrastructure and price may not meet consumers' expectations**. Consumers expect a better range from BEVs (currently about 350 km), which is one reason that prevents them from buying a BEV [16, 17, 26].	• **BEVs will soon offer better ease of use to their users**. As the technology evolves, the range should increase. This convenience may further increase with the emergence of fast charging and the growing infrastructure of charging points. [3, 26] • **The total cost of ownership is comparable for BEVs and ICEVs**. As the technology matures, the balance will tip towards BEVs. [5, 18, 20]
Use: Mobility as a Service (MaaS)	• **The volumes of cars and associated jobs would be lower**. MaaS technologies are an industrial risk, as they reduce the volume of new cars that need to be produced, sold and maintained.	• **MaaS could create new jobs**. MaaS covers a wide range of technologies that can lead to new business and employment opportunities (e.g. in maintenance). • **Maas makes it possible to reduce urban congestion**. MaaS should be considered in the context of multimodal travel, with a growing share of active and public transport and the opportunity to redesign mobility in cities. This would reduce congestion and parking demand [7, 26].

		• **MaaS is associated with a decrease in production demand and an increase in vehicle use** (shared cars). This reduces direct and indirect GHG emissions and other air pollutants (SOx, NOx, etc.). • **MaaS is essential**. Transforming all existing transport demand into electric technologies is not sustainable. Policies to reduce vehicle ownership and use are critical to mitigating emissions and congestion. [34]
Use: Infrastructure	• **The adoption of EVs could lead to an overload of the network.** The envisaged adoption of EVs in Belgium could lead to an overloading of the electricity grids, mainly during peak hours in the evening or on public holidays. [11]	• **Smart charging**, even more so with shared autonomous EVs, can optimise energy demand and help grid management. [3] • **V2G (Vehicle-to-Grid)** will undoubtedly contribute to grid management, but the technology is not expected to be commercially available in the near term[e]. [16]

7.3 The main social challenges

Activities in the value chain	Risks	Opportunities
Mining of materials	• **The working conditions in the mines are poor**. The mining of minerals that are necessary for battery production is associated with appalling human consequences[f], e.g. cobalt mining in the Democratic Republic of Congo (DRC) is linked to human rights violations, child labour and dangerous working conditions[g]. Inequality could increase in the South, which is contrary to the idea of climate justice. [31]	• **Regulations and policy actions will be essential to reinforce human rights.** They can take many forms, for example, a European transparency requirement on mining or a mandatory standard such as ISO45001 on occupational health and safety, to ensure that all materials or products in European markets respect human rights where these materials are produced. [31]
Vehicle and battery manufacturing	• **Manufacturing jobs are expected to decline over the long term.** The automotive industry is likely to decline as a result of reduced European demand due to MaaS and the simplification of manufacturing processes. In the short term, the net balance is expected to be neutral, given the investments. [12] • **An employment strategy is needed.** The EU needs an employment strategy that guides industry, ensures social dialogue and worker participation in the transition. [25]	• **The recycling and renewable energy sectors will grow**. More workers will be needed in the recycling and energy sectors, which could mitigate the decline in manufacturing jobs. However, a strong employment strategy to help workers make the transition from one industry to another is crucial.
Consumer	• **Cultural changes on the part of consumers will be required**. MaaS will require a change in the consumer's perspective: from being a good, mobility will become a service. The consumer may not welcome this evolution with open arms. • **There could be certain inequities and biases**. The adoption of electromobility could erode aspects of distributive justice: only the rich can afford electric vehicles. [4]	• **MaaS provides jobs.** Shared vehicles (MaaS) are a service and require more maintenance management than owned vehicles, this can create skilled jobs in this area. MaaS needs to evolve alongside public transport and active travel, which will develop the logistics sector and related employment. [26] • **Low-income households can benefit from MaaS**. In general, shared mobility is seen as more of a privilege for the wealthy and educated, but it is also an opportunity to provide access to mobility for poorer households [7]. • **Noise reduction**.
End-of-life management	• **Skilled labour will not systematically appear with the transition**. There may be a need for training and support in the event of job losses.	• **The emerging reuse and recycling sector** will create new skilled jobs.

[a] PLVs greatly reduce energy consumption during manufacturing and use, this results in a 50% smaller carbon footprint (LCA) [14, 27]. These light vehicles already exist in certain brands, such as the Renault Twizy [37].
[b] This strategy has significant potential to reduce emissions and materials, up to 50-90% for ambitious scenarios [14, 22, 27, 28].
[c] These LCAs do not include emissions of particulate matter and local pollutants that affect air quality (related to road friction, brakes and tyres), only CO_2.
[d] With an ambitious renewable energy scenario, the LCA of a BEV falls by 50%, just by this lever. [3]
[e] The IEA expects V2G to arrive in the longer term, in fact, they expect only 5% of vehicles to be equipped with V2G technology by 2030 [16]. The technology is ready, but it needs a political push to be accepted and implemented [39].
[f] Responsible sourcing is evaluated by TDI Sustainability, based on the following criteria: freedom from conflict; governance and anti-corruption; respect for human and labour rights; and environmental performance [41]. The DRC, Gabon, Guinea, Mozambique and Turkey are among the countries with the highest risk of supply chain sustainability problems, in particular due to governance issues.
[g] Tesla and Apple are among the companies accused of profiting from child labour in Congo [42]

8 Annex 2: Methodological details of the developed scenarios

8.1 Qualitative description of the transport scenarios studied

REF	CORE95	TECH
Continuation of current social and technical trends	Balanced decarbonization pathway	Technology-oriented decarbonization pathway
Implementation of existing and planned policies, not more	Deep technical (efficiency, fuel switch,…) and behavioral (housing surface, diet, transport demand) changes	Mostly technical changes – less emphasis on behavioral changes
Continuing growth of passenger and freight transport	Curbed demand for passenger and freight transport	Increasing demand
Moderate shift from road transport	Significant modal shift from road transport	Relative modal shift but absolute stagnation for passenger cars
Increasing car and truck fleet, moderate electrification	Drastic decreasing car and truck fleet, significant electrification	Decreasing car fleet, significant electrification

8.2 Key indicators for the transport scenarios studied

Parameters	2015	2050			
Scenario		REF	CORE 95	TECH	BEH
Passenger transport by car (Billion pkm)	109	141	85	110	53
Modal share of the car in passenger transport (%)	62%	62%	45%	51%	33%
Total car fleet (number of vehicles in millions)	5.7	7.8	1.6	2.5	0.5
Technology share of electric cars (%BEV + %PHEV)	0.4%	6.6%	88%	89.7%	91.8%
Freight transport by road (billion tkm)	48	71	39	49	34
Modal share of road freight in total freight demand (%)	2.4%	2.7%	2%	2.4%	1.8%

Total truck fleet (number of vehicles in thousands)	184	274	77	81	79
Technology share of electric trucks (%BEV + %PHEV)	0%	28.6%	43.9%	43.4%	44.2%
Technology share of ICE trucks (%ICE)	100%	71.4%	4.6%	4.7%	4.6%

The remaining % of technology shares go to hydrogen vehicles

8.3 Circularity and material efficiency assumptions in the LIN and CIRC scenarios

Circularity				
Year		2015	2050	
Scenario			LIN	IARC
Recycling efficiency (%)	Aluminium	100%	100%	100%
	Cobalt	100%	100%	100%
	Graphite	10%	10%	20%
	Lithium	10%	10%	20%
	Manganese	100%	100%	100%
	Nickel	100%	100%	100%
Recycling rate (%)	Batteries	5%	10%	100%

Material efficiency				
Year		2015	2050	
Scenario			NON-EFF	EFF
Decrease in material intensity by material (% reduction vs. 2015)	Aluminium	100%	10%	10%
	Cobalt	100%	60%	100%
	Graphite	10%	10%	30%
	Lithium	10%	10%	60%
	Manganese	100%	10%	10%
	Nickel	100%	20%	100%

8.4 Methodological note on estimates of reserves and resources

It is important to remember that estimates of reserves and resources should be treated with caution. Indeed, as the TDI points out (translated): "[...] many of the deposits that will be exploited in the world in 2050 may not yet have been discovered. This shows that while reserve data may provide a good indication of production figures in the near future, they may not correlate strongly with production figures in 20 or 30 years [...] A likely trend is that mining in the coming decades will increase in areas where geological data is currently scarce, as new deposits are discovered and exploited." [source: forthcoming study for the FPS Health]

8.5 Comparing global resources and Belgian needs

Comparison 1: the allocation of resources to Belgium according to the distribution of new cars: To assess the short-term feasibility of Belgian needs in relation to the available resources/reserves, the Belgian share was calculated on the basis of the % of new cars sold in Belgium in relation to new cars sold worldwide. This approach is useful for studying the short-term feasibility.

Comparison 2: the allocation of resources to Belgium is based on population. To compare the Belgian needs with the available resources/reserves, Belgium's "fair" share has been calculated on the basis of the relative size of the Belgian population compared to the world population. This approach is more suitable for studying the long-term feasibility, and is fairer.

8.6 Description of the Pathways Explorer tool

The main features of the Pathways Explorer are the following:

- It is a complete model of the Belgian energy system. It covers all sectors of energy consumption and GHG emissions, and reports on the dynamics of the energy system;
- It makes it possible to develop energy transition scenarios based on realistic and transparent assumptions;
- It is based on more than 10 years of development of models, stakeholder interaction and expert consultation;
- It is a model that is easily accessible in real time via a web interface

However, the Pathways Explorer does not cover the following aspects:

- The scenarios are in no way forecasts, no specific probability is attached to them because they depend on societal and political ambitions;

- There is no cost optimisation in the model. While cost optimisation may be useful in certain cases, avoiding it has the advantage of ensuring that all options can be explored, both those that are cost-effective and those that are not yet cost-effective but are ready to be deployed in the market, and which would not be taken into account by cost optimisation models.
- Macroeconomic analysis and co-benefits are not included in the model, but the results of the scenarios can be exploited by other models that are developed for this type of complementary analysis

The most striking feature of this family of models is the so-called decarbonisation levers. These levers set the 2020-2050 trajectories at the national level for specific technologies, lifestyles and sectoral practices (e.g. agricultural practices). The term "ambition" refers to whether a trajectory represents a continuation of current trends (level 1), medium to high ambition (levels 2 and 3), or profound transformation (level 4), both in terms of societal change and technological deployment. In all sectors, a wide set of levers and trajectories are modelled (over 100, e.g. transport demand per capita, insulation levels in retrofitted houses, life span of certain products such as cars, steel efficiency and technology, installation of renewable electricity generation capacity). These determine the evolution of energy supply and demand. These levels have been defined over the course of various projects, based on an extensive literature review and a series of workshops with industry experts.

In the tool, a scenario is created by choosing a combination of ambition levels for all the levers available to the user. These are grouped by category (e.g. lifestyle and technology) and sector (e.g. buildings and transport). These levers can be described as "trajectories" over which governments have little or no influence (e.g. demographic trends, energy price developments), or as "levers" that can be acted upon directly. Both types of levers can be defined by the user to project the evolution of all model results, including energy consumption, production and cost implications. Higher ambition is always defined as having a higher impact in terms of GHG emission reductions.

9 Annex 3: Details of the main results

9.1 Pressure on cobalt

Figure 21 and Figure 22 below complement the figure presented in section 4.3.4 in the analysis of the pressure on resources. The comments in the same section may also be helpful in understanding these graphs. Methodological explanations of the various indicators are provided in Section 4.2 and in Annex 2.

Figure 21: Primary cobalt needs versus reserve and resource estimates (availability relative to population in Belgium and worldwide (explanation in the methodology section))

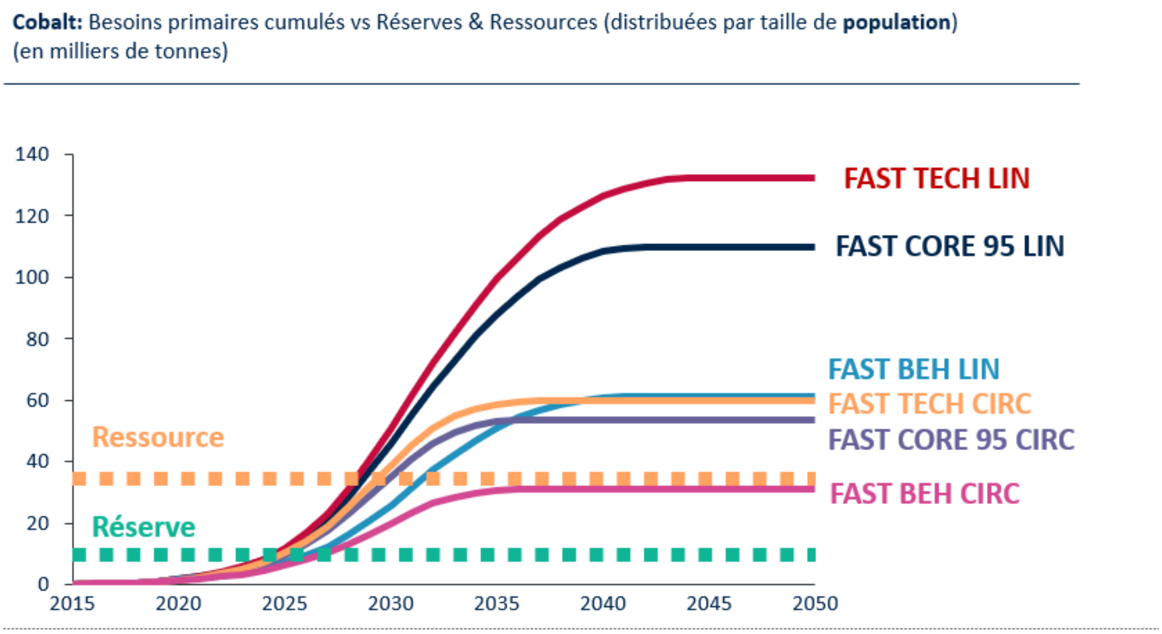
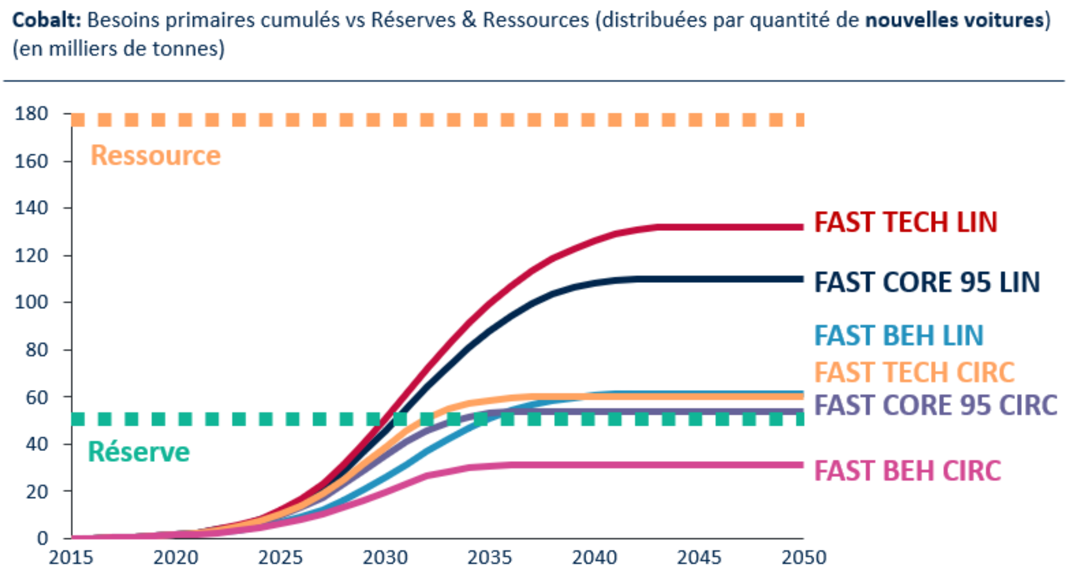


Figure 22: Primary cobalt needs versus reserve and resource estimates (availability relative to the distribution of new cars in Belgium and worldwide (explanation in the methodology section))



9.2 Pressure on lithium

Figure 23: Primary lithium needs versus reserve and resource estimates (availability relative to population in Belgium and worldwide (explanation in the methodology section))

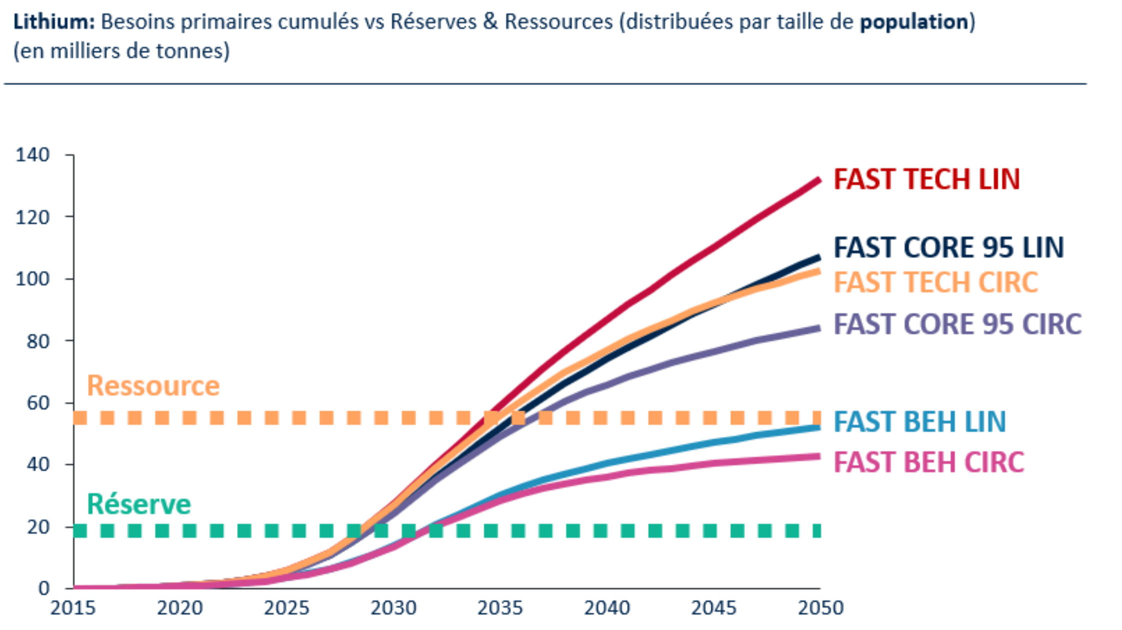
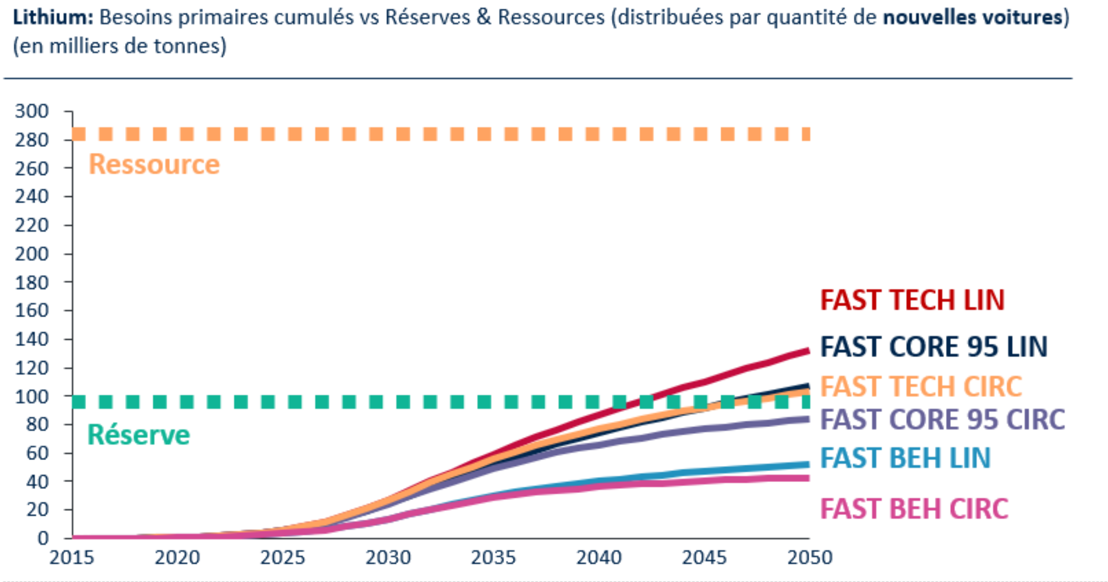


Figure 24: Primary lithium needs versus reserve and resource estimates (availability relative to the distribution of new cars in Belgium and worldwide (explanation in the methodology section))



9.3 Pressure on other resources

9.3.1 Graphite

Figure 25: Primary graphite needs versus reserve and resource estimates (availability relative to population in Belgium and worldwide (explanation in the methodology section))

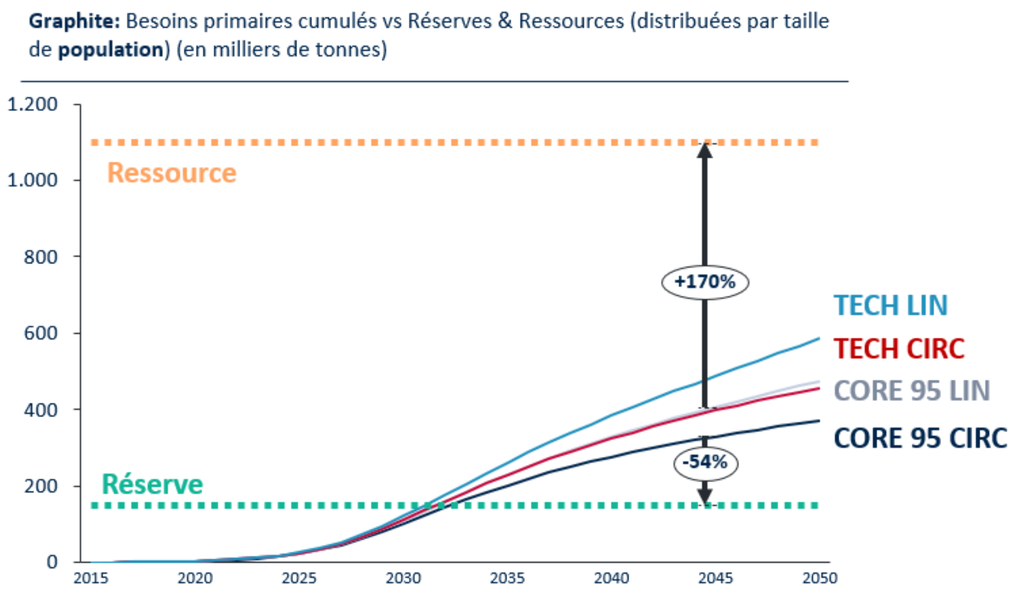
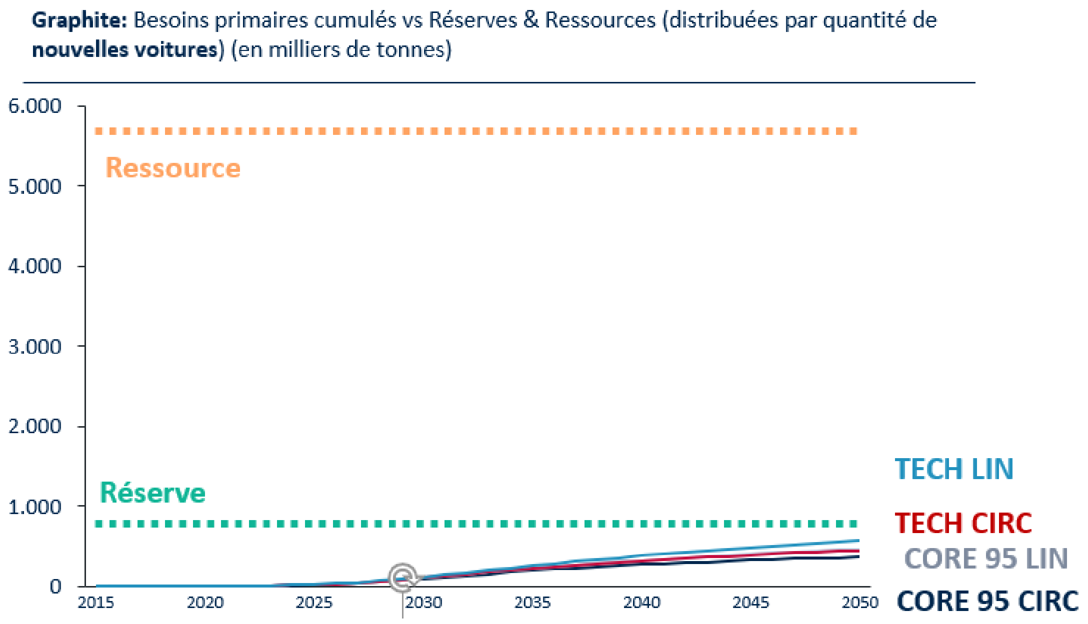


Figure 26: Primary graphite needs versus reserve and resource estimates (availability relative to the distribution of new cars in Belgium and worldwide (explanation in the methodology section))



9.3.2 Nickel

Figure 27: Primary nickel needs versus reserve and resource estimates (availability relative to population in Belgium and worldwide (explanation in the methodology section))

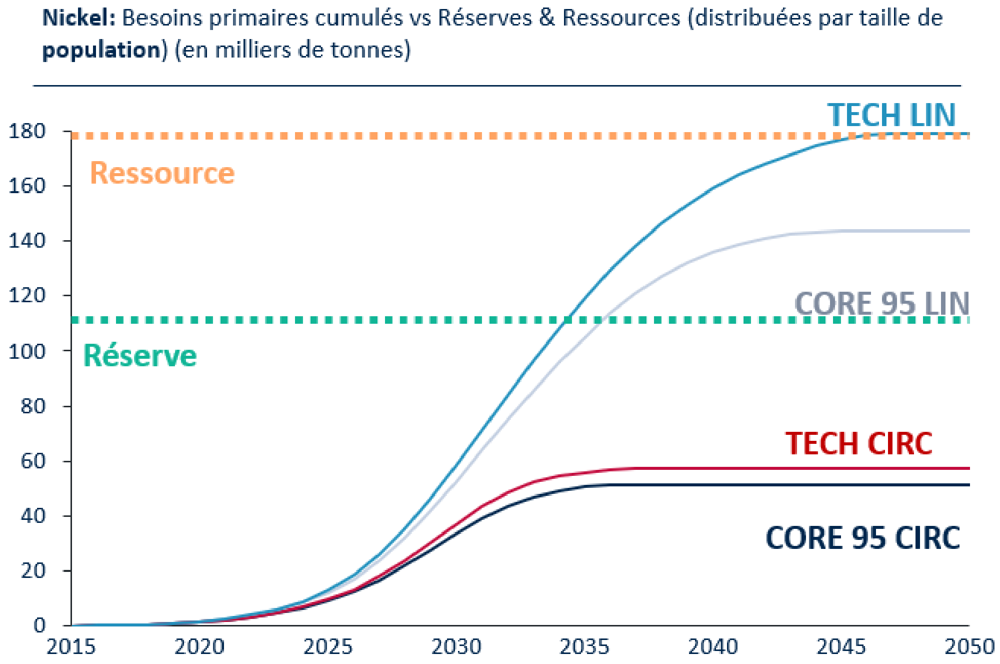
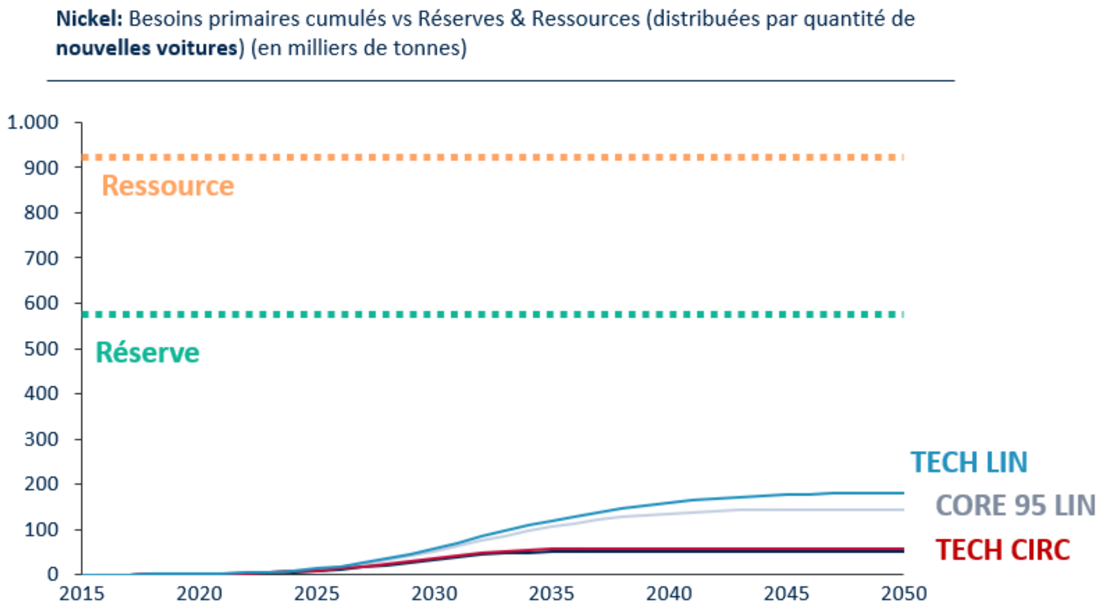
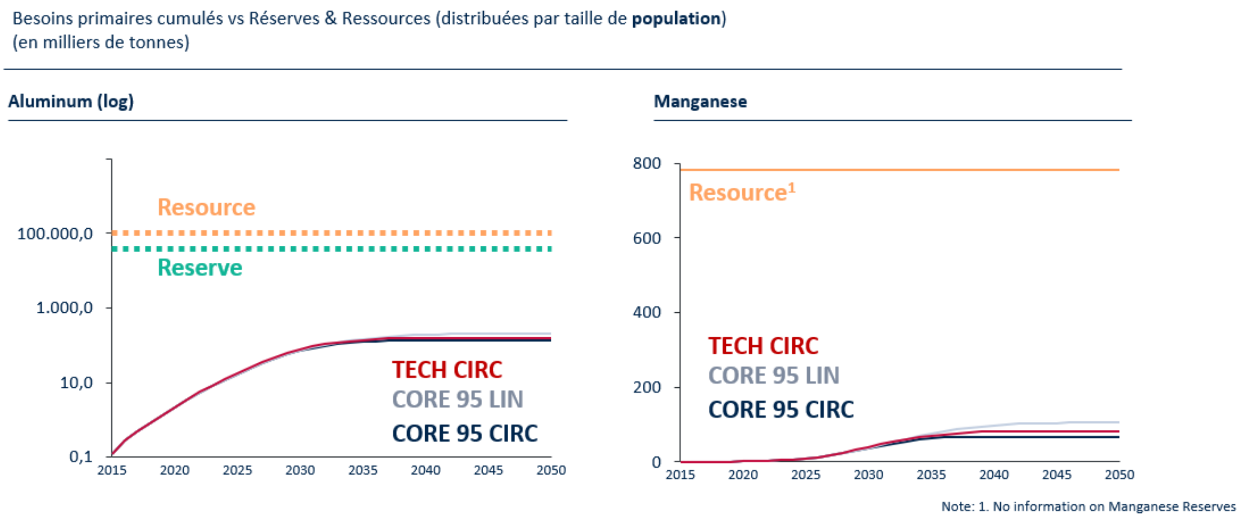


Figure 28: Primary nickel needs versus reserve and resource estimates (availability relative to the distribution of new cars in Belgium and worldwide (explanation in the methodology section))



9.3.3 Aluminium and Manganese

Figure 29: Primary aluminium and manganese needs versus reserve and resource estimates (availability relative to population in Belgium and worldwide (explanation in the methodology section))



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