The LEZ and its future from an exnovation perspective

Potential sustainability impacts and alternative paths

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Summary

This document, together with D2.1 and D4.2, presents the first in-depth case analysis of exnovation in the BCR, which refers to "The Brussels Low-emission zone (LEZ) and its future". While D2.1 takes a Transitions Governance perspective and D4.2 a legal perspective, this document looks at this case from a sustainability assessment perspective. The BCR has implemented a LEZ since 2018 and envisages to phase-out the use of Internal Combustion Engines (ICE) from 2030. The objective of those policies are to reduce air pollution and climate impacts of urban mobility, in the context of non-compliance by the BCR to EU air quality regulations and stricter climate targets to be satisfied. Those two policies can be considered as exnovation policies, i.e. policies seeking to phase out unsustainable modes of production and consumption (in that case the use of most polluting vehicles). The purpose of this report is to examine those policies from the perspective of their sustainability impacts. More particularly, we aim to understand whether those exnovation policies are able to address regional objectives, their potential side effects and how it could be improved and/or complemented with alternative exnovation paths. Results: At the EU level, the tools in place that regulate emissions of newly registered vehicles, i.e. regulation on GHG emissions and Euro standards on pollutants emissions, have both failed to reduce regulated emissions effectively (except for particulate matters). The emergence of LEZs and ZEZs targeting the use of vehicles at a local scale can be considered as a reply or a band-aid to this failure, that is necessary in urban and polluted areas like Brussels. However, the design of the Brussels LEZ is problematic because it is based on Euro-standards, which are precisely one of those tools at EU level that failed for NOx emissions (as revealed by the Dieselgate). Also, the agenda of the Brussels LEZ is particularly incremental (in comparison to London or Paris) and its effectiveness is questioned for NOx emissions, because it leaves access to the bulk of polluting diesel vehicles until 2025, nay 2028 (when only Euro 6d diesel vehicles will be able to circulate). This policy will thus make it to address local air quality issues, but much later than other neighboring capital cities. On the other side, it accelerates the renewal of the fleet (and thus increases overall demand for vehicles), while non-compliant vehicles are not all scrapped but are exported to other regions. Also the LEZ raises social justice issues, since the LEZ bans oldest vehicles first: low-income households would be hit the hardest. To satisfy regional objectives, the exnovation strategy in the mobility sector should go beyond the technological dimension, and target the surge in energy-consuming vehicles, the ownership of individual cars, car use (as done with Smartmove), and transport demand.

Highlights

- Governments of urban areas like the Brussels Capital Region (BCR) consider LEZs and ICE phasing-out, i.e. exnovation tools targeting the use of polluting vehicles at local levels, to satisfy their climate targets and to comply to EU regulations on air quality.
- Those tools are necessary to address the failures of existing EU regulations targeting the placing on the market of new vehicles (regulations on CO2 emissions and air pollutants), that resulted in particularly acute public health issues in dense urban areas like the BCR.
- The effectiveness of LEZs is questioned since it is precisely based on the EU regulation that failed to reduce NOx emissions of diesel vehicles (Euro Standards), as revealed by the Dieselgate. Its very incremental agenda postposes significant reductions of NOx emissions to 2025, nay 2028.
- The LEZ does not address mobility issues and raises other sustainability issues, including for vulnerable households, who own mainly (old) vehicles that are banned first.
- Acting on the use of vehicles (at city/local levels) implies a number of side effects, that could have been avoided if exnovation policies would have been implemented effectively at the level of the placement of vehicles on the market (at EU level).

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1. Introduction

1.1 Some introductory elements about the case

1.1.1 The Brussels LEZ

Context: purpose and origin of the measure

The Brussels Capital Region (BCR) implemented its Low emission zone (LEZ) in 2018 to improve air quality and to reduce health related impacts. Air pollution is a serious issue for the region, for which it is regularly pointed at, including by the European Commission (EC) which launched a sanction procedure against the region because it would exceed pollution thresholds. This procedure would be at the origin of the decision to implement the LEZ in the capital region (Devillers, 2017).

LEZ corresponds to areas "where access is restricted due to the emissions of certain road vehicles" (T&E, 2019a, p. 2), with main principle being "to reduce atmospheric pollution by accelerating the renewal of the vehicle fleet and therefore reducing polluting emissions from road transport" (Air et al., 2019, p. 6).

More than 250 European cities would apply a LEZ in 2018 (T&E, 2018c). LEZs were first implemented in Sweden in the 90's, and from 2005 by Italian, German and Austrian cities with the impetus of the EU Directive on air quality (Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on Ambient Air Quality and Cleaner Air for Europe, 2008). This directive sets limit values for certain pollutants not to be exceeded by Member States, including nitrogen dioxide and particulate matters, which levels are particularly influenced by road transport.

The LEZ development got new impetus in the last five years with the Dieselgate scandal (2015), which revealed a massive fraud by the European car industry (T&E, 2018a, 2019a). This fraud implies that diesel vehicles emit higher levels of nitrogen oxide (NOx) than what was allowed by the related regulation and was reported by the European car industry. It implies that diesel vehicles contribute to poor air quality even more than previously estimated.

Some details about the LEZ: criteria and agenda

Brussels is part of those cities or regions that decided to set up a LEZ in the last five years, together with Antwerp, Gent, Malines, Paris, London or Wallonia (Duquesne, 2020; T&E, 2018c). The region bans vehicles progressively since 2018 (passenger cars and light duty vehicles) according to the fuel used (the ban regards diesel, gasoil and LPG/CNG cars only) and to the Euro standard, which are evolving standards that aim to limit air pollutants emissions. Euro standards of vehicles are estimated according to the age of the vehicle (BE et al., 2020) (cf. Table 1).

Vehicles that were put into service at a certain date are deemed to comply with the Euro standard that was in force at that time. Grosso modo, the Brussels LEZ excludes diesel vehicles in priority because of their known detrimental health impacts, and progressively oldest vehicles[1]. Other LEZs may use other criteria, such as the presence of a particle filter (Air et al., 2019). While some cities allow diesel particle filter retrofits for old diesel vehicles, this is not the case of Brussels, where "the fact that [the] vehicle is equipped with a particulate filter does not in any way permit an exemption to travel in the LEZ" (Bruxelles Mobilité et al., n.d.-a).

[1] Which are not necessarily vehicles emitting the most air pollutants while circulating given the fraud that was revealed by the Dieselgate. We will come back to that point later.

Table 1: Agenda of the Brussels LEZ (BE et al., 2019a)

DIESEL	2018	2019	2020	2021	2022	2023	2024	2025
EURO : 6, 6b, 6d, temp / VI	Accès	Accès	Accès	Accès	Accès	Accès	Accès	Accès
EURO : 5, 5a, 5b / V ou EEV	Accès	Accès	Accès	Accès	Accès	Accès	Accès	Pas d'accès*
EURO 4 / IV	Accès	Accès	Accès	Accès	Pas d'accès*	Pas d'accès*	Pas d'accès*	Pas d'accès*
EURO 3 / III	Accès	Accès	Pas d'accès*	Pas d'accès*	Pas d'accès*	Pas d'accès*	Pas d'accès*	Pas d'accès*
EURO 2 / II	Accès	Pas d'accès*	Pas d'accès*	Pas d'accès*	Pas d'accès*	Pas d'accès*	Pas d'accès*	Pas d'accès*
EURO 1 / I	Pas d'accès*	Pas d'accès*	Pas d'accès*	Pas d'accès*	Pas d'accès*	Pas d'accès*	Pas d'accès*	Pas d'accès*
Sans EURO	Pas d'accès*	Pas d'accès*	Pas d'accès*	Pas d'accès*	Pas d'accès*	Pas d'accès*	Pas d'accès*	Pas d'accès*

Un accès de maximum 8 jours par an et par véhicule est possible via l'achat d'un pass d'une journée.

ESSENCE/LPG/CNG	2018	2019	2020	2021	2022	2023	2024	2025
EURO : 6, 6b, 6d, temp / VI	Accès	Accès	Accès	Accès	Accès	Accès	Accès	Accès
EURO : 5, 5a, 5b / V ou EEV	Accès	Accès	Accès	Accès	Accès	Accès	Accès	Accès
EURO 4 / IV	Accès	Accès	Accès	Accès	Accès	Accès	Accès	Accès
EURO 3 / III	Accès	Accès	Accès	Accès	Accès	Accès	Accès	Accès
EURO 2 / II	Accès	Accès	Accès	Accès	Accès	Accès	Accès	Pas d'accès*
EURO 1 / I	Accès	Pas d'accès*	Pas d'accès*	Pas d'accès*	Pas d'accès*	Pas d'accès*	Pas d'accès*	Pas d'accès*
Sans EURO	Accès	Pas d'accès*	Pas d'accès*	Pas d'accès*	Pas d'accès*	Pas d'accès*	Pas d'accès*	Pas d'accès*

Un accès de maximum 8 jours par an et par véhicule est possible via l'achat d'un pass d'une journée.

1.1.2 The foreseen ICE phasing-out as LEZ future

For the LEZ, a planning is agreed until 2025, but further steps have yet to be decided. In order to continue its fight against air pollution and to address the climate issue frontally, the BCR proposes now further steps for the LEZ and the phasing out of internal combustion engine (ICE, i.e. diesel, petrol, and natural gas vehicles), leaving access to so-called 'zero-emission vehicles' such as electric vehicles (EVs) and hydrogen fuel cell vehicles, i.e. vehicles not emitting emissions during their use phase. A government decision has been made, a roadmap is on the table, that has to be discussed, fine-tuned and operationalized (Bruxelles Environnement, 2021) (cf. Table 1).

The ICE phasing-out is presented as an obvious and natural direction for Brussels mobility by the Brussels government, with other European cities and regions following this path (Duquesne, 2019). While 80 % of consulted actors by Bruxelles Environnement in 2019 totally or quite agree with the objective to evolve towards a zero-emission fleet, "this is not an unconditional support and it is pointed out that the decision to ban ICE fails to win unanimous support" (Hollander, 2019, p. 5).

Table 1: LEZ agenda – minimum authorized standard from 2025 (Bruxelles Environnement, 2021)

	Carburant	2025	2028	2030	2033	2035	2036
Voiture (M1) Camionnette N1, classe I	Diesel/hybride	Euro 6	Euro 6d	🍃	🍃	🍃	🍃
	Essence/hybride/ LPG/CNG	Euro 3	Euro 4	Euro 6d	Euro 6d	🍃	🍃
Bus M3, classe I, II, A	Diesel/hybride	Euro VI	Euro VId	Euro VId	Euro VId	Euro VId	🍃
	Essence/hybride/ LPG/CNG	Euro III	Euro V	Euro VId	Euro VId	Euro VId	🍃
Autocar M3 classe III, B	Diesel/hybride	Euro VI	Euro VI	Euro VId	Euro VId	Euro VIe	Euro VIe
	Essence/hybride/ LPG/CNG	Euro III	Euro IV	Euro VId	Euro VId	Euro VIe	Euro VIe
Mobylettes (L1-L2)	Diesel	🍃	🍃	🍃	🍃	🍃	🍃
	Essence/ LPG/CNG	Euro 5	🍃	🍃	🍃	🍃	🍃
Moto (L3-L7)	Diesel	🍃	🍃	🍃	🍃	🍃	🍃
	Essence/ LPG/CNG	Euro 3*	Euro 4	Euro 5	Euro 5	🍃	🍃
Minibus (M2) Camionnette N1 classe II, III	Diesel/hybride	Euro 6	Euro 6d-temp	Euro 6d	🍃	🍃	🍃
	Essence/hybride/ LPG/CNG	Euro 3	Euro 4	Euro 6d	Euro 6d	🍃	🍃
Poids lourd (N2-N3)	Diesel/hybride	Euro VI	Euro VI	Euro VId	Euro VId	Euro VIe**	Euro VIe**
	Essence/hybride/ LPG/CNG	Euro III	Euro IV	Euro VId	Euro VId	Euro VIe**	Euro VIe**

Politique existante · Nouvelle politique

🍃 Les véhicules fonctionnant avec ce carburant ne sont plus autorisés

1.1.3 LEZ and ICE phasing-out as exnovation processes (among other examples)

The LEZ and the ICE phasing-out can be considered as exnovation processes, i.e. processes of destabilization, decline and phasing-out of industries, technologies, business models or practices that raise systemic sustainability issues (environmental, socioeconomic, related to urban-planning, etc.). As a concept that emerged within *Transition Studies*, exnovation processes/policies are to be distinguished from niche cultivation policies, which focus on the support to innovations or alternatives that are supposed to be sustainable. Examples of niche cultivation policies in the mobility sector are the financial support for households or companies to buy electric vehicles (EVs) or the support to the development of car sharing. Those innovations or alternatives are supposed to disseminate progressively, so that sustainability transition happens.

With the LEZ and the phasing-out of ICE, the BRC tackles the problem from the other end: its implements or plans to implement measures targeting incumbent production and consumption modes that raise sustainability issues (what is called the *regime* in Transition Studies). This is also the case of other measures from the Good Move plan, such as the congestion charge and the city toll that are currently under discussion. It is assumed here that there is a need for binding measures to destabilize or to phase-out what is pointed out as problematic, in addition to niche cultivation policies, for the transitions to a sustainable economy to happen: on one side, their dissemination of sustainable innovations is slow, and on the other side, innovations often only *add* to the existing regime, rather than *replacing* it. This is the rationale for the growing focus of Transition Studies on exnovation processes and policies: exnovation policies would be necessary to transition towards sustainable modes of production and consumption.

1.2 Objectives and research questions

Within WP3, we seek to understand the sustainability impacts of the exnovation processes under study. For this case looking at mobility/transport in Brussels, one policy is already implemented (the LEZ), and its future (the ICE phasing-out) is currently under discussion (contrary to our two other cases).

This policy, including the LEZ and its potential next step, the ICE phasing-out, is put forward by the Brussels capital region to address specific sustainability issues, namely air pollution and climate change. Within this WP, we seek to understand what are the potential impacts of this policy and to address the following main question: i) Are the LEZ and the foreseen ICE phasing-out exnovation policies able to address regional objectives in terms of air quality, reduction of GHG emissions, but also other issues, such as mobility (access to mobility services and traffic issues)? This policy might also generate unwanted side-effects: ii) which ones are those side effects? We foresee that this policy is likely to imply a number of side effects and might not completely satisfy regional policy objectives: iii) What other exnovation futures could be foreseen to reach regional objectives? What are the other parameters/dimensions of the regime on which exnovation policies could play?

Addressing those main research questions implies replying to the following sub-questions:

- In terms of policy objectives
    - What are the objectives of the current exnovation policy? What are its rationale and its origin?
    - What are the regime and alternative(s) modes of consumption and production targeted by this exnovation policy? How sustainable are those modes (regime and alternative(s))?
- In terms of trends and key issues
    - How is the interaction between the regime and the alternative(s)? What is the state of play of the current exnovation/innovation processes/dynamics in the mobility sector?
    - What are the other dynamics shaping the mobility sector and its environmental impacts? What are the issues at stake?
- In terms of impacts
    - What are the potential and assessed impacts of the current exnovation policy?

1.3 Materials and method

As a preliminary remark, it has to be noted that the sustainability assessment analysis carried out within GOSETE builds on existing assessments and data. In fact, sustainability assessment within GOSETE does not focus on one specific issue (e.g. climate change), but on several sustainability issues. Thus, given the allocated resources, we build on existing research and impact assessments.

For this case on mobility/transport in Brussels (as opposed to the two other GOSETE cases), the specificity lies in the fact that public authorities are pushing for one exnovation scenario (LEZ and the technology-based vehicle exnovation, i.e. the ICE phasing-out), and that for both measures, impact assessments are conducted simultaneously to our research (respectively by Bruxelles Environnement and Stratec/MOBI). Those assessments are specific to Brussels and to the implemented measure (LEZ)/the measure to be implemented (ICE phasing-out).

Practically, the material on the Brussels LEZ and on the plan to phase-out ICE (the impact assessments carried out) are used as a starting material for several ends:

- To understand the issues at stake and the potential impacts of the two measures put forward by the region, their potential advantages and limits. Together with the work on the identification of key issues (cf. 2) and trends (cf. 3.), the review of those impacts assessment help us identify alternative exnovation scenarios.

- To understand what is needed and relevant to assess the sustainability impacts of an exnovation policy. Through the review of those impacts assessments, we could configure the multicriteria assessment framework.

Thus, we can split the sustainability assessment work for the present case into four different steps:

- **Step 1: Identification of key issues (cf. 2)**

As a deepening of the introduction, we describe the objectives that the region seeks to address with the LEZ and the ICE phasing-out. This work is based on a literature review of policy documents, NGO reports and scientific studies.

- **Step 2: Analysis of trends of the transport/mobility sector (cf. 3)**

Then we analyze the key consumption trends affecting the sector, including the sustainability issues raised by those trends.

- **Step 3: Critical analysis of existing Brussels assessments of LEZ and ICE phasing-out (cf. 4)**

As just mentioned, for the LEZ, ex-ante and ex-post impact assessments have been conducted (and will be conducted yearly presumably) and for the ICE phasing-out, an impact assessment has been commissioned by Bruxelles Environnement and has been conducted by a consortium composed of the Stratec consultancy and the MOBI research department of VUB. We follow this latter study since the steering committee of September 2020 to which we participated as observers. The study is currently in its last phase of finalization and will be publicly available soon[2].

In order to interpret results of those studies, we review impact assessments conducted for similar measures implemented in other regions. With this review and comparison work, the first objective is to get a better idea of the effectiveness of the implemented measure/measure to be implemented (in terms of achievement of initial objectives) and of other generated effects, the final aim being to feed the scenario development work (step 4). The second objective is to analyze how the assessments of those exnovation policies are carried out (which effects are assessed, which methods are used).

- **Step 4: Scenarios development**

Scenarios are developed on the basis of the key issues and trends of the transport/mobility sector highlighted (step 1 and 2) and on the basis of the analysis of existing Brussels assessments of LEZ and ICE phasing-out (step 3).

[2] It should have been by the end of January 2021, according to our last email exchange with the person in charge at Bruxelles Environnement, but it is not the case yet.

2. Key policy objectives of the LEZ and ICE phasing-out

The objective of this first section is to understand what exnovation policies in the mobility and transport field aim to address as issues.

The transport originates in two main kinds of emissions, namely air pollutants resulting directly in health impacts (through the exposure to those pollutants) and greenhouse gases (GHG or CO2 equivalent) resulting in climate change[3].

The LEZ primarily aims mainly to improve air quality, while the ICE phasing-out seeks to tackle both issues (air pollution and climate impacts). Also, for both measures, the improvement of mobility and reduction in traffic are a secondary objective:

- The LEZ is part of the regional Air-Climate-Energy Plan (BE, 2016) and of the Plan 2030 Energy and Climate Plan (RBC, 2019) and is mentioned as "an opportunity, to orient population towards the Maas concept and the decrease in car ownership", including in the Good Move plan (Bruxelles Mobilité, 2018; RBC, 2019).
- The ICE phasing-out is part of the Energy and Climate Plan (RBC, 2019) and of the Mobility/Good Move Plan (Bruxelles Mobilité, 2018), even if there is no concrete objective in terms of mobility.

2.1 Fighting air pollution from transport and improving health impacts

Air quality is a major issue in Brussels, even if the situation seems to improve gradually.

2.1.1 What are transport related emissions?

Air pollutants emissions from transport come from two main sources (BE et al., 2019a):

- From abrasion of tires, brakes and road surfaces (non-exhaust), resulting in the emission of particulate matters (PMs) and heavy metals, according to the vehicle weight.
- From the exhaust, resulting in the emission of particulate matters (PM10 and PM2.5) and heavy metals, but also of nitrogen oxides (NOx), of sulfur oxides (SOx), carbon monoxide (CO), and varying according to the type of fuel used, and to the type of installed device.

2.1.2 Their health impacts and sources

Those air pollutants result in diverse health impacts, as detailed in the Table 2 below. NO2/NOx emissions contribute to heavy respiratory problems, with transport being the main contributor of those emissions in Brussels (63 %). **NOx emissions** come mainly from diesel vehicles and are at the origin of the Dieselgate scandal revealed in 2015. Only the vehicles put on the market after 2019 (Euro 6d-TEMP) get close to limit values (but still do not comply according to real-world emissions) (Bernard et al., 2021). Brussels is the 8th European city[4] in terms of mortality rate due to high NO2 levels (over almost 1000 cities) (Khomenko et al., 2021).

The emissions of **particulate matters** and black carbon are responsible for respiratory and cardiovascular health troubles, ad can cause cancer, with transport being an important contributor of those emissions in Brussels (around 30% for PM and 56% for BC). Those emissions come from old diesel cars, and from recent direct injection petrol engines, and that are not yet equipped with filter thus (pre-2009 diesel cars and pre-2017 petrol cars) (Corde et al., 2018). The number of early deaths due to PMs was estimated at 8340 in 2014 (against 1870 due to NOx) (BE et al., 2019a). It has to be noted

[3] and in health impacts, but, indirectly, not directly through exposure to emissions.

[4] Antwerp is the 2nd one.

however that the recent cars equipped with filters would release even smaller and dangerous particles (nanoparticles) especially in cities (T&E, 2017b, 2020a).

PMs from the exhaust and NOx are regulated through Euro standards, and so do are three other air pollutants, including carbon monoxide and non-methan hydrocarbons. On the other side, the EU regulation does not include several other **non-regulated air pollutants** linked to motorized vehicles, including heavy trace metals, polycyclic aromatic hydrocarbons, ammonia and non-exhaust PMs (Hooftman et al., 2016).

Table 2: Air pollutant emissions, related health impacts, main sources

Air pollutants	**Health impacts and other problems** (T&E, 2015)	**Contribution of transport to emissions**[5]	**Main source within transport** (BE et al., 2019a)
Nitrogen oxide (NOx)/ Nitrogen dioxide (NO2)	-Adverse respiratory effects incl. airway inflammation in healthy people and increased respiratory symptoms in people with asthma or other pre-existing respiratory problems.	NOx : 63%	Diesel cars, from which NOx emissions measured in real-world conditions are ten times higher than those from petrol cars, even the most recent ones. Those gases are at the origin of the Dieselgate.
Particle matters (PMs and Black carbon (BC), Particle number (PN)	-Can cause/worsen respiratory diseases, such as emphysema and bronchitis, and can aggravate existing heart disease, leading to increased hospital admissions and even premature death. -increased incidence of cancer, especially lung cancer	PM10 : 34.5% PM2.5 : 28.5% BC (part of PM2.5) : 56%	-Diesel cars without particulate filters (Euro 1-4). However, in an urban context, those filters are less efficient since they get clogged more rapidly. Also, through the filter regeneration process even smaller particles of below 1nm in diameter (nanoparticles) would be created, that "can easily penetrate deeply into the lungs and blood stream" (T&E, 2017b, p. 35). - Recent gasoline cars, with direct injection petrol engines (GDI) and without filters would emit "around 10 times more particles (by mass)" than port fuel injection (PFI) engines (T&E, 2016, p. 2), while reducing fuel consumption (and CO2 emissions). Since 2017, GDIs have to comply to PN limits and have to be equipped with filters, as diesel cars (Corde et al., 2018).

2.1.3 Regulations to tackle air pollution at EU level

In order to address this air quality issue in the transport sector, three important regulatory instruments are implemented at the EU level:

- Euro standards specify thresholds for **vehicle emissions** of NOx and PM not to be exceeded (*Regulation (EC) No 715/2007 of the European Parliament and of the Council of 20 June 2007 on Type Approval of Motor Vehicles with Respect to Emissions from Light Passenger and Commercial Vehicles (Euro 5 and Euro 6)*, 2007);
- Concentrations of NOx and PMs are regulated with the Directive on air quality (Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on Ambient Air Quality and Cleaner Air for Europe, 2008), with **thresholds on pollutant concentration** not to be exceeded. For PM, the World health Organization has set even stricter thresholds (cf. Table 3). For NOx, it is likely that the threshold will be revised to 20 µg/m^3[6] (BE et al., 2020);

[5] According to : inventaires d'émissions pour l'année 2018, Mars 2020, Bruxelles Environnement (BE et al., 2020)
[6] The new *WHO Air quality guidelines* should have been published in 2020 (WHO, 2018).

- The National Emissions Ceilings (NEC) Directive (Directive (EU) 2016/2284 of the European Parliament and of the Council of 14 December 2016 on the Reduction of National Emissions of Certain Atmospheric Pollutants, Amending Directive 2003/35/EC and Repealing Directive 2001/81/EC, 2016) sets **maximum emission ceilings for each country** per year for five main pollutants: PM2.5, sulphur dioxide, nitrogen oxides, non-methane volatile organic compounds, and ammonia.

Table 3 : EU and WHO thresholds for air pollutant concentration (yearly average) (BE et al., 2019a)

	Directive européenne	Recommandations OMS
NO_2	40 µg/m³	40 µg/m³
PM_{10}	40 µg/m³	20 µg/m³
$PM_{2.5}$	25 µg/m³	10 µg/m³

The level of compliance of the BRC with existing air quality standards (concentrations)

While this is still today an issue, air quality seems to have improved in the last decades. Calculated air pollutant emissions (from all sectors) decreased (-72% for PM10 and -52% for NOx between 1990 and 2016) (BE et al., 2019a). PM concentrations are currently compliant with EU standards, but well above the WHO thresholds (BE et al., 2019a).

However, **NOx concentrations** in Brussels were still above the legal threshold until 2020, and Belgium was subject to letter of formal notice from the EC, pointing out Brussels[7] and Antwerp (EC, 2018) (together with 17 other member states (T&E, 2018c)). For the first time in 2020, the BCR complies with EU standards for NOx concentrations (BE, 2020c). However, in the same Memo, the EC expressed some doubts about "the way air quality is monitored in Belgium, including the location of measuring points for NO2 in Brussels" (EC, 2018). Those doubts have been confirmed very recently by a ruling from the Brussels court[8], obliging the region to install new measurement sites, that are close to traffic (De Sloover, 2021). Finally, the EC expressed concerns that "the current measures are not sufficient to achieve compliance as soon as possible" (EC, 2018) and it sent a reasoned opinion to Belgium and two other countries in February 2021, calling them to comply with the directive and "to adopt air quality plans to ensure that appropriate measures are taken to keep the exceedance period as short as possible" and mentioning Brussels explicitly, together with Antwerp and Charleroi (EC, 2021b).

The EU regulation on air pollutant from vehicles (Euro standards) (emissions)

How does it function?

Euro standards contains evolving limits for vehicles emissions of air pollutants that are included in the Directive on air quality, i.e. nitrogen oxides and particulate matters[9], as well as other pollutants (cf. Table 4). The first standard dates back to 1991, and the last one to 2020 (Euro 6d, applied from January 2021) (Regulation (EU) 2019/631 of the European Parliament and of the Council of 17 April 2019 Setting CO2 Emission Performance Standards for New Passenger Cars and for New Light Commercial Vehicles, and Repealing Regulations (EC) No 443/2009 and (EU) No 510/2011 (Recast), 2019, p. 631). Limit values are different for diesel and gasoline vehicles, with e.g. no value for PM for Euro 1-4 gasoline vehicles (because PM were considered a diesel issue), but also less stringent value for NOx emissions from diesel vehicles, since the diesel technology was historically favored in Europe.

[7] "Belgium has persistently failed to meet binding limit values for NO2, a pollutant gas, in the Brussels region since they came into force in 2010" (EC, 2018).
[8] For more detail on the case, see (Clientearth, 2020).
[9] While Black carbons are also air pollutants, no standard limits their emission (BE et al., 2019b, p. 45)

Table 4: Euro emission standards (0-6b) for air pollutants for cars (T&E, 2017b, p. 23)

Euro stage	Year of entry into force for new models*	CO g/km	HC	HC+NOx	NOx	PM	PN number/km
Compression ignition (diesel)							
Euro 1	1992	2.72	-	0.97	-	0.14	-
Euro2	1996	1.0	-	0.7	-	0.08	-
Euro 3	2000	0.64	-	0.56	0.50	0.05	-
Euro 4	2005	0.50	-	0.30	0.25	0.025	-
Euro 5a	2009	0.50	-	0.23	0.18	0.005	-
Euro 5b	2011	0.50	-	0.23	0.18	0.005	6.0x10¹¹
Euro 6	2014	0.50	-	0.17	0.08	0.005	6.0x10¹¹
Positive ignition (petrol/gasoline/LPG/CNG)							
Euro	1992	2.72	-	0.97	-	-	-
Euro 2	1996	2.2	-	0.5	-	-	-
Euro 3	2000	2.3	0.20	-	0.15	-	-
Euro 4	2005	1.0	0.10	-	0.08	-	-
Euro 5	2009	1.0	0.10	-	0.06	0.005ᵃ	-
Euro 6	2014	1.0	0.10	-	0.06	0.005ᵃ	6.0x10¹¹ **

* models already in production must comply typically around one year later ** applicable only to direct injection engines

Results and (non)-compliance to the regulation

In terms of PMs

For PMs, the regulation on diesel vehicles functioned well, with a steady decrease in PMs emissions, and a sharp decline for Euro5 vehicles. This can be seen on Figure 1 which represents the real world emissions measured recently by the TRUE project, including in Brussels (Bernard et al., 2021).

Regarding petrol engines, the picture is different. While PMs were historically not regulated for petrol engines, because port fuel injection (PFI) engines did not emit PMs, the regulation had to adapt with the development of direct injection engines that emit PMs. This was done in 2017 with the update of the Euro 6 standard and the inclusion of limit values for petrol vehicles as well. We see on Figure 1 that PMs are indeed less an issue for petrol vehicles, but also that there is no real improvement over time, and PMs from petrol vehicles now equal those from diesel vehicles.

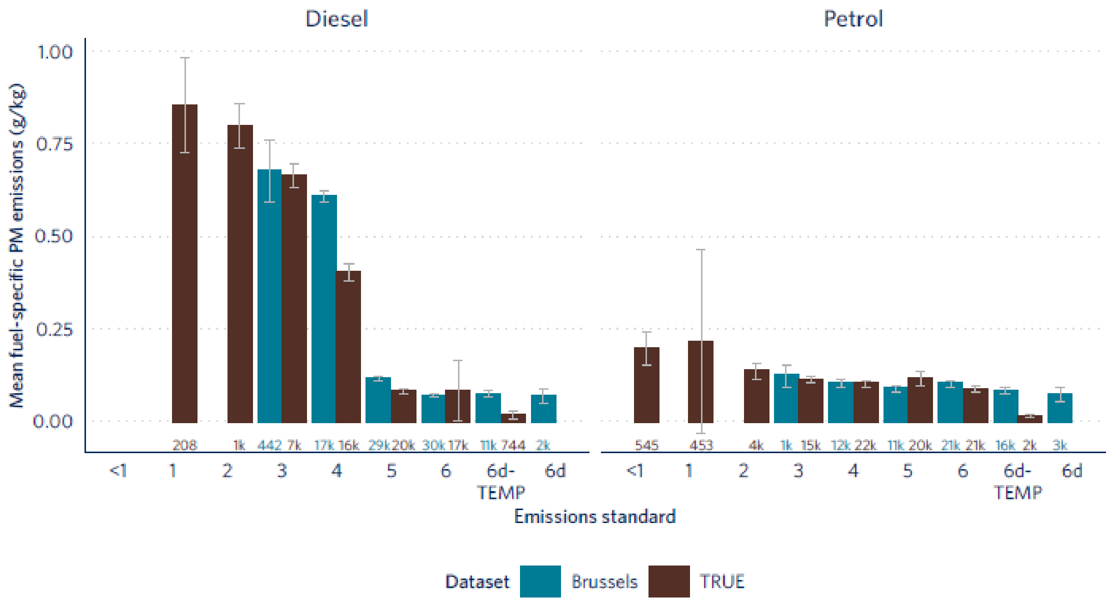


Figure 1: Mean fuel-specific PM emissions from diesel and petrol passenger cars by emissions standard for Brussels and TRUE remote sensing data (Bernard et al., 2021, p. 14)[10]

[10] Number of measurements: at the bottom of each bar. Whiskers: 95% confidence interval of the mean.

In terms of NOx: the Dieselgate and its aftermath

In addition to the bias that makes Euro standards and their limits values different according to engines, the European car industry cheated, so that value limits have not been respected, especially by diesel vehicles. A main failure of the Euro standard regulation lies in the laboratory test procedure used by the car industry to measure emissions: As revealed by the Dieselgate in 2015, measured NOx emissions of diesel vehicles were far from those measured under real driving conditions (T&E, 2017b).

Consequently, emissions from the European diesel fleet were much higher than what was regulated and thought, as shown by Figure 2 showing the gap in NOx emissions from diesel and gasoline vehicles between NOx laboratory limits and real-world emissions measured in Brussels (Bernard et al., 2021)[11].

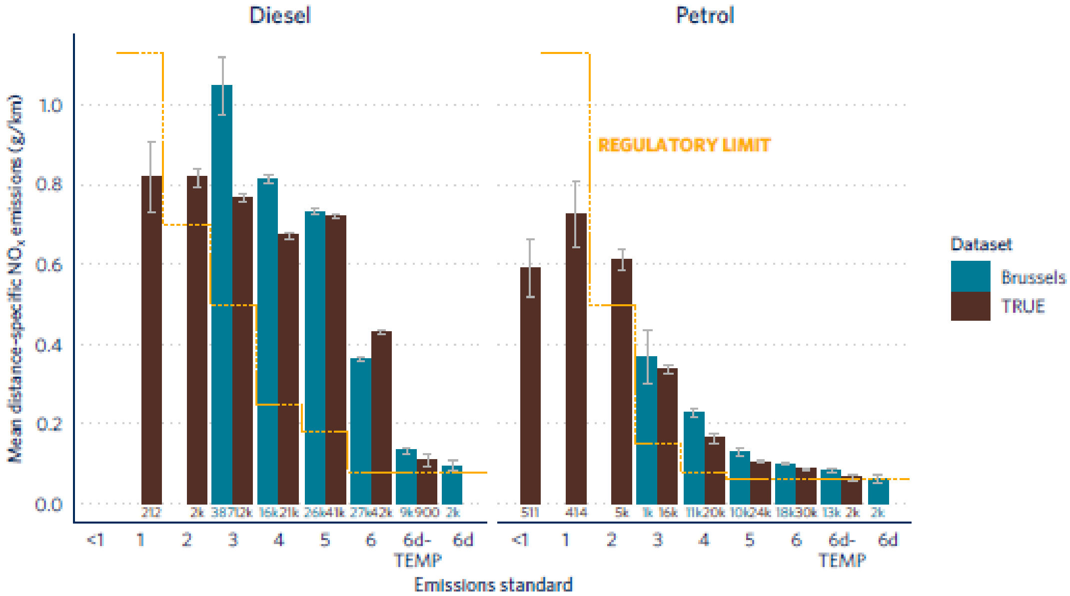


Figure 2: Mean estimated distance-specific NOx emissions from diesel and petrol passenger cars by emissions standard for Brussels and TRUE remote sensing data[12] (Bernard et al., 2021)

Consequently, the Euro6c and 6d standards were released, imposing new and improved test procedures to measure emissions. From 2017, the laboratory test used by car manufacturers to measure emissions of vehicles (the so-called NEDC or New European Driving Cycle test) was replaced with a new laboratory test (so called WLTP or Worldwide harmonized Light vehicles) and a real-world test is required (RDE or Real Driving emissions) (BE et al., 2019a). Concretely, "portable emissions measurement systems (PEMS) […] complement the dynamometer type-approval procedure" for NOx and PMs (Hooftman et al., 2018, p. 1). While those tests still include some failures[13] (Hooftman et al., 2018; T&E, 2020b), they represent a major improvement.

However, in the same time, not-to-exceed limits were made more flexible, with the introduction of high conformity factors that were pushed by the industry to address the technical uncertainties induced by the PEMS. Those conformity factors allow vehicles to emit up to 168 mg/km until 2019 and up to 120 mg from 2020 (instead of 80 mg) (cf. Figure 3)[14].

[11] A similar analysis has been produced for Brussels (publication in 11/2021) (Bernard et al., 2021)
[12] Number of measurements: at the bottom of each bar. Whiskers: 95% confidence interval of the mean.
[13] Including the fact that "cold-start emissions aren't yet mandatory to assess in the type-approval process" (Hooftman et al., 2018, p. 15). Those emissions are important in urban driving.
[14] A seventh Euro standard is currently discussed and will be adopted by the end of 2021 (EC, 2021a).

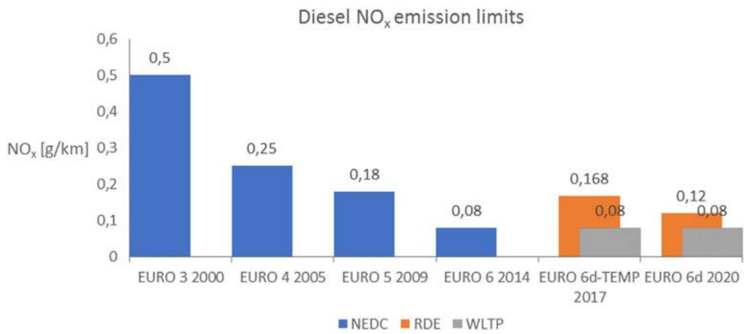


Figure 3: Overview of the diesel emission limits for NOx since Euro 3 (Hooftman et al., 2018)

A VUB research analyzing European passenger car regulations analyze the adoption of those conformity factors as follows:

"Due to the approved 2017 conformity factor, only minor improvements will occur concerning real-world NOx emissions. The reason for this is that the limit would only outperform the Euro 5 NOx ceiling of 180 mg/km by 7%, although the former was agreed upon in 2007. The approved conformity factors, together with the potential transfer function, thus undermine the potential of the entire [Real Driving Emissions] approach, and thus curb the chance for the EU to finally start improving the urban air quality levels » (Hooftman et al., 2018, pp. 10–11).

Implication for LEZs

Euro standards and their compliance by the car industry question the possibility for EU countries to improve air quality. Yet, LEZs (including Brussels's LEZ), which are one of the main tool used by authorities to improve air quality, are mostly based on those standards.

On one side, Euro standards have been made more flexible for NOx from 2017 onward (as we can see on Figure 3). On the other side, until 2019, diesel vehicles still exceeded largely those standards for NOx (as we can see on Figure 2). Thus, for NOx emissions, higher Euro standards or more recent vehicles do not mean lower emissions (for Euro 5 vehicles) or substantially lower emissions (for Euro 6 vehicles). This is different for PMs; recent diesel vehicles emit substantially lower levels thanks to the particle filters that are installed on Euro 5 and 6 diesel vehicles. However, as highlighted in Table 2, filters created new problems with the release of very small particles (T&E, 2017b).

In this regard, the VUB research analyzing European passenger car regulations states:

"Basing LEZ access requirements on Euro emission standards proves to be problematic, despite relatively strong reductions for PM. The reason is simply that for diesel NOx, the Euro standards have failed. […] no significant improvements in local air quality due to NO_x reductions are likely to be reached by banning the majority of diesel cars that are sold up to date. Concretely, as NO_x emissions by diesel cars will only be 'under control' from (e.g.) 2020 onwards, it would make more sense banning diesel vehicles entirely in LEZs » (Hooftman et al., 2018, p. 15).

2.2 Cutting GHG emissions and fighting against climate change

2.2.1 Current state of play: a trend that is not compliant with climate targets

In 2018, road transport contributed to 26 % of the direct GHG emissions of the BCR, including CO2 and nitrogen dioxide (N20), and those emissions remained constant since 1990 (BE, 2020b; RBC, 2019). The trend is different at national level, where direct GHG emissions from road transport increased by 25% between 1990 and 2018 (SPF SPSCAE, 2019a).

Those stagnating and increasing trends contrast with the evolution of total direct GHG emissions, which decreased by 13% and 21% since 1990 respectively at regional and national levels (BE, 2020b;

SPF SPSCAE, 2019b): transport related emissions do not follow the downward trend of other sectors (e.g. industry, housing) and that is needed to meet climate targets of the region: a decrease in direct GHG emissions by 40 % by 2030 at least compared to 2005, and carbon neutrality by 2050 (2030 Energy-Climate Plan) (RBC, 2019).

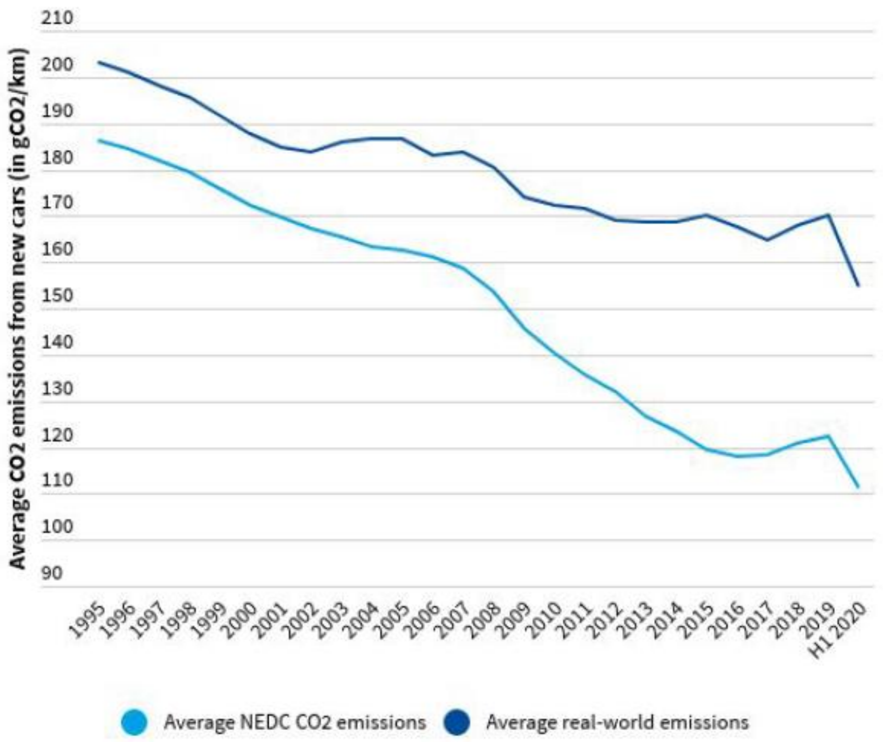
2.2.2 The EU regulation on CO2 emissions of new vehicles and its effects

In order to cut GHG emissions from transport, the **EU implemented a regulation in 2008** (Regulation (EU) 2019/631 of the European Parliament and of the Council of 17 April 2019 Setting CO2 Emission Performance Standards for New Passenger Cars and for New Light Commercial Vehicles, and Repealing Regulations (EC) No 443/2009 and (EU) No 510/2011 (Recast), 2019) that sets evolving targets to decrease CO2 emissions of the vehicle fleets of European vehicle manufacturers. Targets are revised every five year, and become harder. However a number of regulatory flexibilities make it possible for the car industry to reach targets without effectively reducing CO2 emissions of individual vehicles (T&E, 2020d).

As a result**, up to 2015, there was a decrease in the average emissions of newly sold vehicles** (cf. Figure 4). However, from 2016, these emissions start increasing, until 2020, when emissions of newly sold vehicles finally decrease. This recent decrease would result from the growing electrification of the fleet, driven by the revised target of the EU regulation, that went from 135 g to 95 gr of CO2/per km to be emitted during the use phase. The preceding increase in emissions from 2016-2020 would be the result of the increase in weight of vehicles (with the surge in the selling of SUVs), consuming more energy and fuel (cf. Blog article from Exnovation.brussels, Sureau and Callorda Fossati, 2020).

The increase between 2015 and 2020 has been favored by **a main failure contained in the regulation. This failure lies in the "flexibilities"** that would have resulted in an increasingly energy-consuming vehicle fleet, which has not reduced its impact on the climate in recent years (except this year, according to the T&E report). Indeed, one of the flexibilities of the regulation is "mass adjustment" which sets the limits to be reached by manufacturers according to the mass of vehicles: beyond a certain mass (the threshold is currently set at 1379.88 kg), the target to be reached is higher, and below, the target is lower. In addition, this threshold is adjusted every 3 years depending on the average mass of the entire fleet. Thus, this weight adjustment would have favored an increase in the vehicle fleet mass, which de facto would make the target less demanding.

Thus, there seems to be two contradictory factors driving CO2 emissions of the European vehicle fleet: the electrification and the upgrading of the car industry, selling more energy-consuming vehicles. It does not seem that the needed C02 reduction of the transport sector is on track yet. Thus, some countries and cities such as Brussels chose to reinforce the electrification of the circulating fleet and envisage to implement zero-emission zones, i.e. to phase-out ICE vehicles, in order to cut direct GHG emissions from road transport (and air pollution).



Source: Transport & Environment from European Commission & EEA (average NEDC CO_2 emissions) and the ICCT (gap with real-world emissions). The real world gap for the period 1995-2000 is assumed to be equal as in 2001

Figure 4: Average NEDC and real world CO_2 emissions in the EU (T&E, 2020d, p. 25)

2.3 The secondary objective of reducing traffic in Brussels

The reduction of traffic following the LEZ and ICE phasing-out is hoped only, and there is no related numerical targets (BE et al., 2019a; Bruxelles Mobilité, 2018). In the Good Move plan, the LEZ is mentioned in the framework of actions aiming to allow people to reduce the use of private cars. It is seen as an “opportunity to guide the population towards the MaaS concept and the decrease in car ownership” (Bruxelles Mobilité, 2018, p. 86). The plan mentions the ICE phasing-out, because there is the ambition “that [its] implementation is in line with the objective of reducing the vehicle fleet and reducing car use in general” (Bruxelles Mobilité, 2018, p. 137). Thus, the reduction in the number of circulating cars is a secondary objective only for both measures.

Those two measures focusing on making the fleet cleaner in terms of emissions (whether it be pollutant or GHG) are to be considered within the broader set of measures of the Good Move Plan, that seeks “to act on the mobility demand […] in order to develop alternatives to private cars and to encourage Brussels residents and commuters to travel differently” (Duquesne, 2019). The objective of the Good move plan is to reduce the modal share of private cars (as driver) from 33 % to 24 % in 2030. This objective is to be reached through “a 4% increase in car occupancy through carpooling and a reduction in the number of trips made by car by around 25% (both for internal and external trips)” (Bruxelles Mobilité, 2018, p. 45). One main measure of the Good Move plan is the smart kilometer tax (so-called SmartMove project), that can be considered as an exnovation policy seeking to reduce the volume of motorized travels, but carrying also a number of implementation challenges and side-effects (cf. blog article, published on *Exnovation.brussels, Sureau and Callorda Fossati, 2020*).

In brief, the LEZ and ICE phasing-out target two main objectives, i.e. reducing persisting air pollution and growing direct GHG emissions from the transport sector, and a secondary objective which is to reduce the number of circulating cars (that can be seen as a wished side-effect of those policies). While the latter issue is regulated mainly at a regional level through the Good Move plan, there are EU regulations and dedicated tools targeting directly the introduction of new vehicles and their emissions (including the EU regulation on CO2 emissions of new vehicles and Euro standards regulating air pollutants of new vehicles). Those policies and instruments however seem to contain failures and flexibilities that lower their effectiveness. One could interpret the emergence of LEZs targeting the use of vehicles at a local scale as a reply to those failures. It has to be noted yet that the LEZ is precisely based on one of those tools (Euro Standards), whose application failed in the recent years and whose design is criticized.

In order to understand what underlie those main environmental and health issues in the transport sector, we look in the next sub-section at the main trends and consumption behaviors in the sector in the last decades and at the potential environmental impacts of the various existing, growing and declining alternatives.

3. Key trends and consumption behaviors in the mobility sector

We review in this sub-section five main trends at the Brussels or Belgian levels, including general mobility trends (traffic and modal shares) and more specific trends regarding the vehicle fleet (size, engine types and fuel used, age/Euro Standards and segment). Next to the description of those trends, we highlight relating sustainability issues, on the basis of scientific and grey literature.

3.1 General mobility trends

3.1.1 The recent and slow decline in motorized traffic volume in Brussels

At national level, the traffic increases steadily since 30 years (+49 % of vehicles-km) between 1990 and 2019), including freight transport (+120% of tonnes-km) and passenger transport (+26% of passengers transported by car) (SPF SPSCAE, 2019a) .

At the Brussels level, mobility is changing however since a few years. While the number of vehicle kilometers increased between 1990 and 2007 (+15 %) (SPF Mobilité et Transports cited by (BE, 2014)), the trend has then reversed, and the overall traffic decreases slowly since then, despite the strong growth of Brussels population[15] (Bruxelles Mobilité, 2017).

3.1.2 The increasing traffic around Brussels, and worsening of congestion in Brussels

Whereas the traffic decreases slightly, the trend is not homogenous within the Brussels territory: the traffic decreased by 20 % and 6 % respectively on local roads and on metropolitan and main roads but increased by 4.6% on highways (Bruxelles Mobilité, 2017). More importantly, traffic "increases on the outskirts of the city, including in areas very close to regional limits" (Strale, 2019, p. 1).

Also, vehicle congestion gets worse: while the additional travel time required to cover a distance was just above +30% in 2008, it reached +38% in 2016[16] (Bruxelles Mobilité, 2019). The stakes are high, with numerous implications of heavy traffic in the city, including on quality of life, noise, road safety and for mobility services in its self (surface public transport, emergency vehicles, business vehicles and freight).

3.1.3 The modal share of cars: still dominant, yet declining

According to the last large mobility survey (Beldam, 2010), "cars [remained] the main mode (more than 60 %) for inbound and outbound travels", and were the second mode for internal travels (32%), after walking (37%) in Brussels (Lebrun et al., 2013, pp. 14–15). When compared with the precedent survey (MOBEL, 1999), the contribution of cars to the total travelled distance declines for the benefit of all other travel modes ("-7 and -17.7 points compared to the total for inbound / outbound and internal trips respectively") (Ibid, p. 16).

3.2 Trends in terms of vehicle fleet size

There is as yet no data to inform on trends about the circulating fleet in Brussels, but only about the registered fleet (in Brussels or in Belgium). The place of registration does not necessarily provide information on the fleet circulating in Brussels, because "many company cars, although registered in the Brussels Region, do not circulate in the regional territory. Conversely, many commuters come by

[15] Brussels population increased by 16 % between 2008 and 2018, and it should increase by 7% by 2030 (by 5% in Brussels suburbs) (Bruxelles Mobilité, 2018).

[16] What is called the congestion level, measured by GPS TomTom data.

car to the Brussels Region while their vehicle is registered elsewhere. To this are added foreign vehicles traveling to BRC" (BE et al., 2019a, p. 5). Thus data on the evolution of the Belgian registered fleet seems the best proxy to inform on the evolution of the circulating fleet in Brussels.

3.2.1 An increasing fleet at Belgian level

At national level, the size of the registered vehicle fleet surged in 30 years: the number of total vehicles and of private cars increased by 59 % and 48% respectively since 1990 (SPF SPSCAE, 2019a). At regional level, during the 1990-2010 period, the growth was not that important[17] and in the last ten years, there is no clear emerging trend.

3.2.2 And a decreasing ownership rate in Brussels

In Brussels, the rate of car ownership is much lower than in the rest of the country (55 % of households own at least a car in Brussels, against 83 % at national level) (BE et al., 2019a), and this rate is falling (from 75 % in 1999-2004 to 45% in 2014-2018) (BE, 2020a). While this trend can be considered as positive in the perspective of decreasing the use of cars in Brussels, it has to be reminded that vehicles registered in Brussels represent only a share of circulating vehicles in Brussels.

3.3 Trends in terms of types of engines and of fuel used by vehicles

3.3.1 The growing supremacy of diesel vehicles since the 90's and its declining share since 2015

With the LEZ and ICE-phasing-out, there is a will to intensify the current declining trend of diesel vehicles, because of the detrimental health impacts of those vehicles, with diesel engine exhaust classified as carcinogenic to humans by the International Agency for Research on Cancer (IARC) since 2012 (BE et al., 2019a). This is a major issue especially because diesel vehicles constitute the majority of the Belgian (and European more generally) registered fleet (in Brussels 57%), after the exponential growth of diesel vehicles between 1990 and 2014 (+301 % at a Belgian level)[18] (BE et al., 2019a; SPF SPSCAE, 2019a).

This growth has been pushed by various factors, including "air pollution regulations that were significantly less demanding for diesel vehicles and, therefore, they artificially reduced the costs of diesel cars relative to petrol vehicles by requiring less advanced exhaust after-treatment systems" (T&E, 2017b, p. 23). This contrasts with the US, "where limits are strictly technology neutral and no attempt was made to accommodate diesel through special measures. As a result, diesels with anything less than the most sophisticated after-treatment equipment have struggled to meet the US NOx standards, so diesel sales are a niche market as a result" (Ibid).

Since 2015, the Dieselgate, and the awareness raising about the detrimental health impacts of diesel vehicles, the trend has finally reversed, as shown in Table 5 with the case of cars: from 60.8% in 2015, diesel cars represent in 2019 roughly half of the fleet (FEBIAC, 2020). According to latest data from camera installed for the LEZ, the contribution of diesel cars to the circulating fleet in Brussels would be actually a bit higher than at national level: "In December 2019, around 56% of unique Belgian cars in circulation were diesel cars, compared to around 40% petrol cars, 3.5% hybrid cars and 0.5% zero emission cars (electric or hydrogen)" (BE et al., 2019b, p. 31).

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[17] As a comparison, between 2003-16: growth of the car fleet size at Brussels level: +7.55% ; at national level : 16.57%. It has to be noted that comparison between Brussels and the whole country for registered fleet is to take with care since 37% of registered cars are company cars in Brussels, against 15 % at national level (BE et al., 2019a).

[18] in a context of strong increase in the vehicle fleet (see above "Size of the vehicle fleet")

Still according to latest data from camera installed for the LEZ, vans and trucks would function with diesel in majority (95% and 100% respectively). Also, "(mini-) buses and coaches were use mainly diesel as fuel (around 82%). The share of petrol vehicles is almost zero but that of hybrid vehicles is 10%, which is significantly higher than for cars and vans" (BE et al., 2020, p. 32).

Table 5 : Evolution of the Belgian car fleet by type of fuel (Source FEBIAC 2020)

	1990	2015	2019
Gasoline	2.758.646	2.115.906,0	2.770.848
%	72	37,9	48
Diesel	1.028.115	3.396.314,0	2.862.460
%	26,8	60,8	49,2
LPG	26.633	17.110	13.836
%	0,7	0,3	0,2
Elect	-	3.307	18.523
%	-	0,1	0,3
CNG	-	1.860	14.619
%	-	0,0	0,3
Hybride	-	34.066	114.572
%	-	0,6	2,0
H2	-	1	38
%	-	0,0	0,0
Total	3.833.294	5587415	5813771

A good news for air pollution? A bad news for climate?

This declining trend of diesel vehicles is in great majority for the benefit of gasoline cars (+10 points in 5 years). This shift could reduce the presence of NOx in Brussels.

At the same time, this shift could also increase **direct GHG emissions**, given that gasoline vehicles are considered to emit more CO2 during their use, with higher C02 exhaust emissions due to more fuel consumption (EEA, 2017). However, this also depends on a number of factors, and some recent diesel vehicles would actually emit more CO2 than gasoline vehicles both under laboratory conditions and on-road testing under real-world driving condition[19]. The former would in fact require fuel-intensive NOx reduction technologies and would be heavier because of their more powerful engine (ICCT, 2019).

Also, when looking at **GHG impacts of vehicles along their life cycle** (**direct and indirect emissions),** according to a T&E publication based on an EC calculation, "an average diesel car produces over 3 tonnes more CO2 than petrol over its lifetime", because of "higher mileage […], more intensive refinery processes for diesel fuel, high GHG emissions of biodiesel substitutes when ILUC [Indirect land use change] emissions are factored in" (T&E, 2017b, p. 4)[20].

Thus, the higher performance of diesel vehicles in terms climate change impacts is uncertain, both regarding direct (during use phase) and indirect (along the life cycle) GHG emissions. The decline in diesel engines for the benefit of petrol engines is not necessarily a bad news for climate.

[19] Results from a vehicle testing project on a vehicle of the popular lower-medium segment, accounting for about 55% of EU market share (Golf VW, Euro 6 standard).

[20] Emissions from biodiesel (mixed with diesel) are higher than emissions from bioethanol (mixed with gasoline), mainly because of high land use change emissions of some biodiesel (palm and soy). Those figures are based on the Globiom report (2016), commissioned by the EC and commented by T&E here: "Globiom: the basis for biofuel policy post-2020". https://www.transportenvironment.org/publications/globiom-basis-biofuel-policy-post-2020

3.3.2 The surge in the selling of hybrid, the steady and double digit growth of electric and CNG vehicles

The share of alternative technologies, such as electric vehicles (EVs), CNG (Compressed natural gas) and hybrid vehicles are still very low. However, those vehicles show spectacular growths, with double digits growth rates in the past 5 years, especially for hybrid vehicles (cf. Figure 5).

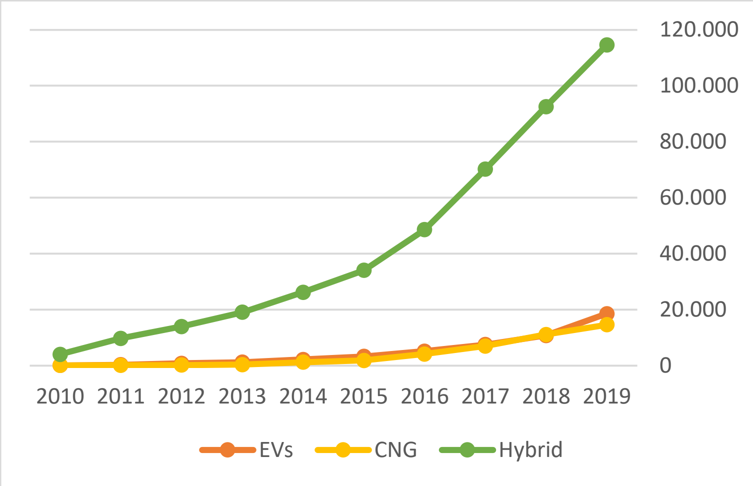


Figure 5 : Size and evolution of the Belgian car fleet of EVs, CNG and hybrid (Source: FEBIAC 2020)

While EVs are put forward by public authorities as sustainable alternatives for ICE vehicles, this is not the case for CNG and hybrid vehicles which are to be phased-out together with diesel and gasoline vehicles within several LEZs. In Brussels, the agenda for banning hybrid vehicles is not set yet.

EVs, CNG and hybrid vehicles, good alternatives to diesel vehicles?

When considering the whole life cycle, climate impacts of **CNG vehicles** are very close to that of diesel vehicles (Van Mierlo et al., 2017). And in terms of local air pollution (emissions during the use phase), CNG vehicles would emit a large number of particles, especially ultrafine particles, and “can emit large amounts of ammonia which contributes to particle pollution », while those vehicle are not subject to a particle number and ammonia emission limit (T&E, 2020c, p. 2).

Impacts of EVs are mixed, but they could indeed help tackle regional priorities in terms of local air pollution and climate change: EVs are advantageous in terms of local air pollution and GHG emissions. This is especially true in a country like Belgium, where a high share of the electricity mix is decarbonized with nuclear power and renewable energy that makes direct GHG emissions from electricity production low. However, in the case of an electrification of a large part of the fleet (and a transport demand following the current upward trend), it remains to be seen how the increased electricity demand will be met, especially given the planned phase-out of nuclear energy in 2025.

On the other side, human toxicity impacts of EVs would be higher than those of ICEs, terrestrial ecotoxicity impacts would be equivalent to ICEs and there is no consensus on their freshwater ecotoxicity and terrestrial acidification potential (cf. Figure 6 and Box 1). All in all, we can draw the conclusion that shifting from ICEs to EVs results in a displacement of impacts. It results in lower impacts generated during the use phase but higher impacts generated during the production phase, and in lower climate and air pollution impacts (in use country) but higher human toxicity impacts (in production countries). Further research is needed on freshwater ecotoxicity and terrestrial acidification impacts.

Box 1: Impacts of EVs compared to ICE over their full life cycle (EEA, 2018)

Key findings from a review from the European Environment Agency bringing together existing evidence on the environmental impacts of BEVs across the stages of their life cycle, undertaking where possible comparison with internal combustion engine vehicles (ICEVs):

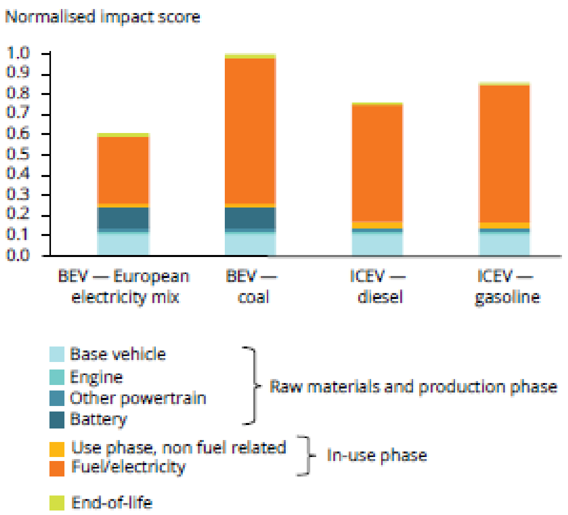
Regarding climate impacts, “the majority of LCAs show that BEVs have lower life cycle GHG emissions than ICEVs” (EEA, 2018, p. 57). Contrary to ICEs, EVs do not emit GHG (or air pollutants) during the use phase through the exhaust.

Regarding human toxicity impacts (which encompasses the effects of emissions to air and water of many different substances), “research does, however, suggest that BEVs could be responsible for greater negative impacts overall than their ICEV equivalents (Figure 6.2). The increased impact of BEVs compared with ICEVs results from additional copper and where relevant nickel requirements associated with BEVs, with toxic emissions mostly occurring in the disposal of the sulphidic mine tailings associated with extracting these metals. Coal mining to generate electricity used in the production and use stage is also associated with human toxicity (e.g. Bauer et al., 2015)” (ibid, 58).

“For freshwater ecotoxicity (Figure 6.3), the evidence is mixed: some research (e.g. Szczechowicz et al., 2012; Hawkins et al., 2013; Helmers and Weiss, 2017) suggests that impacts are higher from BEVs than from ICEVs in Europe, whereas Borén and Ny (2016) suggest that they can be lower. Freshwater ecotoxicity impacts arise to a large extent from mining and processing metals and from mining and combustion of coal to produce electricity (Hawkins et al., 2013), the latter being used both for vehicle production and use.”

« For terrestrial acidification potential, Hawkins et al. (2013) suggest that the life cycle impacts of BEVs and ICEVs are similar, whereas Bauer et al. (2015) report that BEVs have a larger impact. These results largely depend on the assumptions made regarding increased SO2 emissions from battery production and electricity generation for BEVs, on the one hand, versus the benefit of zero NOx tailpipe emissions, on the other hand” (ibid, 60).

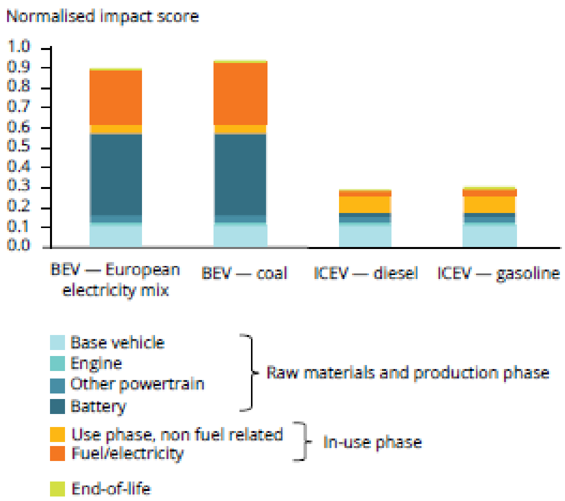
Figure 6.1 Climate change impacts: example comparison of BEVs with ICEVs



Note: See footnote 8 for a description of the study system.

Source: Hawkins et al., 2013.

Figure 6.2 Human toxicity impacts: example comparison of BEVs with ICEVs



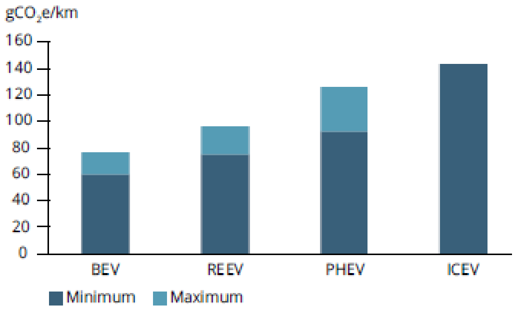
Notes: See footnote 8 for a description of the study system.

Source: Based on Hawkins et al., 2013.

Figure 6: Impacts of EVs in comparison to ICE across the entire life cycle (EEA, 2018)

The impacts of hybrid vehicles are even more controversial, given their mitigated impacts on climate and air pollution. When looking at the use phase only, hybrid vehicles bring much lower benefits than EVs in terms of GHG (EEA, 2018, p. 32) (cf. Figure 7) and they been criticized recently because they would emit much more CO2 when tested in the real world than carmakers claim, according to two different studies (ICCT, 2020; T&E, 2020e).

Figure 4.1 **Comparison of in-use well-to-wheel GHG emissions per km for a range of passenger car drivetrains**



Notes: BEV = Battery electric vehicle, REEV = Range-extended electric vehicle, PHEV = Plug-in hybrid electric vehicle, ICEV = Internal combustion engine vehicle.

Comparisons are based on the EU electricity mix in 2013. Minimum and maximum refer to the range of values reported in the articles reviewed by Nördelof et al. (2014).

Source: Data provided in Nördelof et al., 2014.

Figure 7: GHG emissions from the use phase, focus on hybrid vehicles (EEA, 2018)

3.4 Trends in terms of age of the fleet and of Euro Standard

In Brussels in 2019, around 76% of circulating diesel and gasoline cars had been registered for the first time after 2011 (5-6 Euro standards) (about 32% of Euro 5 standard, 37% of Euro 6 standard and 6% of Euro 6d standard). Around 75% of diesel vans and 80.5% of petrol vans were of Euro 5 standard or newer (BE et al., 2020, p. 32).

The evolution of the distribution of the Belgian fleet according to the age of vehicles or their Euro standards is presented in Figure 8 below, where diesel and gasoline vehicles are mixed up (whereas Euro standards (and effective pollutant emissions) of diesel and gasolines are different). The distribution of the fleet evolves steadily; in 2019 66% of the Belgian fleet had been registered after 2011, this highlighting the recent character of the Brussels circulating fleet (10 points difference), while registered fleet in Brussels is on average older than in the rest of Belgium (BE et al., 2019a). However, overall, the average age of the car fleet increases steadily, from more than 7 years old in 1996 to more than 9 years in 2018 (FEBIAC, 2020).

The newest, the cleanest?

We have seen in 2.1.1 (Figures 1 and 2) that for some pollutants, recent vehicles do not necessarily perform much better than older ones: Euro 5 and oldest euro 6 vehicles would still emit large NOx quantities in real driving conditions, and recent petrol vehicle with direct injection engines would emit PMs contrary to other, older, petrol engines (T&E, 2017a, 2018a). These recent vehicles constitute today the majority of the Belgian fleet. Also, recent vehicles include much heavier and powerful vehicles, consuming more energy and, when not EVs, emitting more CO2, with the rise of Sport Utility Vehicles (SUVs).

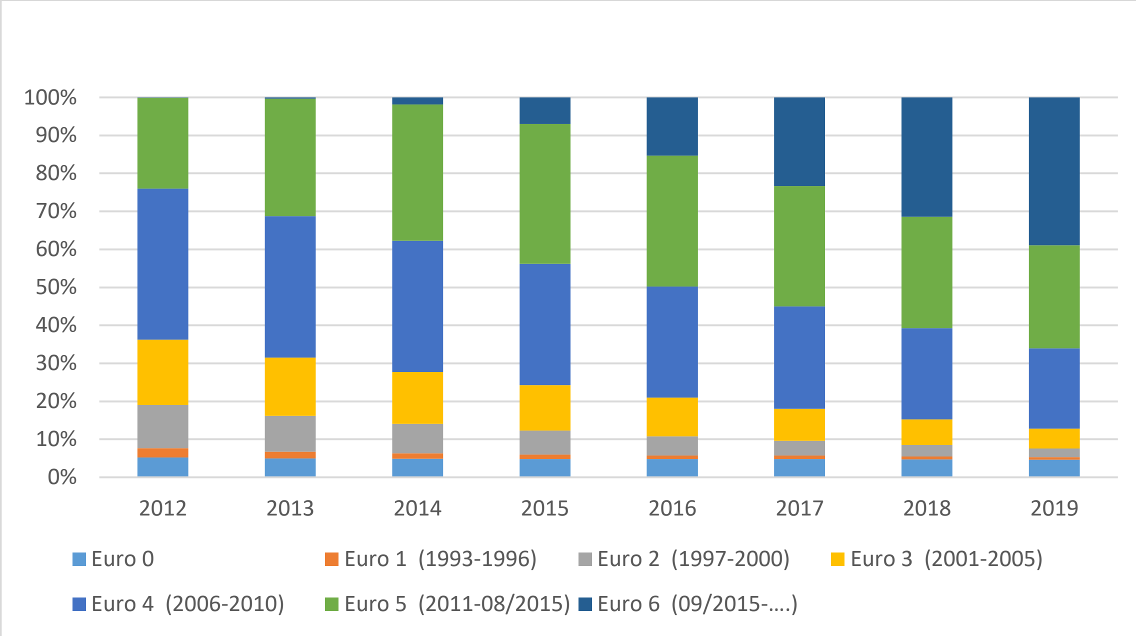


Figure 8: Evolution of Belgian vehicle fleet by environmental class (Source: FEBIAC 2020)

3.5 Trends in terms of vehicle segment/size/weight: the rise of SUVs

In Belgium and in Europe more generally, one can observe the surge in the selling of SUVs. SUVs now represent 40 % of registrations of new cars, while this rate was 30 points lower 10 years ago. This increase is at the expense of all other car segments, especially family cars and people carriers (Figure 9).

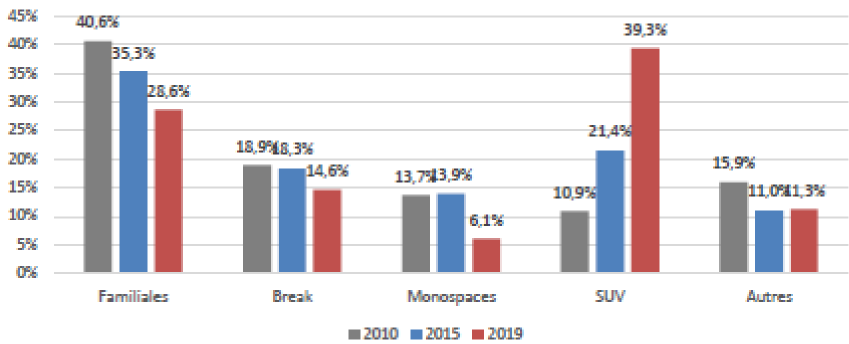


Figure 9: Evolution of new cars registrations by segment (Source: FEBIAC (BE et al., 2020))

A bad news for emissions of GHG and air pollutants

This trend is problematic both for climate and air pollution given the higher weight of SUVs, which would consume on average about 25 % more energy than medium-size cars (Cozzi & Petropoulos, 2019), and emit 16 g of CO2/km (or 14%) higher than an equivalent hatchback model (T&E, 2019b, p. 3).

As highlighted by the International Energy Agency (IEA), "global fuel economy worsened caused in part by the rising SUV demand since the beginning of the decade, even though efficiency improvements in smaller cars saved over 2 million barrels a day, and electric cars displaced less than 100,000 barrels a day" (Cozzi & Petropoulos, 2019).

In brief, several trends affect the mobility sector in Brussels (or in Belgium more generally) that can help explain persisting air pollution problems and growing GHG emissions in the transport sector.

There are recent trends affecting the automotive regime, such as the surge in energy-consuming vehicles, and the weakening of the supremacy of harmful diesel engines, for the benefit of other engines such as petrol and hybrid, CNG and electric vehicles (to a lesser extent for the latter). Those latter technologies are however neither neutral in terms of environmental impacts: while CNG and hybrid vehicles do not necessarily improve air quality greatly, EVs displace impacts to other areas. There are also more long-term trends affecting mobility in general such as the growing size and age of the Belgian fleet, the persisting dominant role of cars, the increasing traffic volume around Brussels and the worsening of congestion in Brussels.

The BCR seeks to accelerate or to tackle some of those trends with various instruments that can relate to exnovation policies such as the LEZ, and the planned ICE phasing-out. With the LEZ, the BCR seeks to accelerate the decline of diesel vehicles and possibly, to counter the ageing of the fleet, while with the ICE phasing-out, it would seek to complete the fall of combustion engines, and their replacement by electric and hydrogen vehicles.

Beyond the LEZ and ICE phasing-out put forward by the Brussels region and targeting the technological core of the automotive regime, there seem to be a number of alternative and complementary exnovation paths. The planned city toll (Smartmove) that would tackle the growing congestion in Brussels (and the surge in SUVs, to a lesser extent, with the amount of the tax linked to the fiscal horsepower of vehicles), is an example of tool towards one of those alternative paths.

Before defining more precisely what would be those exnovation paths, we look in the next section at the effective and potential impacts of the LEZ and ICE phasing-out.

4. Sustainability impacts of LEZ

In this section, we seek to identify the likely impacts of LEZs in general and to analyze the observed or forecasted impacts of the Brussels LEZ. Before starting the exercise, we clarify some elements about the reviewed materials and the methods used by studies assessing impacts of LEZs.

4.1 Introduction

4.1.1 State of play: some elements about materials

LEZs are implemented in Europe since the 90's and a number of ex-ante and ex-post impact assessment have been conducted and are available, though mainly for air pollution impacts only (Air et al., 2019; T&E, 2019a). In Brussels, two kinds of assessments are and have been conducted by regional authorities: ex-ante assessments (BE et al., 2019a; Transport & Mobility Leuven, 2011) and yearly ex-post assessments (BE et al., 2019b, 2020). Assessments focus mainly on air pollution and climate impacts, and only the 2011 ex-ante study include other impacts.

Just a few cities have announced their intention to implement **ICE/diesel vehicles bans** in the coming years (2024: Oslo, Paris, Rome; 2025: Bergen; Amsterdam, London, Strasbourg; 2027: Milan; 2030: Brussels) (Wappelhorst, 2020; Wappelhorst & Cui, 2020). An impact assessment of the Brussels plan to phase-out ICEs has been carried out in 2020, covering environmental and socioeconomic impacts. This impact assessment would be one of the firsts that will be available, since we found only one other study looking at the impacts of a zero emission zone in Oxford in the UK. None of the impact assessments carried out for the Brussels policy is however publicly available at the date of writing this report, this section is thus limited to the analysis of LEZs impact assessments.

For the comparison exercise, we selected studies dealing with measures similar to those implemented/to be implemented by Brussels, including in terms of scope (what is to be exnovated) and in terms of timing: we excluded LEZs that were implemented before 2015 and the Dieselgate (cf. 3.1.2 for rationale), and we focused on recent LEZs such as London, Paris, Gent and Antwerp. The detailed list of those studies and included impacts/issues and a summary of results are included in Annex (Table 12 and Table 13). Existing reviews of LEZs and ICE phasing-out measures in Europe were our starting material to select cities/studies (Air et al., 2019; CLARS/Sadler Consultants Ltd, n.d.; T&E, 2018a, 2018c, 2019a).

4.1.2 Some elements about the methods used

Most studies assessing impacts of LEZs focus on the improvement of air quality (primary objective of LEZs). In order to assess those impacts, there are two main methods (Air et al., 2019):

- **Pollutant concentrations at measurement sites/stations** located within the LEZ are measured before and after the LEZ implementation. This requires that the measurement sites/stations are in number for all pollutants and well located (at various locations within the measured area).
- **Pollutant emissions of the vehicle fleet** with the LEZ are calculated on the basis of the composition of the circulating fleet by engine/fuel type and Euro standard, and of emission factors for each vehicle type. On this basis, pollutant emissions from transport can be estimated, as well as concentrations, with the support of a number of assumptions.

For both types of assessments, **in order to assess the specific impact of the LEZ, results should be compared to a business as usual situation, without LEZ.** For the 1st type of assessment, it is possible to compare evolutions in concentrations in areas where the LEZ has been implemented, with evolutions in concentrations in other areas without LEZ, as done in the study of Flemish LEZs

(Wackenier et al., 2020). For the 2nd type of assessment (pollutant emissions), it is possible to estimate the fleet composition that would prevail without the LEZ (with a natural fleet renewal), as done for the Paris LEZ (Bernard et al., 2020) and for the Brussels LEZ (BE et al., 2019a).

Also, for both types of assessments, results depend on the effectiveness of the measure but also on how the assessment is conducted and its quality. For the 1st type of assessment, in Brussels, there are some question about "the way air quality is monitored, including the location of measuring points for NO2" (EC, 2018), hence, results should be interpreted cautiously. For the 2nd type of assessment, data on the composition of the circulating fleet in a certain area is not easy to obtain (contrary to the composition of the registered fleet); it can be obtained with surveys or with the installation of cameras in the area (as in Brussels since 2018). Also, emission factors are a sensitive and evolving data. It varies according to the method used to measure emissions (laboratory tests, real-word tests, or real-world operation) and it is not always clear which emission factors are used by studies. Some studies use emissions factors from databases (as done for the Brussels LEZ) and some other studies[21] use emission factor calculated in real-world operation (as done for the Paris LEZ), given the observed gap between emissions measured in laboratory tests and emissions from vehicles "in "real-world" operation—on the road, in normal driving" (Bernard et al., 2020, p. 3).

It seems that impacts assessments of LEZs focusing on pollutant emissions (2nd type) and that were conducted before the Dieselgate scandal are likely to be partly biased (and are thus not considered here); real NOx emission levels from recent diesel vehicles especially are much higher than the levels that were claimed by the car industry (and used by impact assessment studies presumably). If those vehicles were supposed to replace old diesel vehicles, the benefits in terms of NOx are likely to be lower than estimated. With this remark we refer to measurement defaults of NOx emissions from recent diesel vehicles only (revealed by the Dieselgate), but it can be generalized to all pollutants, engines and models: methods to estimate or to measure pollutants improves gradually, with new pollutants (such as ultrafine particles) and new pollutant sources (e.g. regeneration process of particle filters, direct injection engines) being gradually unveiled. At the same time, the various scandals around the real environmental impacts of vehicles show that the car industry would find gradually ways to hide partially those impacts. The difficulty in getting the data on real emissions of vehicles is a major impediment to sound impact assessments of policies such as LEZs.

4.2 What are the likely and observed impacts of the Brussels LEZ?

Introduction: Brussels assessments

A first ex-ante assessment of a LEZ in Brussels was carried out a decade ago and published in 2011. It includes a wide range of impacts including mobility, air quality and socioeconomic impacts. The ex-ante assessment published by Bruxelles Environnement in 2019 focuses on air quality only. It includes both emissions and concentrations, with modelling (BE et al., 2019a), and compares two situations, with LEZ and without, in 2020 and in 2025. The two ex-post assessment focus similarly on air quality impacts but without comparing to the Business as usual situation (or a situation without LEZ) and include climate impacts as well (BE et al., 2019b, 2020). The two ex-post assessments cover the 2018-2019 period, i.e. the first two phases of the LEZ (out of 5) when Euro 0-2 diesel vehicles and Euro 0-1 gasoline have been banned.

[21] Such as studies of the Real Urban Emissions (TRUE) Initiative, a partnership of the FIA (Foundation for the Automobile and Society) and the ICCT (https://www.trueinitiative.org/about-true).

4.2.1 Do LEZs satisfy local air pollution objectives?

What can we expect from the LEZ?

LEZs are expected to improve air quality through the replacement of polluting vehicles by other vehicles (or modes of transport), which are assumed to be less polluting. The effects of LEZs rely on one side on their design (access criteria, agenda) and on the other side on the alternatives that will be chosen by vehicles owners to replace banned vehicles, i.e. on the impacts of LEZ on mobility behaviors (which transport modes) and on the fleet composition (which vehicles – age, type of engines). Where the LEZ is meant to modify the fleet composition[22], existing impact assessments state that LEZs do not affect mobility behaviors. The fleet size would thus not be affected, and nor the traffic (Air et al., 2019; CLARS/Sadler Consultants Ltd, n.d.).

Three existing reviews of LEZs from T&E, ADEME and the Urban Access Regulations Portal (CLARS/Sadler Consultants Ltd, n.d.) confirm that LEZs can reduce air pollution[23]. The ADEME review highlights that "the reduction in pollutant *emissions* linked to road traffic is generally significant", but "the expected benefits on air quality [i.e. on *concentrations*] are more moderate, especially given the multitude of emission sources in urban areas and the significant influence of weather conditions" (Air et al., 2019, p. 6). For NO2, "the magnitude of the reduction in pollutants ranges from no discernible effect to a reduction of 32%" (Madrid Central) (T&E, 2019a).

T&E qualifies those conclusions, stating that "not for all of them available data shows significant reductions", with the design of LEZs being critical for "its effectiveness and namely its ability to influence the change in the composition of the vehicle fleet" (T&E, 2019a, p. 7). T&E argues that LEZ should "avoid blanket exemptions of Euro 6 diesels and instead only allow vehicles that are clean in real-world driving, including those fixed. The inclusion/exclusion criteria should be based on vehicles' real-world emissions (RDE) that are now widely available" (T&E, 2018a, p. 2). In the same report it argues that "limiting diesel access in large urban areas is the only effective policy to decrease pollution" (T&E, 2018a, p. 3).

This is also argued by authors of the recent ex-ante impact assessment of the Paris LEZ who advise cities to "schedule access restrictions for pre-Euro 6 diesels as early as possible" (Bernard et al., 2020, p. 17). Their assessment compares two situations, with and without LEZ, with the use of real-world emissions as emission factors (cf. Figure 1), under two scenarios[24]. It finds that "achieving substantial NOx benefits for passenger cars regardless of how drivers choose to comply with the LEZ is only expected from 2024", when Pre-Euro6 diesel are banned from the zone (Ibid, 12–13). In the years before, emissions reductions follow the emissions reductions of the baseline scenario (no LEZ) cf. Figure 10).

In comparison to other cities, Brussels starts with relatively low-ambition level "allowing high pollution levels to remain for much longer", as highlighted by T&E (T&E, 2018a, p. 12). And requirements will only gradually increase (cf. p. 6, Table 1), from 2022 and 2025 with the ban of respectively Euro 4 and Euro 5 diesel vehicles. Comparatively, the London LEZ removes directly Euro 1-5 diesel vehicles, from 2019 (Central London) and from 2021 (broader area) and Paris removes Euro 1-4 diesel vehicles from 2022 and all diesel vehicles from 2024 (cf. Table 13 in Annex).

[22] Which can be influenced itself by the design and agenda.

[23] See also the recent study from EPHA/CE Delft on the subject and reported on in a GOSETE Blog post (Sureau & Callorda Fossati, 2021)

[24] Worst and best cases, where noncompliant vehicles are replaced with respectively vehicles that meet the bare minimum requirements of the LEZ and brand new petrol vehicles.

According to IEB, « *the restriction measures induced by the LEZ follow the natural curve of the renewal of the vehicle fleet* » (Fourneau, 2018). In 2018 and 2019, only 0.5 and 4 % of the fleet would be affected respectively by the ban (this rate progressing to 14 % and 33 % in 2020 and 2025).

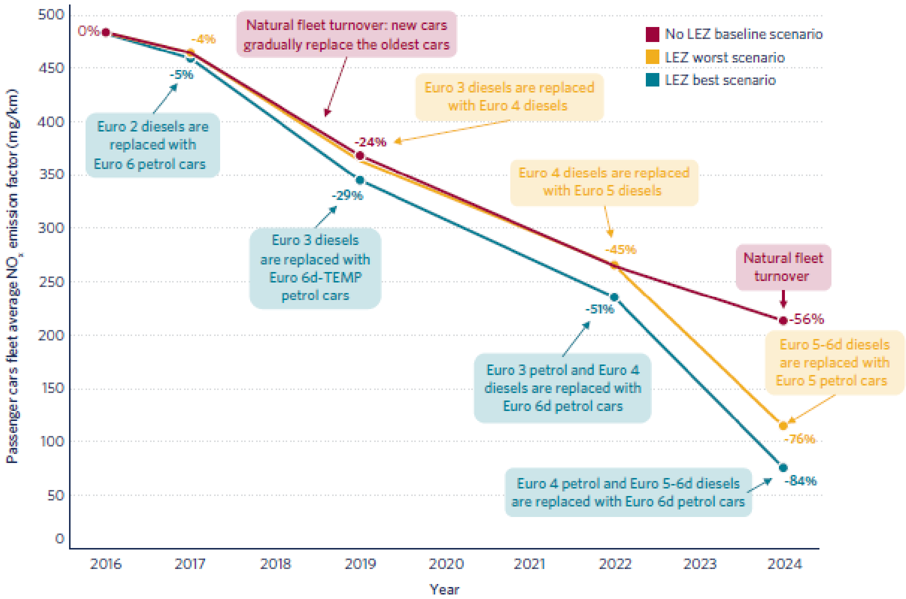


Figure 10: Estimated effects of Paris LEZ on passenger car fleet average NOx emission factors, with summer emission factors and optimistic registration assumptions (Bernard et al., 2020, pp. 12–13)

A very recent study following the same methodology than the one conducted in Paris (Bernard et al., 2020) analyzes the potential impacts of the Brussels LEZ by looking at real-world emissions of the circulating fleet in Fall 2020. Figure 11 and Figure 12 illustrate their results. They show that for PMs, major improvements can be expected from 2022, with the removal of Euro-4 diesel vehicles that contribute the most to PM emissions. However, for NOx, most reductions will have to wait for 2025 with the removal of Euro5 diesel vehicles, and 2028 will see the main final cut of NOx emissions with the removal of first Euro6 diesel vehicles.

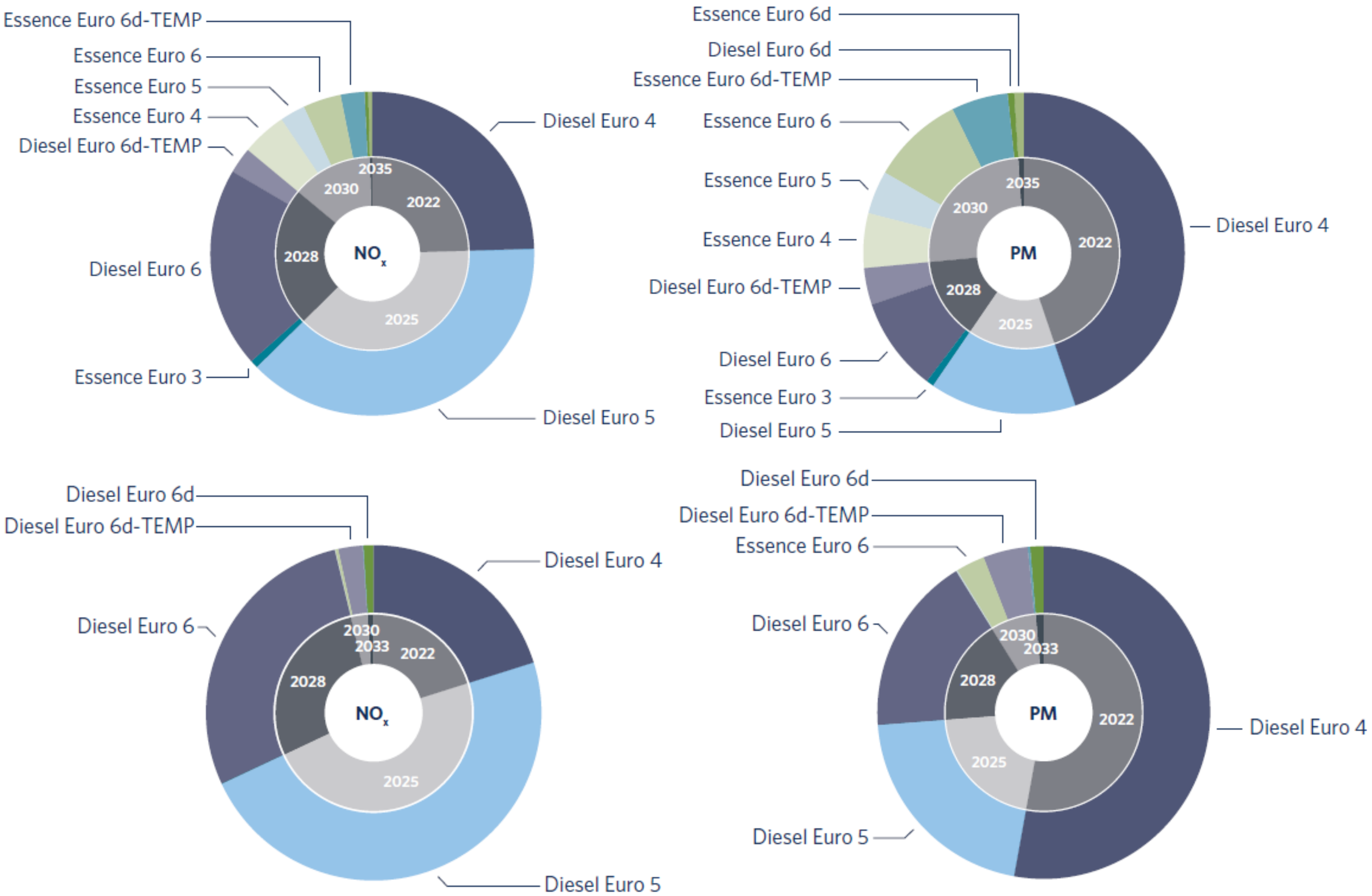


Figure 11 (above) and Figure 12 (below): Estimated share of total NOx and PM emissions from respectively passenger cars (above) and light commercial vehicles (below) operating in Brussels in the autumn of 2020, by emissions standard and fuel type. The inner ring breaks down total emissions by the year in which vehicle groups will be subject to LEZ restrictions (Bernard et al., 2021).

In Brussels: what are the assessed impacts after two years of implementation?

In terms of mobility behaviors (fleet size and traffic)

The 2011 ex-ante assessment estimate that the number of vehicle kilometers would be reduced marginally, by 0.2 to 1.2 % (Transport & Mobility Leuven, 2011). The 2019 ex-ante assessment use this result to assume that the "LEZ will not affect the behaviors of drivers in terms of mobility choice" and that "the number of driven kilometers will remain equal by vehicle category" (BE et al., 2019a, p. 16).

In spite of this assumption, in the same document, it is stated that "the objective of the LEZ is to contribute to a decrease in the number of driven kilometers". This evolution is thus hoped by public authorities. However, ex-post assessments do not make it possible to assess the impact of the LEZ on the size of the circulating fleet or on the traffic (BE et al., 2020).

In terms of fleet composition

Whereas the impact on the fleet size and on the traffic seems uncertain, the LEZ is meant to modify the fleet *composition*: it is mainly through the replacement of some vehicles by other vehicles that the policy would contribute to the improvement of air quality. And the more banned vehicles will be replaced by vehicles emitting few pollutants, the more the LEZ will reduce air pollution.

Among the number of vehicles affected, the December 2019 ex-post assessment calculates that the share of diesel vehicles in the circulating fleet has fallen by 5.5 percentage points since December 2018 and "this reduction has mainly benefited petrol cars and, to a lesser extent, hybrid and zero-emission cars" (BE et al., 2020, p. 31). This evolution is in line with the recent evolution of the registered fleet in Belgium, as shown in Table 6 below.

The assessment does not make it possible to estimate the exact contribution of the LEZ to this phenomenon (a comparison with a BAU scenario would allow to isolate effects of the LEZ from other effects, such as the natural fleet renewal). However, the assessment conducted for the Flemish LEZs can provide some elements to estimate this contribution, since "old diesel cars without a particulate filter disappeared more quickly from the low-emission zones than in the rest of Flanders, and were replaced more often by (older) petrol vehicles" (Wackenier et al., 2020).

Table 6: Evolution of the composition of the fleets circulating in Brussels and registered in Belgium

Evolution of the share of vehicles by fuel/motor type in the fleet [2018-19]	Circulating fleet in the BRC (BE et al., 2020)	Registered fleet in Belgium (FEBIAC, 2020)
Diesel	-5.4 pt	-3.7 pt
Petrol	+4.3 pt	+3.1 pt
Hybrid	+0.8 pt	+0.4 pt
Electric	+0.2 pt	+0.1 pt

In terms of emissions

According to the 2019 and 2020 ex-post assessment, during the 2018-2019 period, emissions of all pollutants have decreased. This is especially true for BCs (-75 % in 18 months); reductions of other pollutants (NOX, PMs) range between -6.8% and -11.7%.

In terms of concentrations

Also, the 2019 ex-post assessment describes a decrease in No2 concentrations on average in all stations by 10 % and a strong decrease in BC concentrations, regardless of the localization of stations (Table 7). However, those results are difficult to interpret given the recognized poor quality of measurement sites of Brussels, especially for NOx (cf. 2.1.1*, The level of compliance of the BRC with existing air quality standards*).

Table 7: Evolutions of average yearly concentrations of NO2 (BE et al., 2020)

Station	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Bruxelles Ville (Arts-Loi) (*)								56	56	52
Bruxelles Ville (Sainte-Catherine)	43	40	38	36	34	31	33	35	34	28
Bruxelles Ville (Eastman - Belliard)	41	39	38							
Bruxelles Ville (Parlement UE)	37	33	34	37	(***)	32	(**)	(**)	(***)	(***)
Bruxelles Ville (Rue Belliard)				63	61	62	54	(**)	(***)	(***)
Berchem-Sainte-Agathe	30	27	27	27	23	22	22	23	21	18
Neder-Over-Heembeek	(***)	(***)	31	32	28	26	27	27	28	28
Avant-port (Haren)	44	44	43	42	42	42	42	39	37	34
Molenbeek-Saint-Jean	43	41	41	42	39	35	38	33	35	31
Ixelles	54	50	48	49	47	45	48	49	42***	33
Uccle	28	26	25	26	22	22	21	20	18	16
Woluwe-Saint-Lambert	39	37	40	40	39	35	33	35	31	27

Also, the conducted assessments do not compare their result with a BAU or no-LEZ scenario. In that case, it is difficult to draw conclusions on the effectiveness of the measure and to compare with results of other cities. Again, the assessment conducted for the Flemish LEZs can provide some elements to estimate this contribution: NOx and BC concentrations have fallen sharply in Antwerp in recent years. But only concentrations of BC in Antwerp "decreased globally more than in the rest of Flanders. From this we can deduce that the LEZ in Antwerp has caused an additional local decrease in BC concentrations" (Wackenier et al., 2020, p. 11). This is not the case for NOx, for which no additional effects locally are observed. Thus, it is likely that the decrease in NOx concentrations in Brussels would have happened also without the LEZ.

These diverging results for NOx and PMs can be explained by the fact that the LEZ focuses in the first years on removing old diesel vehicles (Euro standard 1-3), which are not equipped with particulate filters that aim to capture PMs and BCs. But most recent diesel, which still emit a high level of NO2, are not affected by the measure yet.

What about likely future impacts? Results of the ex-ante assessment

The rather low ambition of the Brussels LEZ at the beginning of its implementation period and its progressive nature are visible in the results of the ex-ante assessment, looking at the impacts in 2020 and in 2025, and comparing it to a BAU scenario (BE et al., 2019a).

In terms of emissions

The effect of the LEZ is only marginal in the first phases. In terms of pollutant emissions, for NOx, effects of LEZ happen in 2025, with almost 20 points difference between both scenarios, while in 2020, only 2.1 points difference are found (despite of the fact that already 14 % of the BAU 2020 fleet would be concerned by the measure) (Table 8). Results are different for BCs and PMs, for which a difference between both scenarios can be seen from 2020 onwards, with 5.5 to 13 points differences. In 2025, effects of the LEZ increase, with 9.6 to 23.3 points differences.

Table 8: Evolution of road transport pollutant emissions, compared with 2015 (BE et al., 2019a)

	2020			2025		
	BAU/without LEZ	With LEZ	LEZ effect	BAU/without LEZ	With LEZ	LEZ effect
Nox	-30,1%	-32,2%	2,1 points	-46,5%	-66,2%	19,7 points
BC	-42,0%	-55,0%	13,0 points	-63,0%	-86,3%	23,3 points
PM2.5	-23,4%	-30,6%	7,2 points	-32,4%	-45,0%	12,5 points
PM10	-16,3%	-21,8%	5,5 points	-21,8%	-31,4%	9,6 points

In terms of concentrations

In terms of pollutant concentrations, which are deviated from pollutants emissions in the ex-ante assessment, for BCs, effects of LEZ are also visible already in 2020, and even more in 2025 (7 and 12,5 point differences between both scenarios at the specific station of Ixelles, cf. Table 9). For NOx, again, effects of LEZ are visible in 2025 only, with a marginal difference in NOx levels with and without the LEZ (1.1 point difference).

According to Bruxelles Environnement, "the European legal standard set for NO2 will be met in all the measurement stations reported to the EU in 2020. For Belliard [whose results are not reported to the EU], it will be between 2020 and 2025 (cf. Table 10). This statement has been indeed confirmed by the ex-post 2019 assessment, which reports that "only measurement stations which are too close to a crossroads (i.e. Arts-Loi and Belliard stations) and which therefore do not comply with the micro-implantation requirements of Directive 2008/50/EC, still exceed the annual limit value for NO2 in 2019" (BE, 2020c, p. 36).

Table 9: Evolution of pollutant (NO2 and BCs) concentrations at the Ixelles station (BE et al., 2019a)

	2015	2020			2025		
		BAU/without LEZ	With LEZ	LEZ effect	BAU/without LEZ	With LEZ	LEZ effect
Nox in µg/m3	45	40,2	39,7		36,3	31,6	
% / 2015		-10,7%	-11,8%	1,1 points	-19,3%	-29,8%	10,4 points
BC in µg/m3	2,09		1,37			1,05	
% / 2015		-23,0%	-30,0%	7,0 points	-34,0%	-46,0%	12 points

Table 10: Focus on NO2 concentrations with LEZ at the four stations under study (Belliard, Ixelles, Molenbeek Saint-Jean and Woluwe St Lambert)

	2015	2020	2025	EU/WHO norms
Nox in µg/m3	[35-65]	[30,8-47,9]	[27,1-35,7]	40

4.2.2 Impacts on GHG emissions

Because diesel cars are supposed to be more climate friendly than petrol cars, the general belief is that the LEZ would increase GHG emissions, if diesel vehicles are mainly replaced with petrol vehicles, and then with so-called 'zero-emission' vehicles. This would however all depend on the emissions factors used for diesel and petrol vehicles. Some recent studies argue that recent diesel vehicles would emit more CO2 during the use phase than petrol vehicles, or that GHG emissions generated by petrol vehicles are underestimated when the whole life cycle is taken into account (cf. "2.2.3 Trends in terms of types of engines and of fuel used by vehicles").

According to the two reviews of LEZ impact assessments, the evolution of GHG emissions following LEZ implementation is not always assessed (Air et al., 2019; CLARS/Sadler Consultants Ltd, n.d.). One of them refers to two LEZs (Milan and London) which have seen their CO2 emissions decrease following the implementation, but in parallel to a decrease in traffic (CLARS/Sadler Consultants Ltd, n.d.). CO2 emissions were not included in the studies on LEZ in Flanders and in Paris (which focused on NOx emissions).

In Brussels

In Brussels, the traffic is not expected to decrease according to the ex-ante assessment. The 2019 ex-post assessment estimates that GHG emissions from road transport increased by 1.8 % for cars and decreased by 0.6% for vans during the period [06/2018-12/2019]. According to the report, "the lack of reduction is explained by the shift from diesel to gasoline engines, while zero-emission engines are progressing very slowly and still remain marginal in December 2019" (BE et al., 2020). This result can be questioned, given the lack of scientific consensus over GHG impacts of a shift from diesel to petrol vehicles (cf. 2.2.3)

4.2.3 Social and socioeconomic impacts

Mixed effects for households, especially vulnerable households

Health impacts

The LEZ implies health benefits for the population, which have been estimated by the 2011 Brussels assessment in monetary terms, on the basis of an external environmental cost of a tonne of NOX emitted by road transport (valued at Euro 577) and the cost of a tonne of PM2.5 in an urban environment (valued at Euro 389,225)[25]. Most health benefits come from the reduction in PM2.5 from exhaust (more than 3.232.178 million euro/year), followed by PM2.5 from non-exhaust (183.163 million euro/year) and NOx (122.156 million euro/year).

Vulnerable households would benefit more than others from the improved air quality since poorer populations are more exposed to air pollution and are also more sensitive to the health risks of air pollution (Wackenier et al., 2020).

Cost of the policy and of transport services

Regarding the cost impacts of the LEZ for households, it has to be noted first that households in general are affected the most by the LEZ since there are relatively fewer company cars of the lowest Euro classes than private cars (Vermaillen & Denys, 2010 cited by (Transport & Mobility Leuven, 2011).

Secondly, regarding the distribution of impacts of LEZs among households, according to the 2011 ex-ante assessment for the Brussels LEZ that is based on figures for Flanders, one can conclude that while poorer households will benefit the most from air quality improvements, if they own a car, they are hit by the policy more than others.

On one side, they are more financially vulnerable (it is more difficult for them to cope with the implications of the policy and to buy a compliant car than high-income households). On the other side, they are more likely to own an old car that is to be banned than high-income households: If low-income households do have a car, chances are high that it is an old car (52% has a car built before 2000, against 18 % for households with incomes above 5000 euro) (Transport & Mobility Leuven, 2011).

In addition, while in absolute numbers, the highest number of affected households are to be found by the highest income households (since high-income households generally have more cars than low-income households), their old cars are often their second car (80% of the owners of a car older than 10 years also have a second car).

[25] These costs relate to damage to human health, ecosystems, buildings and the economy.

Thus, the study concludes that, "with regard to the effects on different income groups, we can say that the introduction of the LEZ will mainly affect the low-income groups" (Transport & Mobility Leuven, 2011, p. 133).

The 2020 Ghent and Antwerp study confirms those findings, but adds some specific conclusions with data specific to Ghent and Antwerp households, that are likely to bring relevant insights for Brussels: "Of all Antwerp and Ghent families with a car, the lowest income quartile is hit the hardest. About a third of those families own a vehicle that does not have access to a low emission zone [against 9 % for the highest-income quartile]. This unauthorized vehicle is usually their only vehicle [contrary to high-income households]. The impact of the low emission zone is greatest for those families" (Wackenier et al., 2020, p. 86). In Brussels, the distribution of impacts is likely to be similar and thus unequally distributed among households, with most burdens falling on vulnerable households.

Accompanying measures

In order to compensate for those impacts, the BCR offers free public transport or a bicycle allowance and access to car sharing for residents scrapping their cars (the Bruxell'Air allowance) (Bruxelles Mobilité et al., n.d.-b). This allowance is not determined by financial resources, and any household might receive it.

While this measure could help reduce the fleet size, it could fall short for residents who cannot use alternative transport modes (shift workers) or for non-residents of Brussels, who cannot benefit from this support. Yet, commuters might be impacted by the measure even more than Brussels residents who generally have access to public transport. As highlighted by a recent study (Strale, 2019), some commuters use their private cars to travel to Brussels because of the poor quality of the public transport offer in the near periphery (on the first peripheral ring). This problem is exacerbated for workers working outside normal working hours, who are also low-wage earners. As IEB highlights, « more and more people from the middle and lower classes are moving from the city to the far outskirts, where these workers often have no other way to get to work than by car » (Rogeau, 2020).

Consequently, the LEZ is likely to deteriorate the access to transport for a significant share of vulnerable households who own a car, especially those that are not able to use alternative transport modes because of their place of residence or because of their working time. This is different for SMEs which can benefit from up to 3000 euros in allowances when switching to compliant vehicles[26].

Cost of goods

According to the London study, consumers would not be affected by an increase in the prices of goods due to the increase in transport costs. The 2011 Brussels assessment concludes also that the LEZ is not likely to increase the prices of goods sold in Brussels because transport costs represent only 2-4% of goods consumer prices, among other reasons.

Adverse effects on enterprises due to increased costs (renewal and transport services)

According to (CLARS/Sadler Consultants Ltd, n.d.), "few negative business impacts have been reported". The ex-ante assessment of the LEZ of London (conducted in 2006) estimates that very small enterprises that use big vans or minibuses would be very much impacted by LEZs: those small companies would own old vehicles, that would have to be replaced. Also, SMEs are more vulnerable to increases of their costs. A particularly affected sector would be the building sector, that operate in a very competitive environment (Air et al., 2019, p. 92).

[26] https://lez.brussels/mytax/fr/alternatives?tab=Primes

In Brussels

The ex-ante assessment conducted in 2011 estimates the overall cost for changing one part of the fleet that corresponds to Euro 0-4 diesel and Euro 0-1 petrol cars and Euro 0-4 trucks: it would amount 621 million euros for changing cars and 63 million for changing trucks. Two groups of companies would be directly affected by the introduction of the LEZ: i) the suppliers and carriers and ii) retailers, catering establishments and market vendors (Transport & Mobility Leuven, 2011).

Cost and revenues effects for public authorities

The LEZ implies costs for public authorities (implementation and management costs) but it also implies earnings (from fines and sales from e.g. day pass). This aspect has not been assessed in Brussels assessments, including the 2011 ex-ante study since no implementation details were known at that time (Transport & Mobility Leuven, 2011).

4.3 How are LEZ impacts assessed?

For assessing impacts of LEZs, studies focus mainly on the initial objective of the policy which is to reduce local air pollution, and health related impacts. To do this, it is necessary to assess or to make assumptions regarding impacts on mobility behaviors and on fleet composition. Some studies assess other impacts such as direct GHG emissions and cost impacts (for public authorities, companies, households). Thus, assessment exercises concentrate on local environmental benefits and socioeconomic losses, leaving aside several potential side-effects.

4.3.1 Environmental impacts

Changes in life cycle impacts and changes in production/demand quantities

A displacement of air pollution impacts?

While LEZs are meant to reduce air pollution in the regarded area, air pollution is likely to be displaced to areas with lower environmental standards (T&E, 2018b; UNEP, 2020). In fact, when LEZs are implemented, banned vehicles are landfilled, or sold to areas where no ban prevails. This can be to rural areas where air quality problems are less acute, or to other urban areas with less strict environmental regulations. As highlighted by a recent UNEP report, the LEZ and other bans have “fuelled the global transfer of used LDVs, including older diesel vehicles, trucks, and buses” (UNEP, 2020, p. 25). EU is the main exporter of used vehicles worldwide (54%), Africa the main importer (40 %), and “Eastern Europe, Caucasus and Central Asia (EECCA) countries have seen a steady increase of imports from the EU, rising on average by 10 per cent each year” (UNEP, 2020, p. 20).

“As the market for diesel vehicles declines in Western Europe, many of these vehicles are finding their way to countries in Eastern Europe, the Caucasus and Central Asia and West Africa. For instance, in 2017 Bulgaria imported over 100,000 used diesel vehicles from the EU, half of which were more than 10 years old and without the standard diesel particle filters found on all new vehicles after 2011 (Transport & Environment, 2018). In Moldova, diesel imports grew from 25 per cent to 58 per cent in 2017 (GFEI, 2018). The number of diesels leaving Germany in 2018 grew by 20 per cent”.

From UNEP report “Used Vehicles and the Environment - A Global Overview of Used Light Duty Vehicles: Flow, Scale and Regulation”, October 2020

Environmental impacts of the accelerated fleet renewal

In LEZ impact assessments, the environmental impacts due to the accelerated renewal of the fleet are not considered either. Yet, if the ban implies that vehicles are more rapidly landfilled, or if that the fleet size increases (in comparison with a BAU scenario), impacts linked to the production of vehicles will likely increase. It is also likely that the increase in the size of the global fleet will increase the traffic globally, this adding environmental impacts linked to the use of this increased fleet.

Rebound effects specific to EVs

Adopting a systemic approach is also important for rebound effects[27] to be taken into account, because those could partially offset air pollution and climate benefits. The differences in purchase prices between EVs and ICE can result in different purchase behaviors and in increased or decreased vehicle ownership (*vehicle ownership rebound effects*). Also, the lower operational costs of EVs and their lower environmental impacts during the use could lead to increased vehicle use, while the limited capacity or range of EVs could restrain vehicle use (*vehicle use rebound effects*). It seems thus important to consider the overall impacts of a policy in a systemic manner, beyond the impacts of individual technologies, including changes in overall demand.

Several studies observe rebound effects linked to the adoption of electric vehicles (cf. Table 11), incl.:

- Where the TCO is very low (Norway), (Bauer, 2018) observes increased vehicle ownership and use;
- Langbroek et al. highlight the risk of increased vehicle use, because of EVs' positive image and use marginal costs (Langbroek et al., 2017). This change in travel patterns depends on the availability of travel substitute (public transport) (Langbroek et al., 2018) (Sweden)

Table 11: Results of studies looking at rebound effects of EVs/policies supporting EVs

Author date	**Objective, material and method**	**Results**	**Policy recommendations**
(Bauer, 2018)	Analysis of market uptake of BEVs in Norway and the impacts on household vehicle ownership and on vehicle miles travelled with a survey among new car owners	BEVs lead to an increase in household vehicle ownership of 15–20% because of the subsidies that make their cost of ownership low. BEV purchases lead to a moderate increase in vehicle miles traveled, and more if the BEV does not replace another vehicle in the household.	Focusing incentives for BEVs on those bought as replacements for a conventional vehicle
(Langbroek et al., 2017)	Comparison of travel patterns of both EVs users and ICEs users in Greater Stockholm (Sweden) with regard to the number of trips made and the modal share of the car in the total travel distance	EV is generally perceived by respondents to be more environmentally friendly than public transport mode EV users make significantly more trips than their non-EV using counterparts EV users choose the car for a significantly larger percentage of their total travel distance than conventional vehicle users => This would suggest a rebound effect, driven by the image of the EV, and the marginal costs of car use that are so low	Avoiding policy measures making EV trips more attractive than trips by alternative transport modes Upfront subsidy in combination with a tax based on kilometres driven, to counteract the low marginal cost of EV-use and the high investment cost

[27] Defined as 'a behavioural or other systemic response to a measure taken to reduce environmental impacts that offsets the effect of the measure. As a result of this secondary effect, the environmental benefits of eco-efficiency measures are lower than anticipated (rebound) or even negative (backfire)' (Hertwich, 2005, p. 85).

(Langbroek et al., 2018)	Investigation of changes of travel patterns with EVs as a result of range limitations or the opposite, abundant range. Stated adaptation experiment with a one day travel diary among active drivers in Greater Stockholm (Sweden)	While EV-use seems to limit people's mobility in some cases because of limited range, some other people made additional trips or started using their electric vehicle instead of alternative transport modes. => The effects on personal mobility seem to depend on the availability of accessible substitutes. Besides that, a rebound effect is observed: EV-adoption can result in more car travelling.	Per kilometre taxation of EV use, improvement of public transports
(Font Vivanco et al., 2014)	Modelling of microeconomic environmental RE stemming from cost differences of EVs in terms of changes in multiple life cycle environmental indicators. Framework based on marginal consumption analysis and hybrid LCA.	Positive rebound effect for PHEV (due to a small decrease in the cost of PHEV, including capital cost and use cost), and a negative rebound effect for BEVs and HFC vehicles (given their higher capital costs). The ERE is found to have an overall appreciable impact on product-level LCA estimates, much more influential than the technology improvement itself.	Consideration of markets and prices as an active element of policy rather than a mere immutable background
(Font Vivanco et al., 2016)	Analysis of implications of methodological choices to quantify microeconomic environmental RE in terms of CO2 emissions due to cost differences of battery electric and hydrogen average cars in Europe, in the short and long term.	The results describe moderate negative rebound effects for BEVs in the short term (−8%). The rebound effect is mostly driven by the indirect effect (76%). In the long-run scenarios (calculated by simulating the total cost of ownership), positive RE are found, as soon as EVs TCO are on a par with ICE TCO (from 2020). If subsidies to EVs are increased (to 6,000 € per electric car), notable rebound effect are found (from 26 to 59%).	Na
(Font Vivanco et al., 2021)	Quantification of economy-wide RE[28] induced by the subsidy policy to electric cars in the UK for four impacts (climate change, acidification, photochemical ozone formation, and particulate matter)	Notable economy-wide RE associated with this subsidy: over or close to 100% (no benefits) for impacts on acidification and particulate matter, and a lower, yet notable, magnitude for climate change (~20–50%) and photochemical ozone formation (~30–80%) impacts. The two components of the economy-wide rebound both contribute importantly across impacts and modelling configurations: micro-economic RE ranging from 24% (PM) to 30% (CC) and economy-wide RE ranging from 52% (CC) to 99% (A).	Policy failure: over-dimensioned subsidy, which is a too high economic incentive to purchasers. Market failure: the subsidy would be much more effective if accompanied by a broader fiscal policy that internalize negative externalities in the price of air-polluting products and activities such as fossil fuels and private transport

[28] Economy-wide rebound includes "micro-economic or partial equilibrium and macro-economic or general equilibrium rebound […]. The first type relates to situations where increases in effective income/profits from consumers/producers are re-invested leaving prices constant [8,9], whereas the second type accounts for changes in output and factor prices which lead to further changes in market composition and economic growth [10]. […] An example of macro-economic rebound is the widespread fuel efficiency improvements in transport driving down oil prices and triggering further demand for energy services worldwide" (Font Vivanco et al., 2021, p. 2).

Font Vivanco and colleagues sought to quantify environmental RE of electric vehicles or of policy support to electric vehicles in three different papers. Two of them calculate microeconomic RE (prices remaining constant) and find negative RE for BEVs in the short term, but with significant amplitude. A first study finds strong negative RE (global warming potential and greenhouse gases indicators, −681 % and −282 % respectively) (Font Vivanco et al., 2014) and the second study finds RE averaging -8% (Font Vivanco et al., 2016). This difference can be explained by the type of cars studied and the related change in the TCO (when compared to conventional cars): the first studies luxury cars with changes in TCO of 70% and the second studies average cars with change in TCO of 9%. In the second study, RE in long-run scenarios (2050) are also calculated, following the evolution of the TCO. This study finds positive RE in coming years, ranging from 5 to 12% (depending on methodological choices, in 2050) in a first scenario where existing subsidies to EVs prevail and ranging from 26 to 59% in a second scenario in which higher subsidies are provided.

A third study calculates economy-wide RE induced by the subsidy policy to electric cars in the UK since 2011 for four impacts. In this calculation, macroeconomic effects from price changes are taken into account (i.e. how the shift from petrol to electricity triggers additional demand for cheaper petrol), in addition to microeconomic effects (Font Vivanco et al., 2021). The study finds notable economy-wide rebound effects associated with this subsidy “that partly or completely offset environmental benefits for all studied impact categories” (Ibid, 1).

Local environmental impacts and global impacts

Those impacts are not taken into account because those assessments do not take a systemic approach and are not life-cycle based: only impacts of the use of vehicles are taken into account, leaving aside impacts relating to production and other life cycle phases.

Also, only local impacts are considered, leaving aside impacts taking place outside of Brussels. For example, in the ICE phasing-out study assessing environmental impacts of various technologies (ICE, EVs, etc.), though a life-cycle based approach is taken, only impact categories that are relevant in an urban context are considered (climate change, PM and SMOG and human toxicity), leaving aside other LCA impact categories (e.g. acidification, water eutrophication, biodiversity, land use, radiation).

4.3.2 Social and socioeconomic impacts

Lack of consideration of socioeconomic impacts in general

As highlighted in the ADEME review, “in general, taking social issues into account is the last part of the themes addressed by studies and ex-ante evaluation of LEZs.[…]. No ex-post evaluation of LEZ social impacts has been conducted to date, in particular for the most vulnerable groups (Air et al., 2019, p. 93).

Beyond cost aspects

Generally, economic aspects relating to costs only are taken into account. This means that positive (economic) impacts of LEZs are also overlooked. Yet, while most companies will have to face costs, the car industry is likely to see the demand for new vehicles and sales growing (in comparison with a BAU scenario), given that the fleet size in LEZs would not be affected (reduced) by the policy and that the fleet renewal would be accelerated. This beneficial side effect could impact value creation and jobs in the whole automotive sector (including manufacture and services), which is traditionally an important job provider in Europe[29]. Even if jobs in the automotive industry is declining in Western Europe, it could affect job creation in other geographical areas, including Eastern Europe.

[29] Vehicle manufacturing represents 8.5% of EU employment in manufacturing, and the automotive sector (inc. manufacturing, services and construction) 6.7% of EU total employment in 2018 (3% in Belgium) (ACEA, 2021).

In brief, assessed impacts of LEZs are limited to local environmental impacts and socioeconomic losses and some elements complicate the interpretation of results of those assessments (lack of comparison with a BAU scenario, problem with air quality measurement in Brussels). Against this background, we can draw from those assessments the following conclusions.

The impacts of the LEZ in terms of air quality improvements seem limited in the first years (2018-19) (most improvements would have occurred without the LEZ), with the LEZ showing significant effects from 2025 for all assessed pollutants. While the policy seems already effective to reduce BCs emissions in the first years, and other PMs in a lesser extent, the contribution of the LEZ to the reduction in NOx emissions and concentrations by 2020 is very low. Those mixed results can be linked to the LEZ criteria (the age of vehicles and their Euro standards), and the LEZ agenda, which leaves the bulk of diesel vehicles circulate in Brussels for several years: Euro 5-6 vehicles represent the majority of the diesel fleet[30] and will start be removing from 2025 only.

Looking at the effectiveness of the LEZ seems important since the LEZ is not harmless. It is not harmless especially for low-income households who would be hit the hardest by the policy (while benefiting the most from air quality improvements): if they do have a car, chances are high that it is an old car, contrary to other households. Some of those households will not be able to benefit from the accompanying measures since those are provided only for those households living in Brussels and willing, or able, to use alternative transport modes. Detrimental socioeconomic impacts are thus unequally distributed, this questioning the social justice dimension of the LEZ. Also, the LEZ would also hit specific sectors, such as suppliers and carriers and retailers, catering establishments and market vendors, especially SMEs, but those are eligible to receive an allowance to replace their vehicle with a compliant vehicle.

Beyond those impacts assessed or considered by existing assessments, it is likely that the LEZ will displace air pollution problems to other geographical areas. While no significant effects on direct GHG emissions are expected, this specific aspect should be investigated further. Finally, the LEZ would create additional demand for new cars, for the benefit of the car industry and the automotive sector more generally (including manufacture and services), but generating also additional environmental impacts due to this increased production.

[30] In 2019, more than 65 % of the fleet (diesel and petrol) were Euro 5 and 6 vehicles.

5. Conclusions at this stage

5.1 About the Brussels LEZ

Our first two main questions to be addressed in this report were about the effectiveness, ambition and other side-effects of the LEZ: *Are the LEZ and the foreseen ICE phasing-out ambitious exnovation policies able to address regional objectives in terms of air quality, reduction of GHG emissions, but also in terms of mobility? Which side effects do those measures likely generate? Who is affected and to which extent?*

5.1.1 A necessary exnovation policy?

The LEZ and ICE phasing-out target two main objectives, i.e. reducing persisting air pollution and growing direct GHG emissions from the transport sector, and a secondary objective which is to reduce the number of circulating cars (that can be seen as a wished side-effect of those policies).

Air pollution is a particular acute issue for the region: Belgium has been subject to letter of formal notice from the EC, pointing out Brussels and Antwerp particularly for their high NOx concentrations. Direct GHG emissions from transport are also a difficult issue for the region (as other European regions), given ongoing still increasing or stagnating direct GHG emissions (depending on levels) that are not compliant with ambitious climate targets.

In order to tackle those two issues, there are EU regulations and dedicated tools targeting directly the introduction of new vehicles and their emissions (including the EU regulation on CO2 emissions of new vehicles and Euro standards regulating air pollutants of new vehicles). Those policies and instruments however contain failures and flexibilities that have lowered their effectiveness. One could interpret the emergence of LEZs targeting the use of vehicles at a local scale as a reply to those failures. The LEZ is precisely based on one of those tools (Euro Standards), whose application failed in the recent years and whose design is criticized, this posing further problems (cf. below). However, now that the damage is done, this exnovation measure implemented at local level and targeting the use of vehicles, seems a necessary band-aid for very dense and polluted urban areas like Brussels. The LEZ design and agenda could be however improved.

5.1.2 A coherent and ambitious exnovation policy?

The LEZ is a policy phasing-out vehicles on the basis of the type of motors, focusing on diesel, petrol and natural gas vehicles, that are deemed to emit more air pollutants during their use phase than other types of motorization such as electric and hydrogen vehicles. In addition to this technology-based criterion, the policy is based on Euro standards that classify vehicles according to their supposed levels of air pollutant emissions: vehicles with lower Euro Standards (old vehicles) are phased-out earlier than vehicles with higher Euro Standards (recent vehicles).

Euro Standards should reflect the environmental performance of vehicles. However, these standards are incomplete since not all air pollutants of concern for the transport sector are included (e.g. ultrafine particles, non-exhaust PMs, ammoniac). Secondly, the LEZ works for PMs, but the technologies to reduce their amount (filters) result in the emission of even smaller and dangerous particles, this representing a displacement of impacts. Thirdly, there have been a massive fraud by the European car industry, as revealed by the Dieselgate, and real NOx emission levels of vehicles were much higher than what was allowed by the regulation and what car manufacturers declared for a number of years. Due to the failure of Euro standards, deriving LEZ access rights on those standards rather than on actual vehicle emissions seems problematic (Hooftman et al., 2018).

In addition, the agenda of the Brussels LEZ is a very incremental. The agenda, phasing-out 15 % of vehicles (Euro 0-3 diesel vehicles and 0-1 Euro petrol and natural gas vehicles) in the first two years of implementation (2018-2020), accelerates the natural renewal of the fleet. It follows existing and recent trends, i.e. the declining share of diesel vehicles for the benefit of petrol (mainly), hybrid and electric vehicles (to a very small extent). The access of most diesel vehicles (of Euro 5 and 6 standards) is not restricted before 2025 (respectively from 2025 and 2028). Comparatively, London Ultra-LEZ and Paris LEZ, which have been also designed in the Dieselgate aftermath, have much more ambitious agendas: Central London allows access to Euro-6 diesel vehicles only since 2019 (and from 2021 on a much broader area) and Paris will ban the use of all diesel vehicles in 2024.

5.1.3 An effective exnovation policy? What are the impacts?

Consequently, while air quality improves globally for a number of pollutants since several years (including black carbons, PMs and NOx), the Brussels LEZ would bring additional reductions in air pollutant emissions for black carbons and PMs in the first years of implementation, but not for NOx. According to the ex-ante assessment conducted by the Brussels administration, effects of the LEZ on NOx emissions will be visible from 2025 onward, when Euro5 diesel vehicles will be banned. It has to be noted that ultrafine particles are not part of assessments (as not regulated by Euro Standards).

Those results reflect the LEZ agenda: vehicles emitting a high level of PMs start being excluded from 2018 onward (those not equipped with particle filters, i.e. Euro 0-4 diesel vehicles), but this is not the case for vehicles contributing the most to emissions of nitrogen oxide. Also, the LEZ would not impact on the fleet size and on traffic, and the use of so-called “zero-emission vehicles” do not take off yet, banned vehicles being mostly replaced with recent petrol vehicles and hybrid vehicles.

It seems important to look at the effectiveness of the LEZ in terms of additional emission reduction since the LEZ is not harmless. Existing assessments show that socioeconomic impacts are distributed unequally, affecting certain sectors and SMEs particularly, and low-income households being hit the hardest.

In conclusion, while LEZs are considered as one of the most effective tools to fight against air pollution (as exnovation policies in the field of mobility such as urban tolls and parking policies) (Hoen et al., 2021), the ambition of that of Brussels and its effectiveness to achieve the desired objectives quickly can be questioned. This conclusion is based on assessments of local air pollution impacts and socioeconomic impacts that have been conducted, that are limited in their scope, leaving apart changes in overall production and consumption quantities and related environmental impacts (e.g. increased production due to the accelerated fleet renewal and related impacts for the automotive industry and for the environment, displacement of air pollution to other areas since not all cars are scrapped, but are exported, etc.).

5.2 About the future of the LEZ (and its assessment)

Our third main research question was about the possible futures for the LEZ, i.e. exnovation scenarios and their assessment: *What are the other parameters/dimensions of the regime on which exnovation policies could play? What are the other exnovation scenarios that can be foreseen to reach regional objectives? How to assess the sustainability impacts of those scenarios?*

5.2.1 Which exnovation scenarios for a low-emissions mobility in Brussels?

The region envisages now to phase-out ICEs, leaving access to zero-emissions vehicles only. This exnovation policy could bring the expected results in terms of local air pollutant and direct greenhouse gas emissions. However, it raises a number of other environmental issues (displacements of impacts to other issues and geographical areas, demand in raw materials and energy) and it seems that exnovation policies could play on additional dimensions of the automotive regime to tackle mobility issues as well and to mitigate side effects.

The predominance of diesel vehicles in the Belgian fleet is certainly a main source of air quality problems that has to be addressed. However, in light of scientific evidence currently available, the issue of what should be the replacing alternative does not seem to be solved. On some aspects, there does not seem to be a scientific consensus yet about impacts of various technologies. Related knowledge is constantly evolving, and so do practices of manufacturers. On some other aspects where some displacements of impacts occur to other geographical areas, there seems to be a lack of deliberation about what should be preserved at the expense of what (e.g. air quality or European urban areas versus freshwater quality in mining areas or air quality in production areas).

Our analysis of key trends and issues in the transport sector suggests that the exnovation strategy should play on alternative and complementary parameters, such as the growing number of driven kilometers (as targeted by Smartmove that the region intends to implement), the growing fleet size (both at national level, with implications for Brussels), the surge in the selling of hybrid vehicles and of energy-consuming vehicles such as Sport Utility vehicles (cf. D.3.4).

5.2.2 How to assess exnovation scenario for a low-emission mobility in Brussels?

In order to understand the relevance of each of the scenarios, there is a need to assess their potential sustainability impacts, including regarding regional objectives (local air pollution, direct climate impacts, mobility) and other potential side effects (other environmental impacts, happening elsewhere, social and socioeconomic impacts, etc.). The assessment of sustainability impacts of exnovation scenarios, including in the transport sector, is yet an open research field.

When considering exnovation policies such as the LEZ or the ICE phasing-out, there is a lack of consideration of systemic impacts of policies (cf. 3.4). Conducted impact assessments of those policies focus mainly on assessing the environmental impacts regarding the targeted issue that would occur in the geographical area at issue (e.g. local air quality for LEZs) and on assessing cost aspects and losses (costs for local public authorities, local companies, local households). Other sustainability aspects are neglected, including those which are actually on the radar of policies (e.g. climate impacts for LEZs) or which could be beneficial (e.g. impacts on economic activity and employment in the automotive industry and in other chain nodes, through the increase in demand for new vehicles). Indirect effects are also overlooked. For example, the fact that LEZs displace air pollution to African and Eastern European urban areas is not considered. Consequently, so-called aftercare measures are not elaborated and implemented to prevent those adverse impacts, whereas solutions exist and seem to have proven successful (e.g. retrofit obligations for diesel vehicles that are to be sold and exported to other areas, such as the setting up of particle filters, or devices to reduce NOx emissions).

Consequently, we propose to investigate systemic sustainability impacts (including local and happening elsewhere, direct and indirect effects, adverse and beneficial side-effects) of exnovation scenarios. We investigate those impacts through a workshop[31] involving stakeholders active in and on the mobility sector in Brussels and Belgium. The results of this workshop will be detailed and analyzed in the next deliverable (D3.4).

[31] Workshop GOSETE, '*Des scénarios de prospective pour une mobilité 'basses émissions' à Bruxelles: quels impacts sur la durabilité ?*', 2 mars 2021, Bruxelles.

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Acronyms

BAU: Business as usual

BC: Black carbon

BCR: Brussels Capital Region

BEV: Battery electric vehicle

CNG: Compressed natural gaz

CO2: Carbon dioxide

EVs: Electric vehicles

GHG: Greenhouse gazes

HFCV: Hydrogen fuel cell vehicles

ICE: Internal combustion engines

LCA: Life cycle assessment

LEZ: Low emission zone

NOx: Nitrogen oxide, NO2: Nitrogen dioxide

PHEV: Plug-in hybrid electric vehicle

PM: Particle matters

SUV: Sport utility vehicles

Annexes

Annex 1: Material for step 2 (Critical analysis of existing impact assessments)

Table 12 : Reviewed impact assessments of LEZs and ICE phasing-out (for Brussels and elsewhere)

Reference	Assessed impacts
Low emission zone	
Brussels	
Bruxelles Environnement. « Effets attendus de la Zone de Basses Emissions sur le parc automobile et la qualité de l'air en Région bruxelloise ». 01/2019. https://www.lez.brussels/mytax/fr/practical?tab=Impact	-Fleet composition -Air pollution : emissions (NO2, BC, PM) and concentrations
Bruxelles Environnement. « Evaluation de la zone de basses émissions, rapport 2018 ». 17/05/2019. https://environnement.brussels/news/decouvrez-le-premier-bilan-encourageant-de-la-zone-de-basses-emissions	-Fleet composition -Air pollution : emissions (NO2, BC, PM) and concentrations (NO2) -Climate change : C02
Bruxelles Environnement. « Evaluation de la zone de basses émissions, rapport 2019 ». 14/09/2020 https://environnement.brussels/news/bilan-2019-de-la-zone-de-basses-emissions-de-bonnes-nouvelles-pour-la-qualite-de-lair	-Fleet composition -Air pollution : emissions (NO2, BC, PM) and concentrations (NO2) -Climate change : C02
Bruxelles Environnement. Enquête mobilité sur la LEZ. Ongoing. https://environnement.brussels/news/impacte-par-la-lez-participez-notre-enquete-mobilite	-Impacts of LEZ on mobility behaviour.
Transport & Mobility Leuven. 2011. "Studie Betreffende de Relevantie van Het Invoeren van Lage-Emissiezones in Het Brussels Hoofdstedelijk Gewest En van Hun Milieu-, Socio-Economische En Mobiliteitsimpact." Brussel, Belgie: Brussels Instituut voor Milieubeheer.	-Mobility -Air pollution: emissions and concentrations -Socioeconomic impacts

https://document.environnement.brussels/opac_css/index.php?lvl=notice_display&id=6833	
Other cities/regions	
Vlammse department Omgeving. 2020. "Impact van de lage-emissiezones op het wagenpark, de luchtkwaliteit en sociaal kwetsbare groepen". https://www.omgeving.vlaanderen.be/evaluatie-lez	-Fleet composition -Emissions from traffic -Air quality (pollutant concentrations) -Health impacts -Impacts on vulnerable social groups (health, districts, car possession)
Greater London Authority. 2020. "Central London Ultra Low Emission Zone - Ten Month Report." London, UK: Greater London Authority. https://www.london.gov.uk/WHAT-WE-DO/environment/environment-publications/central-london-ulez-ten-month-report	-Air pollution
Bernard, Yoann, Joshua Miller, Sandra Wappelhorst, and Caleb Braun. 2020. "Impacts of the Paris Low-Emission Zone and Implications for Other Cities." TRUE publication. London, UK: FIA Foundation. https://theicct.org/publications/true-paris-low-emission-zone	-Air pollution (NOx)
ICE phasing-out	
Brussels	
Stratec/Mobi. "Etude d'impact Sur La Mobilité, Sur Les Aspects Économiques et Sociaux et Sur l'énergie et Roadmap Vers Une Sortie Des Véhicules Thermiques." Bruxelles, Belgique: Bruxelles Environnement. En cours de finalisation. Not publicly available yet.	-Fleet size and composition -Mobility (persons and goods) -Energy/technology impacts -Comparison of environmental impacts (climate change, PM and SMOG and human toxicity) of various technologies including diesel, petrol, biofuel, CNG, EVs, hybrid and hydrogen. -Comparison of the costs (total cost of ownership) of using electric vehicles and ICE, and impact on the second-hand market -Calculation of the financial impact per user-profile (individuals and companies by type and size) -Impacts on the attractiveness of the region
Bruxelles Environnement. Not available yet.	-Transport emissions/climate impacts of the Good move policy as a whole
VITO. Not available yet.	-Air pollution and health impacts
Leefmilieu Brussel, Vrije Universiteit Brussel - MOBI, The New Drive. Not available yet.	-Budget impacts of fleet electrification
Other cities/regions	
Ricardo-AEA. 2017. "Oxford Zero Emission Zone Feasibility and Implementation Study." Oxford, UK: Oxford City Council and Oxfordshire County Council. https://www.oxford.gov.uk/download/downloads/id/4019/zero_emission_zone_feasibility_study_october_2017.pdf	-Emissions and air quality -Costs: for replacing vehicles, infrastructure, implementation -Monetarization of benefits associated with emission savings -GHG impacts -Identification of wider impacts, not captured in the quantitative assessment.

Table 13: Comparison of impacts of recent implemented LEZ

City -Start date -Restrictions -Measurement of NO2 concentration	Paris[32] -2022 Euro 1-4 diesel + Euro 1-3 petrol -2024 Euro 1-6 diesel Euro 1-4 petrol	Antwerpen[33] -02/2017 Euro 1 petrol + Euro 3 diesel with particle filter -01/2020: Euro 2 petrol + Euro 5 diesel	London ULEZ[34] -04/2019 -Euro 1-5 diesel, Euro 1-3 petrol in Central London -10 sites in Central London	Brussels -01/2018[35] -Euro 1-3 Diesel and Euro1 petrol (2019) -9 sites
	Focus on the potential effects on passenger car fleet composition and average emissions per kilometer traveled[36]	Assessment from the measurement sites and comparison with other areas in Flanders with no LEZ + Modelling	Assessment of the impacts of the ULEZ by comparing the ULEZ and a BAU scenario (no ULEZ) -concentrations -emissions	Assessment of emissions from the circulating fleet and measurement of air quality from sites
No2			-37% in concentrations in comparison to no ULEZ scenario (reduction attributable to the ULEZ only)	-10% of concentrations in all stations [2018-19]
NOx	-2022 : 0 to 6 points difference between both scenarios; 2024: 20 to 30 points difference	-From the measurement sites: decrease in NOx in Flanders in the last years, but no additional effects thanks to the LEZ -From the model (2017-19): 5% less NOx thanks to the LEZ	-35% of emissions for 10-12/2018 in comparison to a no ULEZ scenario	-6.8% of emissions [06/2018-12/2019]
PM2.5			-15% of emissions for 10-12/2018 in comparison to a no ULEZ scenario	-11.7% of emissions [06/2018-12/2019]
BC		- From measurement sites: stronger decrease of BC in measurement stations of Antwerpen than in the rest of Flanders		-75 % of emissions [06/2018-12/2019]

[32] https://theicct.org/publications/true-paris-low-emission-zone
[33] https://omgeving.vlaanderen.be/lage-emissiezone-wat-waarom-en-effecten
[34] https://www.london.gov.uk/WHAT-WE-DO/environment/environment-publications/central-london-ulez-ten-month-report
[35] Fines from Fall 2018
[36] Not the potential changes in the total number of vehicles accessing the city due to the LEZ

		-From model (2017-19): 19% less BC		
C02			-6% of emissions for 10-12/2018 in comparison to a no ULEZ scenario	+1.1% of emissions [06/2018-12/2019]

Annex 2: Tables summing up assessments with the multicriteria framework

Table 14: Impacts of the Brussels LEZ based on existing data (06/2018-12/2019)

(i) Impact of LEZ on demand	**Dimensions/criteria**	**Impacts**	**Where relevant, distinction according to geographical area / stakeholder / sector / social class**
Mobility demand	Transport demand overall (whatever the transport mode)		
	Driven kilometers (with individual motorized engines)	Assumption that the LEZ has no impact on mobility behaviors, just on fleet composition	
	Fleet size and composition	-Stable fleet size (assumption)	-Composition: decrease in the share of diesel vehicles (-5 points in 1 year), in favor of gasoline vehicles mainly and other alternative engine to a lesser extent. The LEZ would have contributed only partly to this evolution (Wackenier et al. 2020).
(iii) Sustainability pillars	**Sustainability dimensions/criteria**	**Impacts**	**Where relevant, distinction according to geographical area / stakeholder / sector / social class**
Environmental and health impacts	Climate	-Increase in GHG following LEZ implementation but not assessed in other studies	-Possible increase in GHG impact due to increased sales of new vehicles
	Health impacts, incl. air pollution and human ecotoxicity	-Start of the LEZ: Strong decrease in BC (thanks to the LEZ), decrease in PMs and NOx, but with a priori low contribution of the LEZ for NOx -2025: the LEZ will likely reduce NOx emissions	-Air pollution displacement to areas where banned vehicles are exported, but not assessed
	Ecosystem impacts		
	Energy consumption	-Possible increase in fuel consumption with the increased use of gasoline (rather than diesel)	
Economic impacts	Economic activity and jobs (quantity)	-Increase in sales of new cars, with likely impacts on jobs in the automotive sector (industry and services) (Brussels)	-Impacts on jobs in the automotive industry (Belgium, Europe and rest of the world)

	Costs for changing the fleet[37]	684,22 million euros for changing the fleet (Euro0-4 diesel and Euro 0-1 petrol, Lorries: Euro0-4	
	Affordability of transport services for companies – impact of profitability		Costs especially for - the suppliers and carriers - retailers, catering establishments and market vendors
	Impact on government budget	-Implementation and management costs -Tax and fines revenues (not estimated)	
	Revenues		
	Attractiveness of the region	Relocation of part of the economy (trading activities, offices,…) from within the low-emission zone to outside the zone, but no evidence of that from existing LEZs (Transport & Mobility Leuven, 2011)	
Social impacts	Costs for changing the fleet	621 million euros for changing the car fleet (Euro0-4 diesel and Euro 0-1 petrol)	The LEZ impacts mainly low income groups that own (generally old) cars and that have to replace it
	Accessibility and affordability of transport services for households,	-Impact on vulnerable households that cannot replace their cars	-Increased impacts for low-wage commuters (Brussels non-resident) who do not benefit from accompanying measures
	Cost of goods in Brussels	No increase in the prices of goods are foreseen	
	Well-being and health (Road safety, Travel time and congestion, Noise, Access to public space, Active travel benefits)	-Health benefits from increased air quality monetarized: PM2.5 from exhaust (more than 3.232.178 million euro/year), followed by PM2.5 from non-exhaust (183.163 million euro/year) and NOx (122.156 million euro/year).	-Vulnerable households benefit the most to the air quality improvement since they are the population the most at risks
	Job quality / employment and working conditions		

Table 15: Assessed impacts of the ICE phasing-out in Brussels

(i) Impact of LEZ on demand	Dimensions/criteria	Impacts	Where relevant, distinction according to geographical area / stakeholder / sector / social class
Mobility demand	Transport demand overall (whatever the transport mode)		
	Fleet size and composition	Estimation of the number of vehicles that would not be renewed with the ICE phasing-out on the basis of a survey of car drivers and	Consideration of impacts according to income-levels

[37] This includes the loss of asset value of non-compliant vehicles and the cost of buying a new vehicle

		of the modal shift implied by the measure, for residents and non-residents of Brussels.	
	Driven kilometers (with individual motorized engines)	Calculation of the variation of the number of vehicle kilometers in Brussels for persons and goods following the ICE phasing-out	
(iii) Sustainability pillars	**Sustainability dimensions/criteria**		
Environmental and health impacts	Climate	Calculation of the evolution of direct GHG emissions as a result from the implementation of the Good move policy as a whole (the ICE phasing-out being one of the programme component)	
	Health impacts, incl. air pollution and human ecotoxicity	Calculation of air pollution decrease from the ICE phasing out in comparison with BAU, including NO2 and PM2,5 exposure. Related health benefits are also calculated, including saved lives per year, decrease in NO2 related diseases and savings in related expenses.	
	Environmental and energy impacts	Comparison of the environmental impacts of various technologies including diesel, petrol, biofuel, CNG, EVs, hybrid and hydrogen. Environmental impacts include climate change, PM and SMOG and human toxicity.	
	Energy consumption	Identification of solutions to reduce (carbon-intensive) energy consumption	
Economic impacts	Economic activity and jobs (quantity)		
	Affordability of transport services for companies – impact of profitability		
	Impact on government budget	Calculation of the budget impact for replacing the public fleet.	
	Revenues		
	Attractiveness of the region	On the basis of the TCO and on the evolution of pollutant emissions and noise	
	Costs for changing the fleet[38]	Calculation of the Total cost of ownership for electric vehicles and an ICE and impact on the second-hand market	Calculation of the financial impact per user-profile (individuals and companies by type and size)
Social impacts	Costs for changing the fleet		
	Accessibility and affordability of transport services for households,		

[38] This includes the loss of asset value of non-compliant vehicles and the cost of buying a new vehicle

	Cost of goods in Brussels		
	Well-being and health (Road safety, Travel time and congestion, Noise, Access to public space, Active travel benefits)		
	Job quality / employment and working conditions		

Annex 3: Data availability and gaps

Table 16: Data availability and gaps to assess our alternative scenarios

Engine/enegy type-based scenario (1)		TD	ENVI	ECO	SOC
Brussels/Belgian studies					
Stratec/Mobi. "Etude d'impact Sur La Mobilité, Sur Les Aspects Économiques et Sociaux et Sur l'énergie et Roadmap Vers Une Sortie Des Véhicules Thermiques." Bruxelles, Belgique: Bruxelles Environnement. En cours de finalisation.	-Mobility (persons and goods) -Energy/technology/ environment -Socioeconomic impacts for households (costs, affordability) and companies (costs, attractiveness of the region)		X	X	X
Bruxelles Environnement. On the ICE phasing out in Brussels.	-Transport emissions		X		
VITO. On the ICE phasing out in Brussels.	-Health impacts		X		
Leefmilieu Brussel, Vrije Universiteit Brussel - MOBI, The New Drive. On the ICE phasing out in Brussels.	-Budget impacts of fleet electrification			X	
TML/KUL. 2011. Studie betreffende de relevantie van het invoeren van lage- emissiezones in het brussels hoofdstedelijk gewest en van hun milieu-, socio-economische en mobiliteitsimpact. https://document.environnement.brussels/opac_css/index.php?lvl=notice_display&id=6833	-Mobility -Air pollution: emissions and concentrations -Costs for changing the fleet -Effects on prices of goods in BCR -Health impacts -Effects on costs for different groups of income	X	X	X	X
Other studies					
Cambridge Econometrics. 2020. "The Impact of a 2030 ICE Phase-out in the UK." London, UK: Greenpeace. https://www.greenpeace.org.uk/resources/the-impact-of-a-2030-ice-phase-out-in-the-uk/	-Fleet composition -Energy consumption -Charging infrastructure -Net government revenues -GDP and employment (sectoral impacts and government revenues)	X	X	X	X
Ricardo AEA. 2017. Oxford Zero Emission Zone Feasibility and Implementation Study. Oxford City Council and Oxfordshire County Council	-Emissions and air quality -Cost assessment (vehicles, infrastructures, implementation)		X	X	

https://www.oxford.gov.uk/downloads/file/4019/zero_emission_zone_feasibility_study_october_2017	-Benefits associated with emissions savings -GHG impacts -Wider impacts (environmental, social and economic impacts not quantified)				
Cambridge Econometrics and Element Energy. 2018. "Low-Carbon Cars in Europe: A Socio-Economic Assessment." Brussels, Belgium: European Climate Foundation. https://www.camecon.com/what/our-work/fuelling-europes-future	Economic impacts: GDP impacts, Sectoral impacts Government revenues, Oil imports, Employment Environment: CO2 emissions, Implied emissions from electricity, air pollution (emissions of particulate matter and nitrogen oxides)		X	X	X
T&E. 2017. "How Will Electric Vehicle Transition Impact EU Jobs?" Brussels, Belgium: Transport & Environment. https://www.transportenvironment.org/publications/how-will-electric-vehicle-transition-impact-eu-jobs	Review of studies on jobs impacts of fleet electrification				X
Lefeuvre A.G. and Ş. Guga. 2019. "Troubled Waters Ahead: What's next for the European Automobile Industry and Jobs?" In Towards a Just Transition: Coal, Cars and the World of Work, Béla Galgóczi, 38. Brussels, Belgium: ETUI (European Trade Union Institute). https://www.etui.org/publications/books/towards-a-just-transition-coal-cars-and-the-world-of-work	Analysis of the of the electrification challenges for EU jobs in the automotive industry				X
Onat, N.C. et al. 2014. "Towards Life Cycle Sustainability Assessment of Alternative Passenger Vehicles." Sustainability (Switzerland) 6 (12): 9305–42. https://doi.org/10.3390/su6129305	Impacts environnementaux, économiques et sociaux de différentes technologies pour les voitures de tourisme (à essence conventionnelle, hybride, hybride plug-in hybrid) and véhicule à batterie.		X	X	X
Giordano, A. et al. 2018. "Environmental and Economic Comparison of Diesel and Battery Electric Delivery Vans to Inform City Logistics Fleet Replacement Strategies." Transportation Research Part D: Transport and Environment 64: 216–29. https://doi.org/10.1016/j.trd.2017.10.003	Environmental, social and economic impact of BEV and diesel delivery vans.		X	X	
Harris, A. et al. 2018. "Assessing Life Cycle Impacts and the Risk and Uncertainty of Alternative Bus Technologies." Renewable and Sustainable Energy Reviews 97: 569–79. https://doi.org/10.1016/j.rser.2018.08.045	Assessment of costs and GHG emissions for the manufacture, use, maintenance and infrastructure phases of diesel and battery electric buses.		X	X	
Energy-demand scenario (2)					

Kim, H.C., and T.J. Wallington. 2013. "Life-Cycle Energy and Greenhouse Gas Emission Benefits of Lightweighting in Automobiles: Review and Harmonization." Environmental Science and Technology 47 (12): 6089–97. https://doi.org/10.1021/es3042115	Review of 43 studies on the environmental impacts of vehicle lightening.		X		
Mello Bandeira et al. 2019. "Electric Vehicles in the Last Mile of Urban Freight Transportation: A Sustainability Assessment of Postal Deliveries in Rio de Janeiro-Brazil." Transportation Research Part D: Transport and Environment 67: 491–502. https://doi.org/10.1016/j.trd.2018.12.017	Evaluation of the use of electric vehicles of smaller dimensions, tricycle and LDV, in the last mile of parcel deliveries, assessing two alternative scenarios: one with the use of electric LDV type BEV; and the other with electric tricycles.		X	X	
ITF and OECD. 2017. "Lightening Up: How Less Heavy Vehicles Can Help Cut CO2 Emissions." Text. Paris, France: International Transport Forum. https://www.itf-oecd.org/less-heavy-vehicles-cut-co2-emissions	Modelling the impact of lightening vehicles on CO2 transport emissions		X		
Ownership-type scenario (3)					
Wiegmann, Mareile, Imre Keserü, and Cathy Macharis. 2020. "L'autopartage en région bruxelloise." Brussels Studies. La revue scientifique pour les recherches sur Bruxelles / Het wetenschappelijk tijdschrift voor onderzoek over Brussel / The Journal of Research on Brussels, August. https://doi.org/10.4000/brussels.4956	Impact of car sharing on car use and mobility	X			
Chapman, Donald A. et al. 2020. "Does Car-Sharing Reduce Car-Use? An Impact Evaluation of Car-Sharing in Flanders, Belgium." Sustainability 12 (19): 8155. https://doi.org/10.3390/su12198155	Impact of car sharing on car use	X			
T&E. 2017. "Does Sharing Cars Really Reduce Car Use? Brussels, Belgium: Transport & Environment. https://www.transportenvironment.org/publications/does-sharing-cars-really-reduce-car-use	Impact of car sharing on car use	X			
Van Zeebroeck, B. 2019. "Duurzaamheid van Innovatieve Economische Modellen met Focus Op Mobiliteit." Brussel, Belgie: Federale Raad voor Duurzame Ontwikkeling. https://www.frdo-cfdd.be/nl/publicaties/studie-duurzaamheid-van-innovatieve-economische-modellen-met-focus-op-mobiliteit	Assessment of sustainability impacts of car sharing and car pooling	X		X	
Rademaekers K. et al. 2018. "Environmental Potential of the Collaborative Economy." Brussels, Belgium: European Commission. http://op.europa.eu/en/publication-detail/-/publication/8e18cbf3-2283-11e8-ac73-01aa75ed71a1	Environmental impacts of collaborative economy in the transport sector		X		
Nurhadi, L. et al. 2017. "Competitiveness and Sustainability Effects of Cars and Their Business Models in Swedish Small Town Regions." Journal of Cleaner Production, Systematic Leadership towards Sustainability, 140 (January): 333–48. https://doi.org/10.1016/j.jclepro.2016.04.045	Evaluation des impacts CO2 and du coût total de possession pour différents business modèles (achat, covoiturage ou voiture partagée, leasing, taxi)		X	X	

	appliqué aux voitures privées pour différentes sources d'énergie (Agrocarburant, biogaz, éthanol, essence, hybride plug-in et électrique).				
Neef, M. et al. 2019. "Comparing Carbon Performances of Mobility Services and Private Vehicles from a Life Cycle Perspective." Sustainable Production, Life Cycle Engineering and Management, 47–60. https://doi.org/10.1007/978-3-030-12266-9_4	Review of studies on life cycle carbon emissions of mobility services and passenger vehicles.		X		
Transport mode scenario (4)					
Transport demand scenario (5)					
Various scenarios					
T&E. 2019. "Less (Cars) Is More: How to Go from New to Sustainable Mobility." Brussels, Belgium: Transport & Environment. https://www.transportenvironment.org/publications/less-cars-more-how-go-new-sustainable-mobility	Assess through modelling the possible outcomes of the autonomous (and connected), electric, shared (new mobility), and urban planning revolutions. On CO2 and transport demand	X	X		