4 Air quality and mobility

Chapter 4 examines the road transport sector in Luxembourg, and its relationship to local air pollution and emissions of fine particulates ($PM_{2.5}$), nitrogen oxides (NO_x) and carbon monoxide. It pays particular attention to the implications of tax policies on emissions from land transport by non-residents.

In addition to analysing emissions of $PM_{2.5}$ from transport, Chapter 4 examines the impact of emissions from the housing sector, as well as the costs to society of air pollution. It highlights findings of a special campaign of the Climate Pact to measure NO_2 concentrations through 100 stations established in 36 municipalities. Luxembourg's effort to update its strategy for sustainable mobility (Modu 2.0) is examined, as well as steps taken to promote car-pooling, public transport and active mobility, low-emission vehicle use, rail transport and teleworking.

Chapter 4 ends with a discussion of tax competition between sub-national authorities and fiscal threats from promotion of sustainable mobility abroad.

4.1. Introduction

Luxembourg's economic and population growth of the last decade have led to increasing need for mobility for professional and private purposes. This has translated into a constant increase of road traffic and saturation of the road network. Due to its geographical location, Luxembourg is a crossroads for goods traffic and a pole of attraction for employment in the Greater Region.[1] More than 44% of jobs are held by cross-border commuters, who live in neighbouring countries and commute daily. In addition, Luxembourg's energy tax system keeps road fuel prices below those of neighbouring countries and is a driver of significant fuel exports (Chapter 3). In the coming years, Luxembourg will continue to attract cross-border residents and workers, which risks further exacerbating problems of urban sprawl, congestion and air pollution, and the associated environmental and other social costs.

Luxembourg authorities have acknowledged these challenges and have taken steps to reduce air emissions and improve public transport. Significant investments have been made in the development of rail infrastructure, the creation of park-and-ride facilities and multimodal platforms, as well as in the purchase of low-emission buses. Despite this, the vast majority of personal trips are still made by car, 67% compared to only 17% by public transport. Car ownership is the highest in Europe (over 600 private cars per 1 000 inhabitants); the car fleet is relatively young, but with an average engine capacity higher than in many other countries.

4.2. The transport sector

The road transport sector in Luxembourg is in some respects special compared to most other countries. While the sector's share in value added in Luxembourg's economy (4.4% in 2015) is equal to that found in France and Germany, it is lower than in many other countries. The number of vehicle-kilometre driven per USD 1 000 of gross domestic product (GDP) was 10.0 km in 2015; this was lower than in any other OECD member country for which data are available. Part of the explanation is the large weight that, for example, the financial sector plays in the economy of Luxembourg. This sector does not rely much on road transport. Motor fuel sales per capita (2.7 tonnes in 2016) are several times higher than what is registered in any other OECD member country. Carbon dioxide (CO_2) emissions from the sector per capita are therefore also much higher than in the rest of the OECD. Most of the fuel (75%) is sold to non-resident drivers filling their tanks in Luxembourg, due to the country's historically low fuel-tax rates.

Fuel exports cause only a small part of local air pollution and congestion in Luxembourg. The large number of foreign citizens coming across the borders on a daily basis to work in Luxembourg contributes both to air pollution and to high levels of congestion. According to TomTom's Traffic Index, the City of Luxembourg is the tenth most congested European city with fewer than 800 000 inhabitants (TomTom, 2020).[2] Globally, the city is ranked at 64, across all sizes of cities affected. The congestion value in the City of Luxembourg is 33%; it represents the measured amount of extra travel time spent by drivers in the city across the whole year.

4.3. Emission of air pollutants

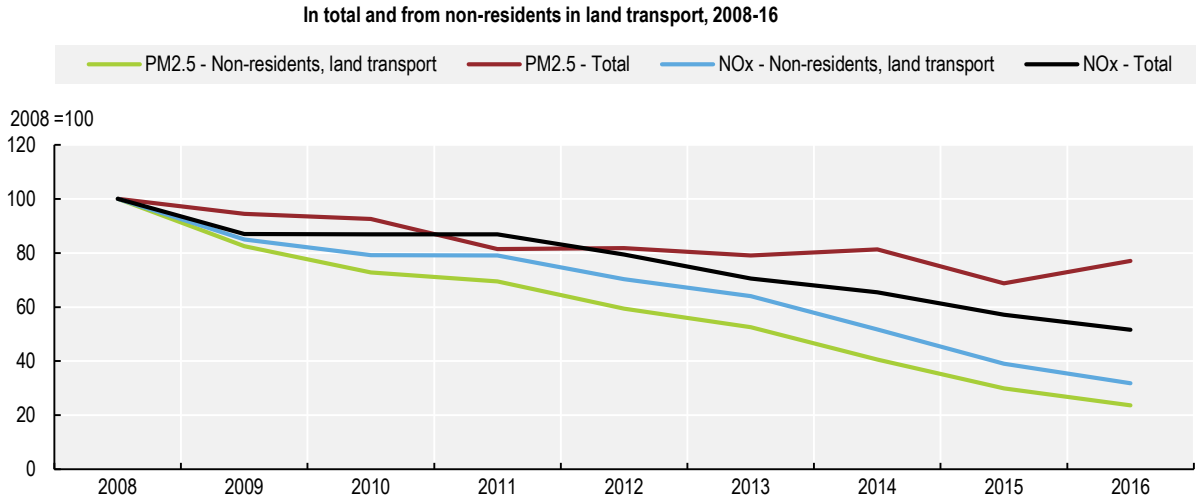
Total human-made emissions of local air pollutants have been decreasing in Luxembourg over the last decade (Figure 1.9; Chapter 1). Total emissions of fine particulates ($PM_{2.5}$) decreased by 45% over 2005-17; $PM_{2.5}$ emissions from road transport decreased by more than 70%. Total emissions of nitrogen oxides (NO_x) decreased by more than 65% over the same period; emissions of NO_x from road transport decreased by more than 75% (OECD, 2020).

Lower $PM_{2.5}$ and NO_x emissions are largely explained by reduced land transport emissions from non-residents. Reductions in land transport emissions of $PM_{2.5}$ and NO_x caused by non-residents were

significant over 2008-16; in both cases, they were much larger than reductions in total emissions (Figure 4.1).

Historically, emissions of $PM_{2.5}$ and NO_x from land transport by non-residents have constituted a much larger share of total emissions of these pollutants in Luxembourg than in any other OECD member country for which detailed emission accounts are available. This is still the case. However, the difference compared to other countries decreased significantly from 2008 to 2016 as a result of the emission reductions (Figure 4.2).

Figure 4.1. Non-residents' emissions of $PM_{2.5}$ and NO_x have decreased rapidly



Source: OECD (2019), "Air and climate: Air and greenhouse gas emissions by industry", *OECD Environment Statistics* (database).

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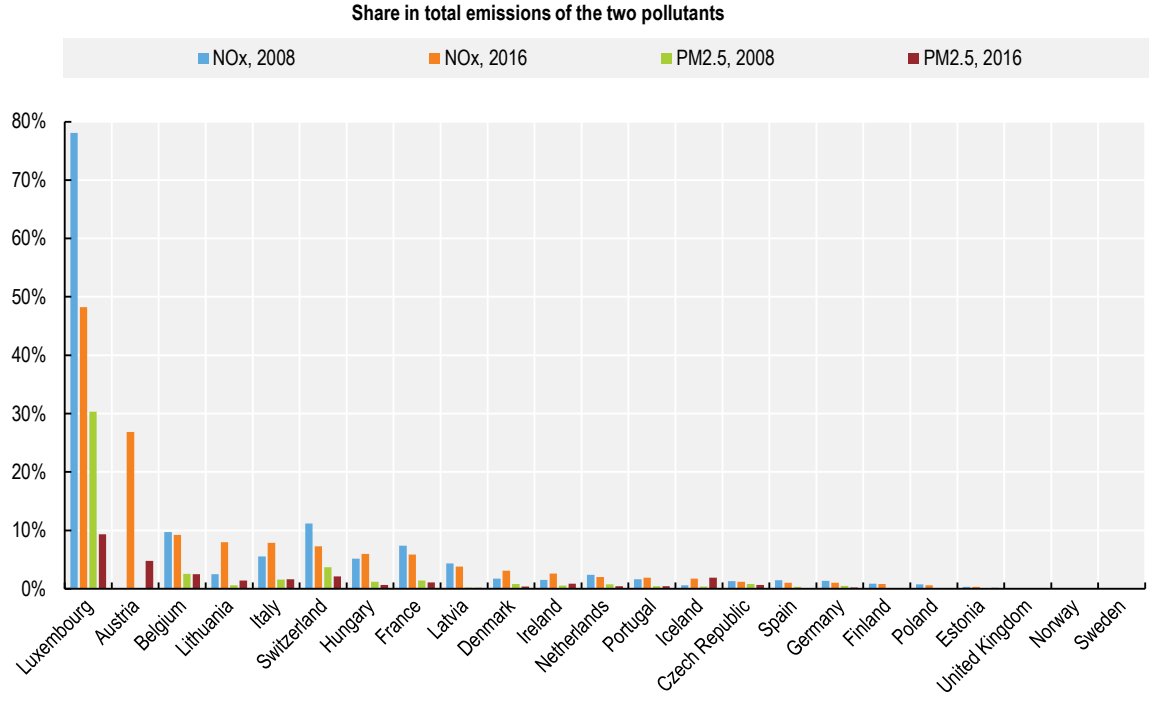
Figure 4.2. Non-residents' emissions of $PM_{2.5}$ and NO_x are high in Luxembourg



Source: OECD (2019), "Air and climate: Air and greenhouse gas emissions by industry", *OECD Environment Statistics* (database).

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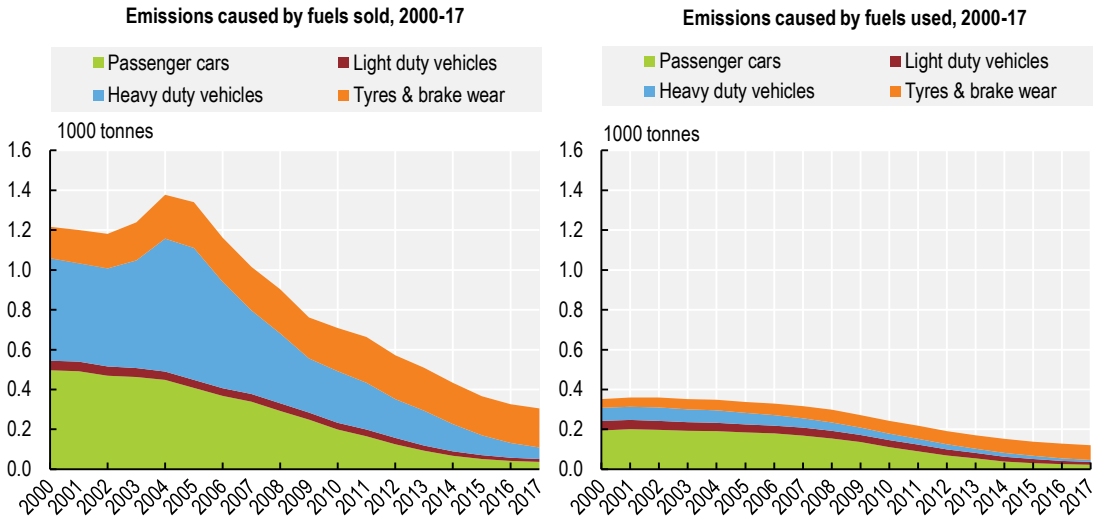
In spite of recent planned tax rate increases, Luxembourg's tax policy regarding motor vehicle fuels still causes fuel prices to be lower than in neighbouring countries. This has been attracting a large number of drivers who visit Luxembourg primarily to fill their tanks with cheaper fuel (Chapter 3). Drivers of passenger cars and, in particular, heavy goods vehicles registered in other countries cross the border to buy diesel. To a lesser extent, they buy petrol, as well as alcohol and tobacco, which are also taxed lower than in neighbouring countries. Most of this fuel will thus be used, and cause emissions, in other countries.

The transport sector also causes major emissions of $PM_{2.5}$ through tyre and brake wear. These sources have in fact caused much larger emissions than what fuel combustion did in recent years (AEV, 2018). This is true both for fuels bought and for fuels used in Luxembourg (Figure 4.3), when considering only emissions of primary particulates. The use of diesel vehicles also contributes importantly to the formation of secondary particulates, via the NO_x emissions they cause.

Figure 4.3. The share of $PM_{2.5}$ emissions caused by tyres and brake wear is increasing



Note: Fuel combustion by passenger cars and light and heavy duty vehicles, as well as by tyres and brake wear from all vehicle categories.
Source: Administration de l'Environnement (2019), Luxembourg's Informative Inventory Report 1990-2017.

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The share of road transport in total emissions of NO_x, PM_{10}, $PM_{2.5}$, carbon monoxide (CO) and volatile organic compounds (VOCs) decreased significantly between 2005 and 2017 (Figure 4.4). For sulphur dioxide (SO_2), there was a minor increase in road transport's share over this period, but from a low starting point.[3]

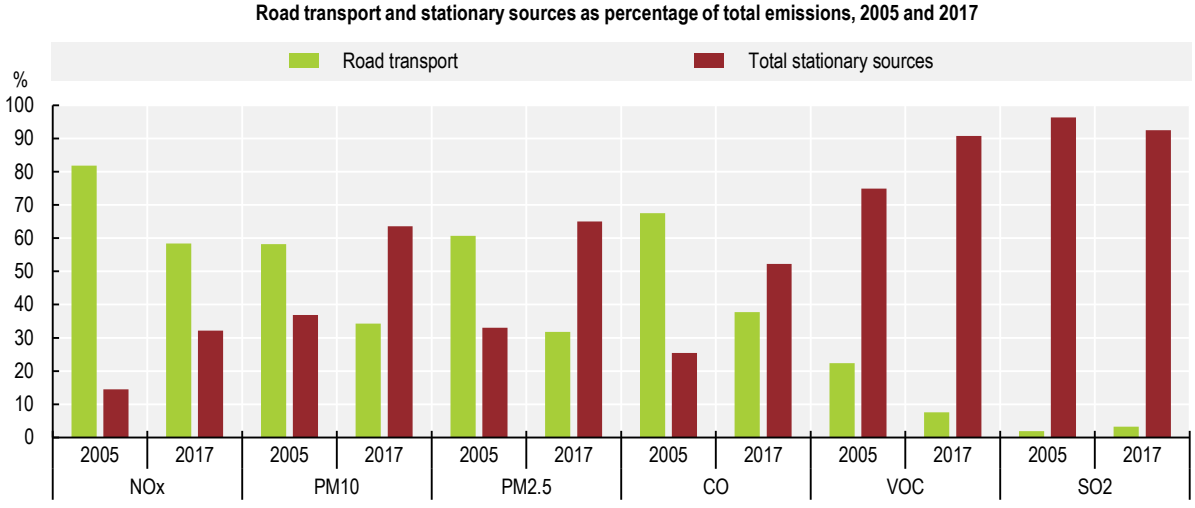
A closer look at emissions that affect air quality in Luxembourg shows that primary $PM_{2.5}$ emissions from the housing sector are significantly larger than *primary* $PM_{2.5}$ emissions from motor fuels *used* in Luxembourg, even if emissions from tyre and brake wear are considered (Figure 4.5).

The emissions in the housing sector stem, among others, from the use of wood biomass for heating. Wood biomass has been promoted as a renewable energy source with the aim to limit emissions of greenhouse gases. As a result, $PM_{2.5}$ emissions from the housing sector have gradually been increasing over the last decade.

The country has set emission limits as an eligibility criterion for public subsidies granted for investments in new wood burners. In addition, in April 2015, the European Commission adopted a regulation with regard to eco-design requirements for solid fuel local space heaters (EC, 2015). This regulation sets emission

limits regarding particulates, NO_x and carbon monoxide (CO), which will come into force from 2022. In spite of this new regulation, there are potential conflicts between climate change mitigation objectives and local air pollution objectives. One response is to focus use of wood biomass for heating on relatively large distance-heating plants. These plants should have a distribution system for district heating, preferably with co-generation of electricity. In such plants, it can be easier to install technologies to limit emissions of $PM_{2.5}$ and other local air pollutants at reasonable costs per unit of heat generated.

Figure 4.4. The share of road transport in emissions of most local air pollutants is decreasing



Note: Among mobile sources, the graph only takes into account primary emissions stemming from road transport. Therefore, the sum of the two bars generally does not add up to 100%.
Source: OECD (2019), "Air and climate: Air emissions by source", *OECD Environment Statistics* (database).

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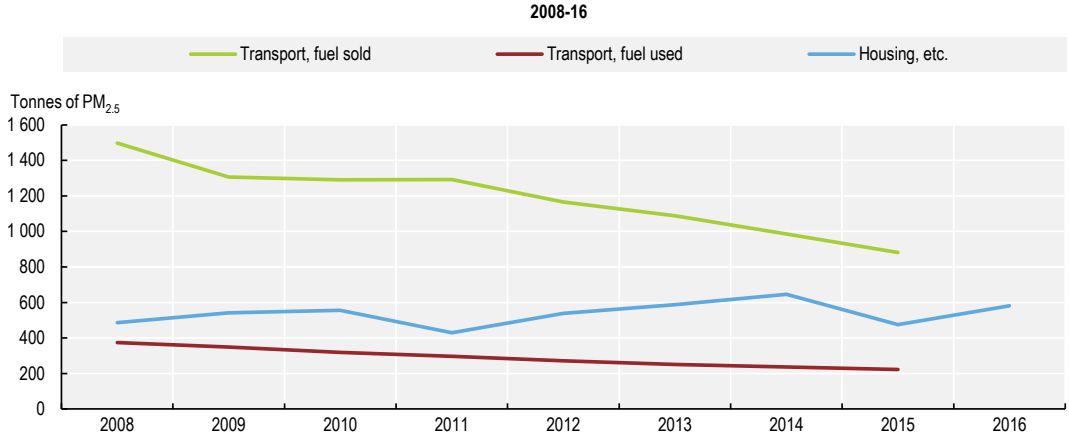
Figure 4.5. $PM_{2.5}$ emissions from the housing sector have increased



Note: Emissions stemming from tyre and brake wear are included in the transport sector numbers.
Source: Administration de l'Environnement (2018), "Luxembourg's Informative Inventory Report 1990-2016"; OECD (2019), "Air and climate: Air and greenhouse gas emissions by industry", *OECD Environment Statistics* (database).

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4.4. Ambient concentrations of air pollutants

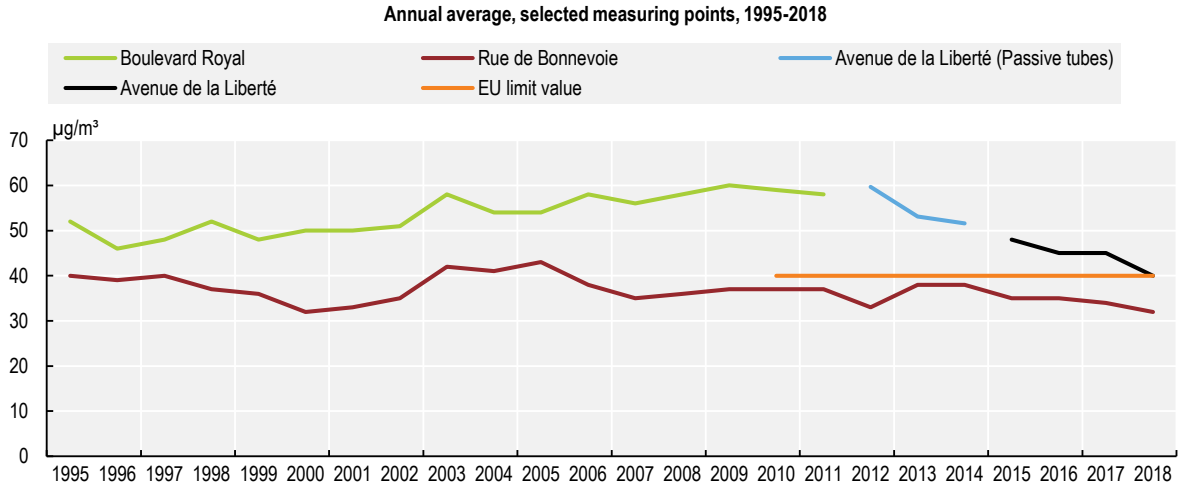
Air quality is monitored through an extensive network of measuring stations located in the City of Luxembourg and in Esch-sur-Alzette, close to the border with France, and in more rural areas of the country. Reductions in air pollution levels have been much smaller than emission reductions otherwise could have suggested. This is because emission reductions in the transport sector have been primarily linked to emissions caused by non-residents. It does not reduce air pollution levels in Luxembourg much if fewer foreign vehicles, mostly used abroad, fill up their fuel tanks in the country.

As part of the Climate Pact, a special campaign to measure NO_2 concentrations was implemented in 2018, with more than 100 measurement stations in 36 municipalities. Average annual concentrations of NO_2 at selected places in the City of Luxembourg have declined somewhat in recent years, but remain close to the EU limit value for these concentrations[4] (Figure 4.6). Buses used to be the main source of NO_2 emissions in the city. However, a recent reorganisation of bus lines and fewer buses at peak hours in the streets with the densest traffic have helped reduce these emissions. The measurement campaign in 2018 indicated that ambient NO_2 concentrations were well below the EU limit value in most parts of the country.[5]

Annual air concentrations of $PM_{2.5}$ have been decreasing. However, they remain above the World Health Organization (WHO) guideline value of 10 µg of $PM_{2.5}/m^3$ of air, both for the national average and at selected places. Thanks to the decreases, the national average is now approaching the guideline value. In remote areas, concentration levels are below the guideline value (Figure 4.7).

There is no known threshold value as regards health damages caused by $PM_{2.5}$ exposure. Shi et al. (2016) did, for example, find significant mortality impacts well below the WHO's guideline value. Even if the number of mortalities per 1 million inhabitants is well below the OECD and European averages, an estimated 150 persons died prematurely in 2017 from exposure to $PM_{2.5}$ in Luxembourg (OECD, 2020).

Figure 4.6. Ambient concentrations of NO_2 in the City of Luxembourg remain high



Source : MECDD (2019), "Historique des valeurs mesurées pour les oxydes d'azote (NOx)" (website).

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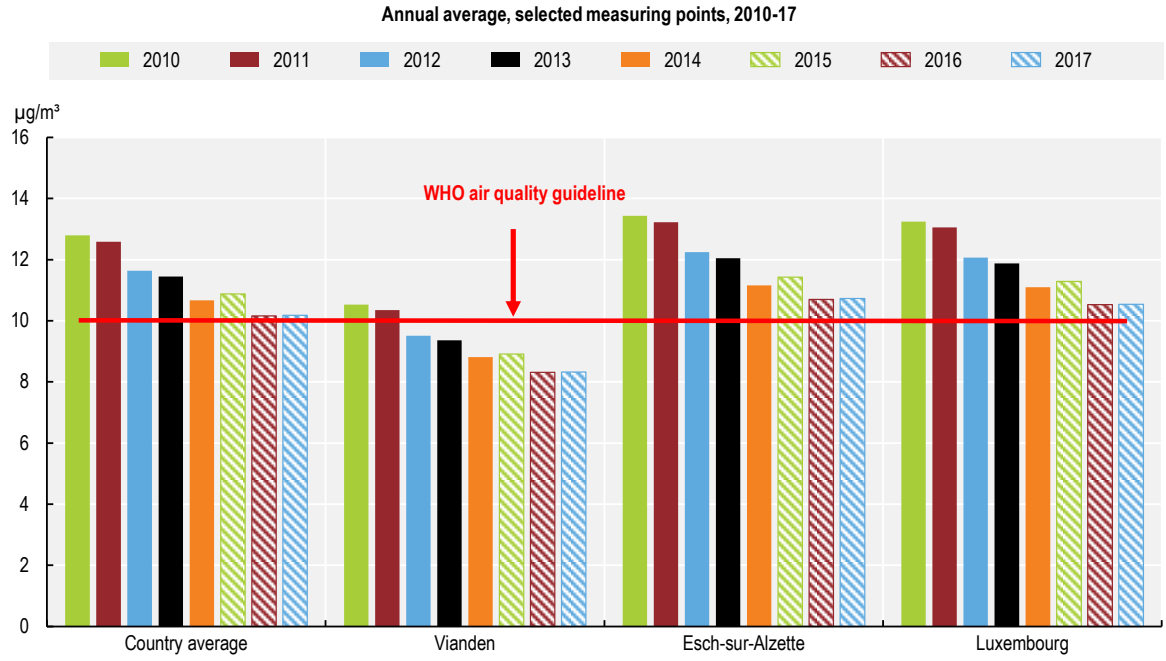
Figure 4.7. Ambient concentrations of $PM_{2.5}$ remain above the WHO guideline in several places



Note: The horizontal red line shows the WHO's air quality guideline regarding annual average $PM_{2.5}$ concentrations.
Source: OECD (2019), "Air quality and health: Exposure to $PM_{2.5}$ fine particles – metropolitan areas", *OECD Environment Statistics* (database).

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4.5. Costs to society of air pollution

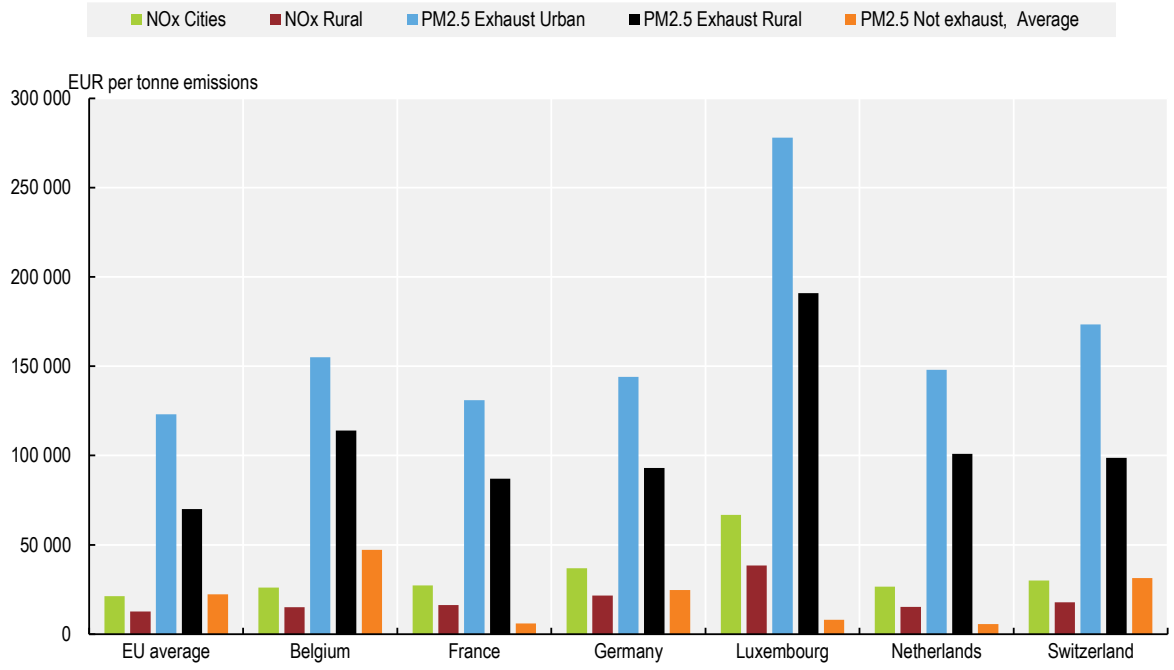
Air pollution imposes costs on society. Hunt et al. (2016) distinguish between three main categories of costs:[6] resource costs, opportunity costs and disutility costs. Resource costs include avertive expenditures, e.g. relocation to area of lower air pollution, staying inside, etc., and mitigating expenditures, e.g. the direct medical and non-medical costs associated with treatment for the health impact. Opportunity costs include costs related to loss of productivity or leisure time due to the health impact.[7]

The disutility costs, which includes pain, suffering, discomfort and anxiety linked to the illness and to any premature mortality, remain the largest of the cost components. OECD (2020) estimates that people in Luxembourg would have been willing to pay an amount equal to more than 2% of GDP to avoid the premature mortalities caused by $PM_{2.5}$ exposure, from all contributing sources. Also, according to OECD (2019b), 25 persons are estimated to have died prematurely in 2017 due to ozone (O_3) exposure. The same study estimates that people in the country would have been willing to pay an amount equal to around 0.35% of GDP to avoid these premature mortalities.

Recent estimates indicate that the external costs of transport in euros per tonne of pollutant emitted are high in Luxembourg (Figure 4.8; van Essen et al., 2019). These external costs include the social costs of air pollution, but also costs related to climate change, habitat damage, noise, accidents and congestion. With the exception of non-exhaust $PM_{2.5}$ emissions, the estimated costs per tonne of pollutant emitted is considerably higher in Luxembourg than in other EU countries. The high cost estimates for Luxembourg are partly explained by the high incomes per capita. These cause the estimated Value of a Statistical Life (VSL) to be much higher than in neighbouring countries. Naturally, for both NO_x and $PM_{2.5}$, the cost estimates are much higher in urban than in rural areas: a given tonne of pollutant emitted in a densely populated area affects more people. The estimated costs of air pollution per passenger-kilometre in cars,

buses and light-duty vehicles are also higher in Luxembourg than in other EU countries. The same is true for the costs per tonne-kilometre for heavy goods vehicles (Figure 4.9, van Essen et al., 2019).[8]

Figure 4.8. Estimated costs of air pollution are high



Note: 2016 money value. Emission costs in metropolitan areas are excluded as there are no such areas in Luxembourg.
Source: van Essen et al. (2019), "Handbook on the external costs of transport".

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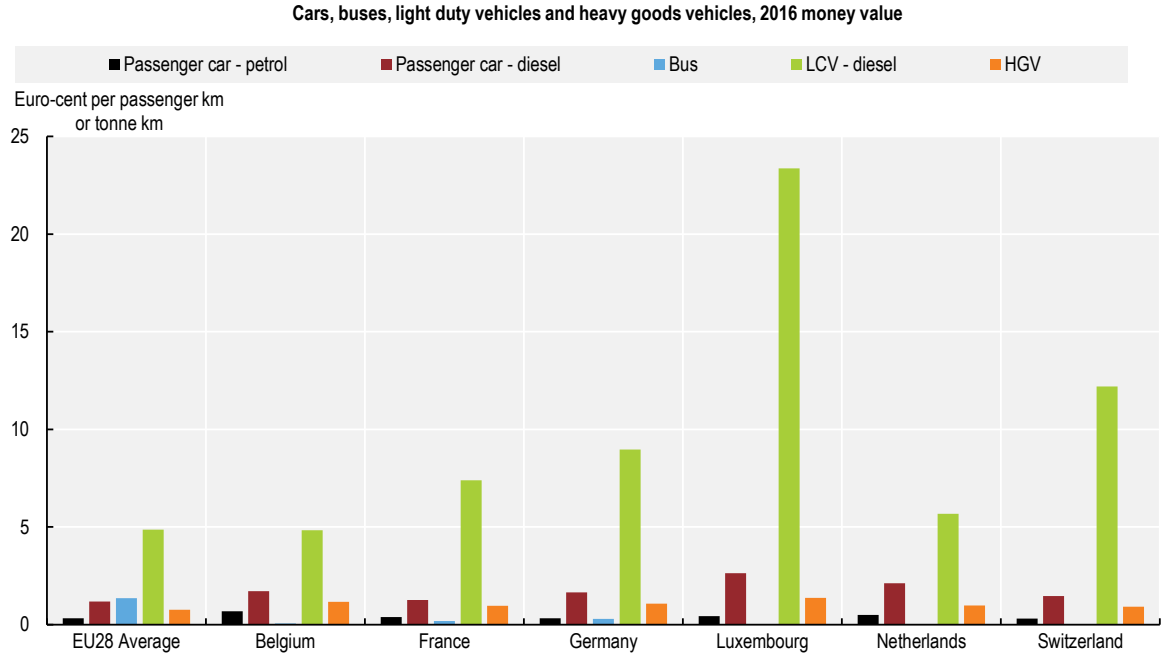
Figure 4.9. Air pollution costs per passenger- or tonne-kilometre are high



Note: Euro-cent per passenger km for cars, buses and light duty vehicles; Euro-cent per tonne km for heavy goods vehicles, 2016 money value. LCV: Light Commercial Vehicle. HGV: Heavy Goods Vehicle.
Source: Based on van Essen et al. (2019), "Handbook on the external costs of transport".

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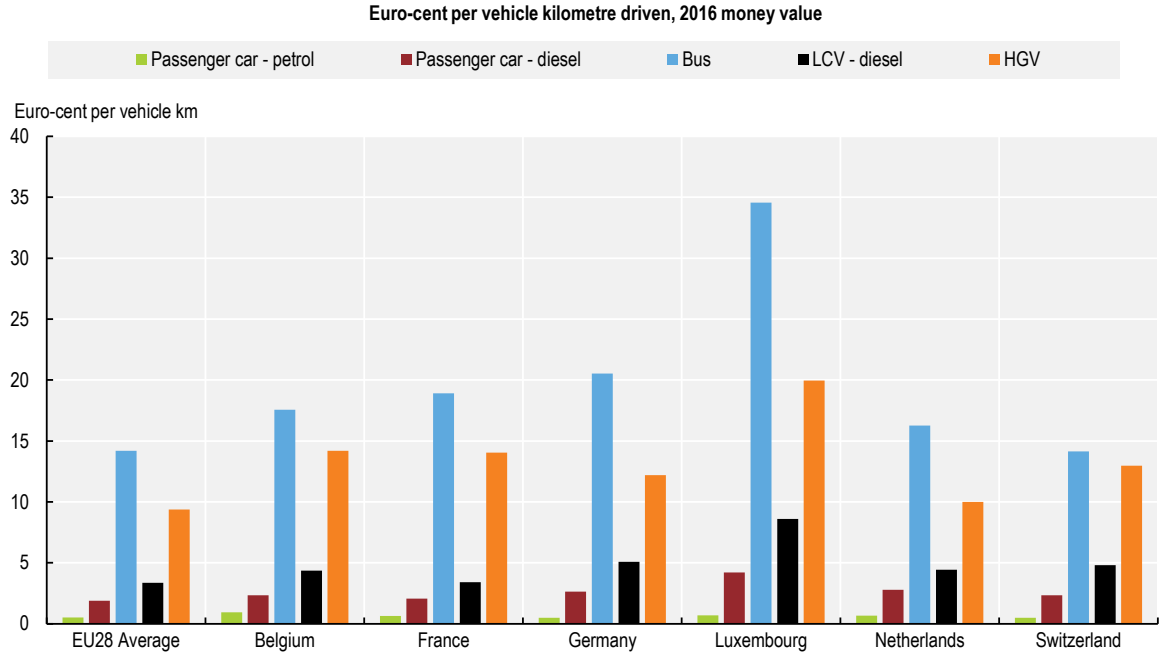
The high VSL value is not the only explanation for high social costs of transport in Luxembourg. Santos (2017) found that external costs caused by heavy goods vehicles in Luxembourg were particularly high. This was mainly because a larger proportion of traffic of heavy goods vehicles the found is taking place on urban roads.

When relating air pollution costs to each kilometre driven by a vehicle, the values for Luxembourg are again higher in the countries used in the comparison, and compared to the EU average. Similarly, the costs per kilometre driven by buses (and by heavy goods vehicles) are much higher than the costs per kilometre for passenger cars and light commercial vehicles. This information in van Essen et al. (2019) refers to 2016. Since then, Luxembourg and other countries have taken measures to introduce hybrid and electrical buses, which would tend to reduce the air pollution costs per kilometre driven. However, such buses may cause large emissions of $PM_{2.5}$ due to tyre and brake wear (Figure 4.10).

Figure 4.10. Air pollution costs per vehicle kilometre are high



Note: LCV: Light Commercial Vehicle. HGV: Heavy Goods Vehicle.
Source: Based on van Essen et al. (2019), "Handbook on the external costs of transport".

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4.6. The strategy for sustainable mobility

There are many ways to make mobility more sustainable. Motorised mobility will, to a varying extent, cause a range of external impacts, including emissions of CO_2 and air pollutants, noise, accidents and congestion. The development of infrastructure to accommodate such mobility will often damage habitats and biodiversity. So-called active mobility – walking and bicycling – will cause much fewer, if any, of these externalities and can be good for people's health.

A number of actions could make mobility more sustainable:

- Reducing the total number of movements of people and goods, e.g. by promoting teleworking
- Reducing the number of vehicles used to transport a given number of people and a given amount of goods, e.g. by increasing the load factors of the vehicles used, for instance through ride-sharing

- Switching to environmentally less harmful vehicles within one mode of transport, such as from fossil fuel-driven passenger cars to electricity-driven cars
- Switching to environmentally less harmful modes of transport, such as from road to rail, or from the use of private cars to the use of public transport, or to walking or bicycling
- Displacing mobility to places where it causes fewer negative externalities, such as by using ring roads around cities, instead of crossing them
- Displacing mobility to times of the day or of the week when traffic is lower, such as from peak hours to late evening, or from workdays to weekends.

In 2012, Luxembourg published a global strategy for sustainable mobility, Modu (referring to the French term *mobilité durable* – sustainable mobility). This plan set a double objective for 2020: 25% of all trips should be non-motorised and 19% of all trips should be made by public transport. These targets were based on model projections built on the incomplete data available at the time of preparing the plans, which makes comparisons to actual achievements difficult.

The 2018 Modu 2.0 is a revised strategy for making mobility in Luxembourg more sustainable (Département des Transports, 2018). It was built, among other things, on responses from some 37 500 persons to the Luxmobil survey in 2017 about their mobility habits, etc.[9] According to this survey, 17% of motorised movements were made via public transport in 2017. Meanwhile, 12% of all movements were made on foot or by bike, excluding "trips" on foot as part of a longer journey by car.

Modu 2.0 focuses on four categories of mobility "actors": employers and education establishments; municipalities; citizens; and the state (Box 4.1). The document also highlights the difference between "traffic" and "mobility": Whereas "traffic" is the movement of vehicles, "mobility" is the possibility and capability to reach a destination. As its key message, the strategy says that mobility in the country can only be improved sustainably and within reasonable timelines if all four actor-categories take a multitude of concrete actions.

The strategy encompasses a number of interrelated actions that the different actors can take to make mobility more sustainable, including the following:

- Undertaking spatial planning in general
- Limiting and managing the availability of parking spaces
- Creating a nice atmosphere for pedestrians
- Making space available for cyclists
- Reducing mobility activity at peak hours
- Stimulating car-pooling and car-sharing
- Promoting use of public transport
- Promoting use of cleaner vehicles.

A strategic objective is to reduce congestion at peak hours while transporting 20% more people in 2025 than in 2017. It sets a number of quantitative targets to reach this objective (Box 4.1). Other objectives referred to include the EU emission reduction targets for 2005-30 (i.e. an 83% reduction for NO_x, 42% for non-methane VOCs and 40% for $PM_{2.5}$).

Implementation of the strategy will be key to the future development of the country. As a strategic document, the Modu 2.0 suggests around 50 measures that the four categories of mobility "actors" could take to make mobility more sustainable. To achieve the paradigm shift from catching up with demand by supply to anticipating it, work has started on the National Mobility Plan 2035. The plan is expected to be presented to parliament in 2021 or 2022. It will be centred on mobility (e.g. measures to reduce individual transport, promotion of public transport, improvement of traffic flows and information measures) and on mobility infrastructure.

Box 4.1. Sustainable mobility targets for 2025

The Modu 2.0 sets a number of targets for 2025, such as:

- Increasing by 50% the number of passengers in public transport through the entry into operation of new infrastructures for the railway company CFL and a reorganisation of the network of the public transport company RGTR
- Increasing to 95% the number of commutes on foot from home to work shorter than 1 km (compared to 56% in 2017)
- Increasing to 10% the number of commutes by cycling from home to work shorter than 5 km (compared to 5% in 2017)
- Increasing to 1.5 persons the average occupation rate of cars used for commutes from home to work
- Increasing to 75% of the movements by foot from home to schools shorter than 1 km (compared to 58% in 2017)
- Increasing to 15% of the movements by cycling from home to schools shorter than 5 km (compared to 3% in 2017)
- Increasing to 50% of the movements from home to primary schools by bus (compared to 29% in 2017), and increasing to 77% of the movements from home to secondary schools by bus or train (compared to 70% in 2017)
- Cancelling fewer than 1 train of 100 (compared to cancelling 1 train of 40 in 2017)
- Reducing by 25% the share of trains delayed six minutes or more (compared to 2017)
- Ensuring that travels by express buses at peak hours between the first stop and the end station are faster than similar travels by cars.

Promotion of public transport

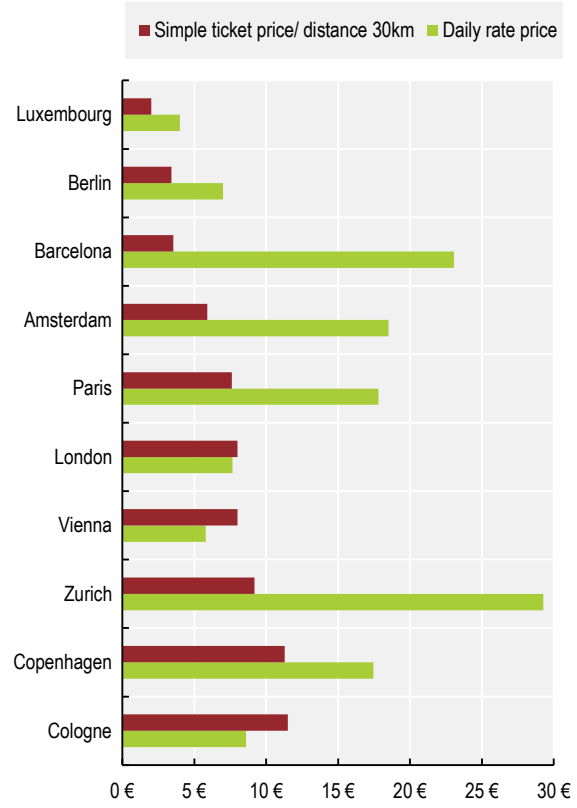
Luxembourg has taken a number of steps to promote the use of public transport to make mobility more sustainable. Between 2015 and 2019, it invested around EUR 1.8 billion in infrastructure for public transport. This includes building a first tramline, establishing new bus corridors, increasing the number of park-and-ride places throughout the country and in border regions, and developing new data systems to provide information to passengers about departure times, delays, etc.

There have also been large purchases of hybrid and electric buses. In 2019, the country introduced 110 new buses in the national bus network; more than 40 of them were 100% electric. This should clearly help reduce combustion-related emissions of local air pollutants. *Ex post* assessments are needed to determine the extent to which hybrid buses run on their batteries rather than on their diesel motors. The batteries add weight to the buses. Therefore, hybrid buses will normally burn more diesel per kilometre driven when the internal combustion motor is used than buses only equipped with such motors (Braathen, N., 2011; Rosendahl, K., 2019).[10] As the experiences with hybrid buses were not so positive, Luxembourg wants to introduce 100% electric buses where possible, and rely on the highest available Euro standard buses elsewhere. It has a set a goal for the bus fleet to be 100% electric by 2030. This will require adequate access for buses to charging stations of sufficient capacity (see below).

A switch to electrical- or hydrogen-driven vehicles will not reduce the emissions caused by tyre and road wear. On the contrary, these vehicles in a given category tend to be heavier than similar vehicles with only an internal combustion engine. Consequently, emissions from tyre and road wear could tend to increase as the share of electrical vehicles in the fleet increases.

The price of public transport in Luxembourg City is lower (in some cases, much lower) than in other European cities of a comparable size (Figure 4.11). It is also free several weekends in the year to encourage citizens to take public transport for their shopping during the sales periods or around special holidays (Christmas, Easter, etc.). As part of its sustainable mobility strategy, the government recently made public transport completely free across the whole country for all users – including a large number of daily commuters from neighbouring countries. Only first class seats continue to require a fee. This measure, introduced in March 2020, is financed by the government and the City of Luxembourg. It is seen as a signal for inducing behavioural changes that would rebalance the modal split and for demonstrating the government's political will. However, it raises questions about the measure's environmental and economic effectiveness. The 2017 Luxmobil survey found that time, comfort and parking possibilities are the most important factors influencing the choice between public transport and other modes of transport among different categories of users. Hence, making public transport totally free is on its own unlikely to have much impact on the choice of transport mode. The measure has also been portrayed as a "social policy measure", but in this case, its targeting is particularly ineffective. It provides subsidies to a large number of people not really in need of such aid.

Figure 4.11. Prices for public transport are low compared to other cities in Europe



Source: Département des Transports (2018), *Modu 2.0 - Stratégie pour une mobilité durable*, Département des Transports, Luxembourg.

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Free public transport will deprive the state of some EUR 40-45 million per year in ticket revenue, given current ticket prices. There will hardly be any cost savings related to an abolishment of the ticketing system. This is because the so-called mKaart provides an increasing number of other services to the card holders, which will likely increase operating costs. These services include free access to safe areas for storing bicycles near public transport stations, and payments for the use of charging stations for electrical vehicles. The revenues only represent about 10% of the costs of operating the public transport system.[11] However,

should the government have less money to spend, the loss of revenues from ticket sales could have a negative impact on the quality of its services. Therefore, the effectiveness of this and other measures to promote sustainable mobility should be assessed in a few years.

Stimulation of active mobility

Luxembourg has a number of measures to stimulate active mobility (walking and biking). A national network of bicycle lanes is being developed. In 2019, more than 600 km of bicycle lanes were available, while about 500 km were being planned. Efforts are being made to integrate bicycle use as a mobility mode into all infrastructures and transport offers.

Many cities around the world, including the City of Luxembourg, are promoting different forms of "shared mobility". Through a subscription, participants have the option of using an electric car, or a conventional or electric bicycle. Due to an increasing number of accidents, and to questions about "sustainability", among other concerns,[12] several cities, including the City of Luxembourg, have started to restrict their use (Garrahan, 2019).[13] Luxembourg is revising the road transport regulation. Electric micro-mobility, which achieves speeds of about 25 km/h, will be allowed to use the cycling infrastructure. Meanwhile, non-electric micro-mobility, which achieves speeds similar to pedestrians, will be allowed to use the sidewalks, with priority accorded to pedestrians.

Stimulation of low-emission vehicle use

Luxembourg also has a number of measures in place to stimulate the purchase and use of low- or zero-emission vehicles (electric and hybrid cars, electric bicycles and scooters, etc.). A network of charging stations for electric and plug-in hybrid vehicles has been established. As of January 2019, more than 200 charging stations had been set up. This gave Luxembourg the third densest charging network per capita in Europe, after the Netherlands and Norway (Chargy, n.d.). By the end of 2020, 800 charging stations (each able to charge two vehicles at a time) should be operational. Luxembourg aims for 49% of the total passenger car fleet to be electric by 2030.

An increasing number of European cities have banned vehicles judged to be particularly polluting from entering the city, or certain parts of it. They base their bans on the Euro classification that the vehicles were supposed to comply with.[14] Such measures can help keep some polluting vehicles off the roads, but these measures are not precise. Among other studies with similar findings, Bernard et al. (2018) suggest real-world NO_x emissions can vary significantly across vehicle models that are supposed to comply with the same Euro standard. Furthermore, some vehicles tested according to an "old" standard can have real-world emissions significantly lower than other vehicles approved according to a newer standard.

Luxembourg has not established such a low-emission zone, partly because the vehicle fleet in the country is relatively new. This seems appropriate based on assessments of schemes in other cities, such as Dallmann et al. (2018). Instead, the country promotes the sale and hence later use of low-emission vehicles through the annual motor vehicle tax and through direct subsidies.[15] The latter is the most important instrument. The amount of the subsidy is based on the type of vehicle: EUR 5 000 for battery electric vehicles and fuel cell electric vehicles; EUR 2 500 for plug-in hybrid electric vehicles; EUR 500 for electric motorcycles; and EUR 300 for bicycles. The subsidy, introduced in January 2019, replaced a tax credit for electrical vehicles established in 2017 that had had only a small effect on sales.

The incentive for selecting a low-emission vehicle stemming from the annual motor vehicle tax is modest. For a petrol-driven vehicle emitting 100 grams of CO_2 per km, the annual tax rate is EUR 36. For a diesel-driven vehicle with similar CO_2 emissions, the annual tax rate is EUR 54.[16] These tax rates are unlikely to have much impact on the choice between petrol- and diesel-driven vehicles. Nor will these rates provide strong incentives to select an electric vehicle instead.

Regarding private use of company-owned cars, the estimated taxable benefits added to the employee's income increase with the estimated CO_2 emissions of the vehicle. These estimated benefits are higher for diesel-driven than petrol-driven cars. For full-electric vehicles, 0.5% of the value (including value added tax) is added to the employee's income each month; for diesel vehicles emitting more than 150 grams of CO_2 per kilometre, 1.8% of the value is added to the employee's income each month. For petrol and diesel vehicles emitting between 50-110 grams of CO_2 per kilometre, the imputed income per month for the employee would be 1% and 1.2% of the value of the car, respectively. If the two cars both had a value of EUR 30 000, the difference in the imputed income would be EUR 720 annually. This difference could have *some* impact on the choice between a petrol or diesel version of a car.

Governance for sustainable mobility

In a number of countries, tax competition could occur between different sub-national authorities regarding taxes of environmental importance. For example, some countries have partially devolved vehicle registration taxes to regional governments, but have set minimum rates to prevent tax competition. For instance, some years ago, Mexico transferred such authority regarding the tax on vehicle ownership from national to state governments. As a result, many states abolished the tax, and others compete with larger neighbours to take the tax revenue through lower rates. This is the case for Mexico City and the surrounding states. Consequently, a large proportion of Mexico City residents register their cars in neighbouring Morelos. This means Mexico City's tax is no longer an effective instrument for promoting greener cars. In Luxembourg, such tax competition is not a problem for the annual tax on motor vehicle ownership, as it is managed by the central authorities.

Licensing of micro-mobility (such as the operation of bicycle-sharing schemes, etc.) is often the responsibility of the lowest level of government because of its impact on pavements and on the kerb side. This tends to lead to fragmented smaller-than-efficient service areas for operators of shared mobility services. In response, Transport for London, for example, has issued good practice for licensing operators of free-floating bicycles (Transport for London, 2018). This guidance is not compulsory, but operators get licensed if they follow it. Luxembourg could consider if it could usefully draw on London's experiences in this regard.

In Luxembourg, national and local authorities have overlapping responsibilities. This creates challenges for implementation of certain policy measures that could have contributed to more sustainable mobility patterns and better air quality (Chapter 2). For example, when central authorities tried to impose parking restrictions on municipalities, the *Conseil d'Etat* said they would limit the municipalities' autonomy too much, and conflict with the Constitution. Given that management of parking spaces is the main lever for steering personal motor traffic in a targeted, economic and ecological manner, this constraint penalises mobility planning.

Promotion of rail transport

As the (mostly electrified) rail network in Luxembourg is largely saturated on certain routes, the confirmed purchase of rolling stock that will increase the number of seats by 43% between 2019 and 2024 is absolutely needed to increase the modal shift of passenger transport, and thus reduce pollution. Regarding rail transport of goods, in 2017, an intermodal goods terminal was opened in Bettembourg, close to the border with France. The idea was to shift transport of heavy goods vehicles from road to rail along the North Sea–Mediterranean freight corridor established by the European Union. According to the Département des Transports (2018), transporting a semi-trailer by rail from Bettembourg to Boulou in southern France would cause emissions of 245 kg of CO_2.[17] This compares to 1 843 kg of CO_2 if the semi-trailer was transported by road. In addition, emissions of local air pollutants along the route would be largely eliminated through the rail option. The number of goods train connections being served by this intermodal terminal is steadily increasing (Kiel, Trieste, Poland, People's Republic of China, etc.).

As regards Europe-wide emissions, the building of this terminal seems most welcome. However, as this terminal is close to the border with France, it would not contribute significantly to reduce emissions in Luxembourg. On the contrary, it could attract additional vehicles from countries such as Belgium, Germany and the Netherlands to drive by Bettembourg for further transport by rail. In this case, emissions of both CO_2 and local air pollutants within Luxembourg could actually increase.

Traffic management

Increased use of teleworking could reduce the need for physical movements of people. The large number of cross-border employees in Luxembourg represents a particular challenge in this regard, as teleworking can affect the income taxation of the employee in question. If they work too much from their home in a foreign country, they will be liable for income taxation in that country – potentially on top of income tax liabilities in Luxembourg. A double taxation treaty with Belgium has for some time limited the problem in relation to that country. Luxembourg has also recently ratified a new double taxation treaty with France that could help improve the situation in relation to that country. Previously, the more than 100 000 persons living in France and working in Luxembourg were not allowed to telework from France at all. The new treaty allows them to telework 29 days per year, or a bit more than once every fortnight [see Orliac (2019)]. This is clearly a step in the right direction, but such a limited allowance for teleworking will not have much impact on congestion levels.

As mentioned above (Section 4.2), congestion is a major issue in Luxembourg. Displacing trips to less busier hours could limit congestion at peak hours. At the same time, fewer trips at rush hour could also reduce time lost, overcrowding of public transport and additional emissions of both CO_2 and local air pollutants. Such an option is available to civil servants through a flexitime system. A car-sharing scheme has also been made available to inhabitants of the Greater Region. The Département des Transports (2018) suggests that some high schools could modify the start of their day. In addition, it suggests employers schedule shift changes during off-peak hours. Finally, it suggests that businesses and local authorities could ensure that deliveries take place at times of limited congestion.

Measures to limit congestion and pollution from road transport are, however, partly undermined by the under-taxation of the benefits employees gain if they are allowed to use a company-owned car for private purposes. Based on data from 2012, Harding (2014) estimated that about half of the benefits – relative to a "benchmark" elaborated in the paper – goes untaxed in Luxembourg. At that time, 1.5% of the value of the car was added to the employee's income each month, regardless of the vehicle type. In 2017, differentiated tariffs were introduced, with lower tax rates for low-emission vehicles. This reform has likely reduced the share of benefits being taxed even further than estimated by Harding (2014).

As Harding (2014) and Roy (2014) discuss further, under-taxation of the benefits of private use of company-owned cars can trigger major environmental and other costs for society. Under-taxation will stimulate the use of private cars compared to public transport and to active modes of transport, especially at times when congestion levels are at their highest.

The income tax treatment of commuting expenses can also have an impact on traffic levels. In Luxembourg, such expenses are deductible from taxable income based on the premise that commuting expenses are incurred to earn income from employment. The deductible amount varies according to the distance travelled to work. For example, EUR 396 is the minimum, if the distance to work is 4 km; EUR 2 970 is the maximum for 30 km or more. Such a tax deduction has the disadvantage of giving people an incentive to live farther away from their workplace – or to seek a job farther away from their home – thus increasing overall transport activity. The same deductions are allowed, regardless of whether the expenses were actually incurred. As an advantage, the deduction does not discriminate against active modes of transport. However, this advantage has limited relevance for long-distance commutes. In addition, the system does not give any incentive to use public or active transport compared to the use of private cars.

Fiscal threats from promotion of more sustainable mobility abroad

Historically, Luxembourg has raised large amounts of tax revenue by attracting visitors from other countries who take advantage of less expensive fuel. The low fuel prices are possible through the application of relatively low tax rates on petrol and – especially – diesel (Chapter 3). As indicated above, "fuel exports" have declined significantly over the last decade, but the practice still raises important tax revenues for Luxembourg. Such revenues will likely decrease significantly as mobility becomes more sustainable in coming years. Electrification of the transport sector, for example, will lead to decarbonisation. Electric passenger cars and light-duty vehicles will likely have a shorter range than vehicles with internal combustion engines. Therefore, it will be less tempting to detour across the border to charge the vehicles at a potentially lower cost than in the country of origin.

For heavy goods vehicles, several countries are considering possibilities – or concretely planning – to supply electricity along the roads in question. If implemented, this would eliminate Luxembourg's possibilities to attract tax revenues from such vehicles in the longer term. The country should therefore start to prepare for the day when this change in taxation possibilities might occur. For example, it could gradually increase fuel tax rates to a level more comparable with practice in neighbouring countries (Chapter 3).[18] It should reinforce the pricing policy of parking spaces to relieve congestion of the road network and encourage car-pooling. It could also consider introducing a road toll system.

4.7. Performance outlook

Luxembourg has set ambitious objectives to address air pollution and mobility issues. Their achievement will depend on the level of commitment of all players (state, municipalities, employers, citizens, cross-border workers); co-ordination between national and local levels; and co-operation with neighbouring countries within the Greater Region. Policy coherence and Luxembourg's ability to exploit synergies between measures concerning transport and mobility, housing (construction, heating), spatial planning, air quality, climate and energy efficiency will be crucial. For a successful transition to sustainable mobility, the government will need to co-ordinate with municipalities and enterprises, especially for reassessing the needed parking spaces for cars, introducing car-sharing systems and reorganising working hours. The commitment of municipalities is particularly important to integrate mobility and air quality issues into local development plans, and to ensure coherence with other spatial planning tools (the Strategic Spatial Planning Programme, sectoral master plans) and with climate and energy-efficiency measures. This can be supported by the Climate Pact, which includes mobility-related measures and since 2017 an "air quality" component , and rewards the action of municipalities in these areas.

In the coming years, it will be important to monitor the evolution of mobility needs and to assess the impacts in terms of costs and benefits of the various measures, including free public transport. Luxembourg should specifically review the costs and benefits of the various financial aids (premiums, subsidies), taxes (on fuel, cars, service vehicles) and other financial incentives. The review should assess whether these financial aids contribute to the government's sustainable mobility objectives and to a further internalisation of external environmental costs. Luxembourg will need to base future choices related to sustainable mobility and the monitoring of results on a solid and reliable information base with accurate, complete and up-to-date data. This should include data on activity levels that have been previously lacking for the different modes of transport, and a regular monitoring, notably by the mobility observatory that is being established.

Recommendations on air quality and mobility

Air pollution management

- Take the most cost-effective measures across all sources and sectors to achieve the 2030 emission reduction objectives of major air pollutants; assess the social cost and benefits of measures to reduce emissions of local air pollutants caused by stationary sources.
- Limit the use of wood biomass to installations where air pollutant emissions can be controlled effectively and at reasonable costs per unit of heat energy generated (e.g. large heat-generation installations with electrical co-production).
- Carry out *ex post* assessments of various new means of public transport expected to cause low amounts of air pollution to verify these vehicles also have low emissions under real-world operating conditions.

Promotion of sustainable mobility

- Promote increased institutional co-ordination on spatial planning to advance sustainable mobility policies and measures and fully use the synergies with policies and measures concerning energy, climate and air quality.
- Evaluate within two-three years the experiences gained from measures that encourage the use of public transport, car-pooling and active mobility, including the introduction of free public transport; ensure proper investments to improve the quality of public transport (more frequent departures, more comfortable equipment, etc.).
- Review the environmental and economic effectiveness of the mix of economic instruments that apply to transport and mobility; increase vehicle taxation and revise the rates to take account of emissions of both CO_2 and local air pollutants; consider reducing the fiscal benefits accruing to employees when using a company-owned vehicle for private purposes and introducing a differentiation by distance driven; reinforce the pricing policy of parking spaces; and evaluate the possibility of creating road tolls.
- Invest sufficient resources in developing systems necessary for obtaining accurate, comprehensive and up-to-date data for sustainable mobility planning, including data on activity levels in different transport modes.

Notes

[1] The Greater Region is the geographical area comprising Luxembourg, the Walloon Region in Belgium, Lorraine in France and two German states (Saarland and Rhineland-Palatinate).

[2] www.tomtom.com/en_gb/traffic-index/. The nine cities ranked worse than the City of Luxembourg are all located in either Poland or in the United Kingdom.

[3] SO_2 emissions in Luxembourg are dominated by the emissions of a single industrial plant.

[4] There is also an hourly EU limit value of 200 µg of NO_2/m^3 of air, with which Luxembourg has always complied.

[5] Based on findings of the initial campaign, measurements are continuing at about 40 places.

[6] Chapter 1 in OECD (2014) discusses further the term “cost”.

[7] Recent OECD work by Dechezleprêtre, Rivers and Stadler (2019) found that opportunity costs are much larger than previously thought. Using annual GDP data for a large number of European regions, they found that a 1 µg/m³ increase in $PM_{2.5}$ concentration in the air in a given year caused a 0.8% reduction in real GDP per capita that same year.

[8]van Essen et al. (2019) indicates that road transport performance data are taken from Eurostat, following the nationality principle. This means that transport activity is allocated to countries where the vehicle is registered. In an alternative approach, using the so-called territorial principle, transport activity would be allocated to the country where the activity actually takes place. For example, kilometres driven by Belgian vehicles in Luxembourg would be allocated to Belgium when the nationality principle is applied, and to Luxembourg if the territorial principle were applied. As a detailed EU-wide data set on road transport performance based on the territorial principle is not available, van Essen et al. (2019) used the official Eurostat dataset based on the nationality principle. There is, however, significant uncertainty regarding the transport activity numbers, as Luxembourg is lacking good-quality estimates of tonne-kilometres and passenger-kilometres driven. For example, there is no system to automatically count the number of passengers in a given bus.

[9] See http://www.luxmobil.lu/ and https://transports.public.lu/fr/mobilite.html.

[10] It is sometimes argued to consider the emissions of CO_2 and local air pollutants caused by the generation of electricity by electric buses and other electric vehicles. However, in European countries, CO_2 emissions from electricity generation are covered by the cap of the EU ETS. A higher electricity demand will thus not much affect EU-wide CO_2 emissions. Indirectly, this cap will also affect EU-wide emissions of local air pollutants; see Braathen (2011). Since the EU ETS was modified in 2018, the overall cap is no longer completely fixed. Therefore, generation of electricity to run electric vehicles will cause *some* increase in EU-wide CO_2 emissions, but this impact will be small. Rosendahl (2019) discusses further the impacts of recent changes to the EU ETS.

[11] EUR 45 million would equal 12.5% of the average annual investments in public transport between 2015 and 2019.

[12] Some of these vehicles may only last a few months, especially if they are used in harsh weather conditions. In some places, groups throw such bicycles or scooters in rivers, canals or the sea for “sport”.

[13] According to Garrahan (2019), e-scooters have never been allowed on public roads or pavements in the United Kingdom. Paris recently banned their use on pavements, but they can be used on public roads.

[14] For example, as of 1 July 2019, new circulation limits were put in place in Paris. Diesel-driven passenger and light-duty vehicles older than from 2006 and petrol-driven vehicles older than from 1997 may not be driven in the city between 8:00 and 20:00, Monday to Friday. Similar restrictions are in place for diesel-driven heavy goods vehicles and buses older than from 2009, seven days a week.

[15] See https://transports.public.lu/fr/contexte/initiatives/mesures-fiscales/clever-fueren-steiere-spueren.html.

[16] In addition, for a given vehicle category, a diesel vehicle will typically cause lower CO_2 emissions per kilometre than a petrol vehicle. This would tend to make the differences in the annual motor vehicle taxes even smaller.

[17] Along the lines of the discussion in note 10, this estimate could in fact be too high. The generation of the electricity used to operate the trains is covered by the “cap” of the EU ETS. Hence, running an additional train would not increase EU-wide CO_2 emissions. Leakage effects triggered by the modifications to the EU ETS in 2018 could only increase Europe-wide CO_2 emissions if rail transport were to increase.

[18] Van Dender (2019) discusses in-depth the taxation of motor fuels, motor vehicles and road use.

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