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Potential reductions of CO_2 emissions due to the landside accessibility of Brussels Airport through adapted policy measures and use of electric vehicles

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Abstract

Besides its airborne operations, the landside accessibility of an airport also induces a burden on the environment. In this paper, the current environmental situation of the passenger and employee transport to and from Brussels Airport is analyzed. The different landside access modes to the airport are inventoried and their shares of traffic and emissions are illustrated. To reduce CO_2 and other emissions, a cluster of measures (consisting of a transition towards hybrid and battery electric vehicles, a modal shift away from internal combustion engine passenger cars and some accompanying political interventions) needs to take place. An estimation of the current CO_2 emissions related to the landside accessibility of the airport is performed and a set of potential improvements, including the introduction of hybrid and battery electric vehicles, are described. It appears that, especially when they are combined, the suggested measures can save over 30% percent of the CO_2 emissions due to the landside mobility of the airport.

Keywords: emissions, mobility, public transport, environment, EV (electric vehicle)

1 Introduction

Brussels Airport is a medium-sized passenger airport with 18.5 million passengers in 2008 [1]. Although it's obvious that the important amount of cargo handled on the airport grounds induces some additional mobility burden on the surrounding highways, the focus of this paper is on the environmental impact of the landside transport of people (passengers and employees). Between 1990 and 2008, passenger numbers doubled and, as a consequence, the road traffic flows to and from the airport strongly increased as well. This traffic, which is currently mainly composed of internal combustion engine (ICE) passenger cars, results in the emission of pollutants affecting climate and air quality. Moreover, it creates additional noise pollution around the airport. The focus of this paper is on CO_2 emissions but other emissions are likely to be reduced as a collateral effect of the suggested measures as well. In this context, hybrid and battery electric passenger vehicles and (electrically powered) public transport offer many opportunities to reduce transport-related pollution [5]. As the latest large-scale, global enquiry concerning the mobility of employees and passengers of Brussels Airport is almost ten years old, some assumptions have been made based on intermediate reports and various information sources [1,3,4,6,11,12]. Therefore this paper shouldn't be viewed as a general emissions inventory but rather as a qualitative and quantitative policy support tool.

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2 The current accessibility and mobility

Several large parking lots are located within walking distance of the airport terminal and are an indication of the predominant role of the passenger car over the other transport modes to reach the airport. As far as public transport is concerned, the airport is currently connected through electrified railways and through ICE public and private buses. The airport is connected to the three main railway stations in Brussels 4 times an hour, while a limited number of other trains link the airport with other cities in Belgium. The amount of people (passengers and employees) traveling to and from the airport by train has increased by 30% from nearly 2.1 million in 2002 to more than 2.7 million in 2006. A dedicated express public bus line connects the European district of the city center and the airport terminal and 17 other regional bus lines operate to and from the airport. The number of people using these public bus services has been increasing as well over the years (Figure 1) [1]. The total amount of people using public transport to reach or to leave the airport has thus been growing over time during the last years. Nevertheless, the share of public transport in the airport connections is still relatively low. Overall, the latest available data show that approximately 20% of the passengers coming from or going to the airport used public transport services. The most recent data concerning employees' mobility show that only 11.9% of the commuting trips were performed using public transport. However, the use of public transport increased much faster than the number of passengers and employees in the last few years, which indicates a slight modal shift has occurred in this period [1].

The very important share of airport passengers and employees using individual passenger cars to reach the airport can be explained by several factors: the airport is well-connected to the highway infrastructure and these highways are not yet reaching full-time saturation. At the same time, extensive parking space is available around the terminal.

Figure 1: Bus and train user statistics to and from Brussels Airport 2002-2007 [1].

Figure 2 shows that, although the total number of passengers (including transit passengers and Origin & Destination passengers) of Brussels Airport is lower than in 2000 (due to 9/11 and the bankruptcy of two Belgian carriers: Sabena and Citybird in 2001), it still more than doubled between 1990 and 2007. Approximately 16.7 million Origin & Destination (O&D) passengers generated a mobility burden on the roads and railroads to and from the airport in 2007 [1]. Transit passengers don't generate this mobility burden, as they generally don't leave the airport building.

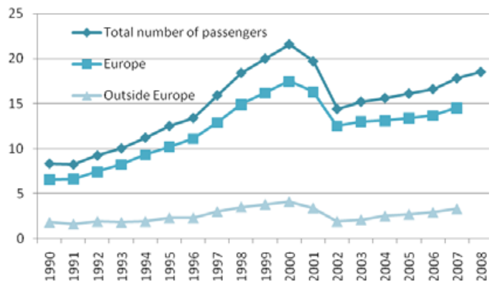

Figure 2: The evolution of the annual total number of passengers (in millions) [1].

To be able to compare the emissions of the different transport modes in an objective and exhaustive way, it's essential to take the complete well-to-wheel (WTW) emissions into account. The WTW emissions relevant for this paper are provided in Table 1. The indirect and direct emissions are provided as well and correspond respectively to the well-to-tank (WTT) and tank-to-wheel (TTW) emissions.

Table 1: Overview of the direct and indirect CO_2 emissions for the different energy carriers [2].

Energy carrier	CO_2 emissions per liter or per kWh		
	Indirect (WTT)	Direct (TTW)	Total (WTW)
Gasoline	297 g/l	2 212 g/l	2 509 g/l
Diesel	250 g/l	2 697 g/l	2 947 g/l
Electricity (Belgian mix)	277.7 g/kWh	0	277.7 g/kWh

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To enable an optimal understanding of the situation concerning the accessibility of the airport, a number of aspects need to be clarified. These are listed below:

- The calculations are based on an O&D passenger number of 16.7 million and a number of 20 962 employees commuting to the airport 230 times a year on average.
- There's a variety of vehicles used as taxis to operate to/and from Brussels Airport. Nevertheless, the most typical taxi in operation is the Mercedes E-type. Therefore, it will be assumed that all taxi operations are performed using a Mercedes E 300 Bluetec Elegance (presenting an Ecoscore of 65 [2]), running on diesel fuel and emitting 206.5 g CO_2/km (7.01 l of diesel fuel per 100 km) on the New European Driving Cycle (NEDC) on a WTW basis (TTW = 189.1 g CO_2/km, WTT = 17.5 g CO_2/km). In this case-study, it is assumed that a taxi carries 1 passenger.
- The distance by train from Brussels Central station is 15 km, while to travel from Antwerp it's currently necessary to change trains in Brussels North station. This results in 57 km in total (45 km for the first leg of the trip and 12 km for the second leg).
- The distance to reach the airport by bus is approximately 15 km both for the Airport Express bus line from Brussels of the MIVB/STIB as for the regional buses of De Lijn.
- When using a personal vehicle to reach the airport, several possibilities can occur: 1) The passenger can drive his/her vehicle to the airport, park it and drive it back after his/her return. 2) Two or more passengers share a car to/from the airport and leave the car there until their return. 3) One or more passengers are dropped-off at the airport by a relative or friend. In this last case the return trip of the vehicle is accounted for as well by the passenger(s), which is comparable to the current situation for a taxi trip. The selected approach in this paper is to the first one.
- Although it's unlikely that the passenger and employee numbers remain stable in the future ([11] predicts a strong growth in the coming years), it has been considered that these numbers remained the same before and after the suggestions are implemented. This assumption allows comparing the different options with the same mobility burden as a reference. However, when definitive decisions have to be made concerning the optimal modes of transport to connect the airport, it's essential to consider the expected mobility burden as well as the capacity and cost per passenger.kilometer (p.km) of the different options.

Based on the previous assumptions, the CO_2 emissions per p.km are provided in Table 2.

Table 2: Overview of the WTW CO_2 emissions per p.km for different transport modes and options.

Transport option	CO_2 emissions / p.km
Taxi Brussels (1 passenger)	206.5 g
Regional bus (rush hour / 100% OR)[1]	21.1 g
Regional bus (average / 30% OR)	64.0 g
Train (rush hour)	19.3 g
Train (average)	77.1 g
Personal vehicle (driver only)	166.0 g
Personal vehicle (driver + passenger)	83.0 g
Personal vehicle (drop-off)[2]	166.0 g

[1] OR = Occupancy Rate
[2] drop-off = 1 passenger escorted to the airport. In this case the emissions per p.km are similar to the 'driver only' option, but the amount of km is twice as high.

The ten provinces of Belgium, as well as the Brussels capital region and Brussels Airport are depicted in Figure 3, while the distance between the most significant cities of the different provinces are shown in Table 3.

Figure 3: Map of Belgium indicating the different provinces and the Brussels capital region (The numbers correspond to the data provided in Table 3).

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Table 3: Overview of the current average distances and CO_2 emissions for the different transport modes to/from the airport [adapted from 5] for a number of significant cities over the country.

	Province/City/District	Distance to the airport (km)	
		Road	Rail
1.	Brussels capital region	15	15
2.	Antwerp	45	57 (12 + 45)
3a.	Halle-Vilvoorde[3]	15	n.a.
3b.	Leuven[3]	25	25
4.	East Flanders (Ghent)	68	68
5.	West Flanders (Bruges)	110	110
6.a	Charleroi[4]	70	70
6.b	Mons[4]	79	79
7.	Liège	93	93
8.	Limburg (Hasselt)	76	76
9.	Walloon Brabant (Nivelles)	46	46
10.	Namur (Namur)	66	66
11.	Luxembourg (Libramont)	143	143
12.	D, F, L, NL, UK[5]	150	150

[3]Flemish Brabant is composed of the districts of Halle-Vilvoorde (approximately corresponding with the outskirts of Brussels) and of Leuven. Due to their strong specificities regarding access to the airport, they are considered individually. Currently, railway accessibility is very limited in this region. Therefore it is not considered in this phase.
[4]In the case of this study the employees of the Hainaut province are allocated either to the districts of Charleroi (in the West of the Hainaut province) and Mons (in the East of the Hainaut province). This is due to the very different levels of the public transport connections between these cities. Currently there's a direct train from the airport to Mons, while there is no direct train to Charleroi.
[5]As a compromise, a distance of 150 km is assumed for foreign passengers of the airport.

Table 4: Distribution of the landside origin/destination of the passengers of Brussels Airport [3] (N = 16.7 million passengers/trips).

	Province/City/District	Proportion of the passengers 100% = 16.7 million	Car	Taxi	Public transport	Tour operator
1.	Brussels capital region	40.36%	44.0%	38.0%	15.7%	2.2%
2.	Antwerp	13.33%	67.0%	14.3%	6.8%	11.9%
3a.	Halle-Vilvoorde[3]	4.94%	73.4%	18.3%	6.4%	1.8%
3b.	Leuven[3]	4.67%	72.8%	9.7%	11.7%	5.8%
4.	East Flanders	6.85%	67.5%	7.9%	15.2%	9.3%
5.	West Flanders	5.17%	61.4%	7.0%	24.6%	7.0%
6.a	Charleroi[4]	2.68%	83.1%	1.7%	6.8%	8.5%
6.b	Mons[4]	2.63%	67.2%	3.4%	20.7%	8.6%
7.	Liège	4.58%	80.2%	3.0%	14.9%	2.0%
8.	Limburg	2.77%	83.6%	9.8%	4.9%	1.6%
9.	Walloon Brabant	3.45%	85.5%	6.6%	5.3%	2.6%
10.	Namur	2.45%	70.4%	0.0%	24.1%	5.6%
11.	Luxembourg	0.73%	50.0%	6.3%	43.8%	0.0%
12.	D, F, L, NL, UK[6]	5.40%	73.1%	2.5%	17.6%	6.7%
	Total		60.5%	20.5%	14.0%	5.0%

[6]The distribution per country is as follows: Germany/D (0.23%), France/F (1.18%), Luxembourg/L (0.59%), the Netherlands/NL (3.31%), United Kingdom/UK (0.09%).

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Table 5 provides information concerning the distribution of passengers as well as the transport mode they use to reach the airport. Clearly, taxi use is quite common for Brussels, Halle-Vilvoorde and Antwerp. Regarding Antwerp, the higher use of tour operators is due to the existence of a private bus operator connecting the city of Antwerp to the airport on a regular, scheduled basis.
Table 5 provides an overview of the distribution of the employees depending on their place of residence and on the mode of transport they use to reach the airport. The annual number of trips for employees is based on 230 working days per year (2 trips per day), resulting in 460 trips per year per employee (Table 5). It clearly appears that employees having a comparatively easy public transport connection to the airport (e.g. Mons), use public transport to a much larger extent than employees living at a comparable distance but with less convenient public transport connections (e.g. Charleroi or Namur). Only employees living reasonably close to the airport (e.g. Halle-Vilvoorde and Leuven) go to work walking or using their bicycle.

Table 5: Distribution of the residence of the employees working on the grounds of Brussels Airport [adapted from [3,4], based on the postal codes of the employees' residences].

	Province/city/district	Number of employees	Proportion of employees	Annual number of trips	Car	Public transport	Walk/bike
1.	Brussels city	3 401	16.22%	1 564 271	83%	16%	0%
2.	Antwerp	2 224	10.61%	1 023 115	94%	5%	1%
3.a	Halle-Vilvoorde	4 633	22.10%	2 131 116	86%	8%	6%
3.b	Leuven	4 594	21.92%	2 113 245	89%	9%	1%
4.	East Flanders	1 340	6.39%	616 549	76%	23%	0%
5.	West Flanders	393	1.88%	180 944	79%	21%	0%
6.a	Charleroi[4]	568	2.71%	261 363	85%	15%	0%
6.b	Mons[4]	955	4.56%	439 515	69%	30%	0%
7.	Liège	537	2.56%	246 843	89%	11%	0%
8.	Limburg	590	2.81%	271 416	81%	18%	0%
9.	Walloon Brabant	1 297	6.19%	596 445	94%	6%	0%
10.	Namur	387	1.85%	178 152	82%	18%	0%
11.	Luxembourg	42	0.20%	19 546	84%	15%	0%
	Total	20 962	100.00%	9 642 520	83.1%	11.9%	1.6%

Table 6: Distribution of the trips, covered p.km and CO_2 emissions per transport mode for employees and passengers together.

	Car	Taxi	Public transport	Tour operator	Walk/bike	Total
Distribution of trips	69.90%	13.00%	13.31%	3.18%	0.61%	100%
Number of trips	18 374 031	3 416 082	3 498 908	836 924	159 231	26 285 175
Distribution of p.km	67.88%	13.61%	14.32%	3.95%	0.24%	100%
Number of covered p.km	830 039 355	166 427 561	175 137 495	48 277 594	2 906 717	1 222 788 722
Distribution of CO_2 emissions	75.46%	18.82%	4.59%	1.13%	0.00%	100%
CO_2 Emission quantities (tons)	137 787	34 367	8 386	2 054	0	182 594

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Based on the previous paragraphs, Table 6 summarizes the distribution of the emissions by transport mode. It is assumed that half of the users of public transport use it during peak hours. For Brussels more or less one third of the public transport users used the bus, while two thirds used the train. For Halle-Vilvoorde it was assumed that no significant train connection was available, so all passengers were assumed to use the bus. All the other public transport users have been assumed to use the train. Finally, tour operators have been assumed to have the same average emissions per p.km than the average public bus operators. Table 6 shows that public transport generates a much lower amount of CO_2/p.km compared to personal vehicles or taxis.

3 Ongoing, planned and suggested interventions influencing traffic emissions

The current mobility and accessibility situation of the airport, including the evaluation of the current WTW CO_2 emissions, has been described in the previous paragraphs. In this paragraph, some suggestions are made to reduce the emissions due to landside accessibility of Brussels Airport. Several working suggestions are made, some are based on confirmed interventions being currently developed or under construction, while others are suggested by the authors and are consequently hypothetical at the moment. These suggestions have different characteristics; they can be political, technological or infrastructural and can concern both public transport fleets and personal vehicles used to travel to and from the airport. In this paragraph, the potential emission reductions obtained through these interventions are quantified. Although various suggestions are described individually below, this doesn't mean several measures can't be implemented in parallel, which could increase their beneficial effects as compared to the current situation. The emissions of the different transport modes are based on the ESTIMATE project [5] and on the Ecoscore methodology [2].

3.1 Suggestion 1: Taxi operation agreement

A specific issue concerning taxis operating on Brussels Airport is that there is no agreement between the municipality of Zaventem -where the airport is located- and the Brussels Capital Region. As these authorities are responsible for delivering their respective taxi licenses, it means that most taxis carrying passengers from the airport to the city can't pick up passengers to drive them back to the airport and vice versa, taxis bringing passengers from the city center to the airport can't pick up arriving passengers on their way back. This means that one of the trips is always an empty trip, which obviously reduces the ecological efficiency of the taxis operating these trips as a passenger carried by taxi will be allocated twice the distance of 15 km, thus 30 km.

Consequently, one of the measures to reduce the current emissions is to find an agreement between the Brussels capital region and the municipality of Zaventem. One option could be to develop a common license for both Zaventem and Brussels or to come to an agreement on the specific operation of the taxis between the airport and the city center. This suggestion and analysis specifically concerns taxi operations between the airport and Brussels city.

For 2007 it can be assumed that 2 561 246 taxi trips (38.0% x 40.36% x 16 700 000) were performed to Brussels (Table 4). Assuming the distance of 30 km per passenger and the CO_2 emissions of 206.5 g /p.km this results in a total 15 867 tons of CO_2 on a yearly basis.

Implementing this measure, without any adaptation to the vehicle fleet is expected to reduce the emissions of CO_2 due to the taxi operations by half. This means that, taking the assumptions described in the previous paragraph into consideration, a reduction of the emissions by 7 933 tons on a yearly basis is feasible.

Looking at the number of passengers reaching the airport by taxi and the potential emission reduction, this measure will not solve the issue of CO_2 emissions as such, but it doesn't require any significant investments. Moreover this agreement would have immediate results and it would have some beneficial effect on congestion and on the local air quality as well. Moreover, it would be an exemplary, positive signal from the policy makers towards the citizens of whom they ask some efforts in this matter.

If this measure were to be combined with a slight downsizing of the vehicles and the replacement of the taxi fleet by typical hybrid electric vehicles (with an average TTW +WTT CO_2 emission of 104 g/km + 14.0 g/km = 118 g/km), the total CO_2 emissions due the taxi fleet would be reduced to a mere 4 533 tons per year (with this potential 71% CO_2 emissions reduction reaching in total 11 334 tons per year).

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3.2 Suggestion 2: Connection of the airport with a tram line

In the coming months, the infrastructure works will be started to build a new tram line connecting the NATO headquarters with central Brussels. These new tracks bring a connection of the airport on the tram network closer, as the NATO headquarters and Brussels Airport are located on one straight line from the center of the city. The distance between the NATO headquarters and the airport is approximately 5 km.

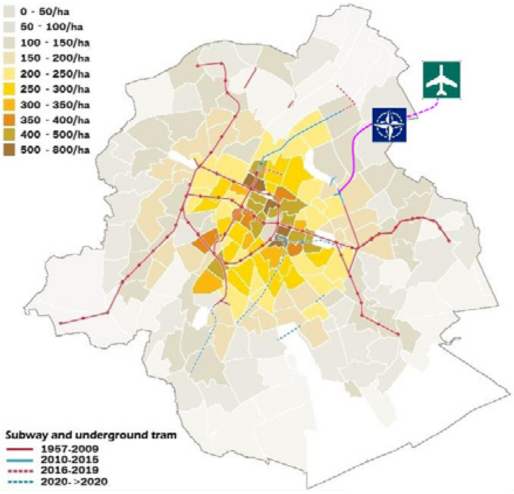

Figure 4: Urban density of the Brussels Capital Region (adapted from [6]).

In recent news reports [7] the tram extension between the NATO headquarters and the airport has been confirmed (dashed line in Figure 4). The same reports even indicate that another tram line might potentially connect the airport with the neighbouring municipalities of Machelen and Vilvoorde. However, no concrete time frame has been communicated up to now.

This new tram line will not only improve the accessibility of the airport, but will also improve the public transport offer in the Northeastern side of the city, which is home not only to the NATO, but also to many companies and inhabitants. The urban density of the city is provided in Figure 4 in "(inhabitant + jobs) / hectare" The NATO headquarters and the future tramline (purple line) are also depicted on the map. The suggested extension of the tramline to the airport is depicted as a dashed purple line. This line will also allow line interchanges with other existing tram lines (23, 24, 25 and 55) and bus lines (59, 63, 64, 65 and 69), hereby increasing the catchment area for users and thus its profitability.

For the tram the values used during the calculation are based on a peak time substation consumption value of 0.03 kWh/p.km if the tram is loaded with 4 persons per m [8] corresponding with 7.6 g CO_2/p.km. Simulations of the energy consumption with a reduced occupation of the tram during average operation (off-peak) of approximately 30% results in CO_2 emissions of 21.6 g /p.km (When implementing some adaptations in the mobility system, these have some implications for the emissions of the system, but also have some other advantages or drawbacks. These can be economical, ecological, political or technical. To put the suggestions discussed above into perspective, Table 13 provides some of the most important additional benefits or drawbacks.

In this suggestion, it is assumed that the tram catches twice as many trips as the current 'airport express' bus line, which would be suppressed, while its passengers would be completely transferred to the tram. The other half of the passengers is assumed to be originating from the other modes except the tour operators.

Table 7 shows that the implementation of the new tram line would reduce the CO_2 emissions by 1 624 tons.

Table 7: Possible modal and emissions distribution between Brussels and the airport before and after the implementation of the new tram line.

	Car	Taxi	Public buses	Rail	Tour operator	Tram	Total
Current modal distribution (# trips)	4 263 998	2 561 246	436 161	872 321	148 283	0	8 282 008
Current distribution of CO_2 emissions (tons)	10 617	15 867	278	631	95	0	27 488
Suggested modal distribution (# trips)	4 022 390	2 416 120	0	822 893	148 283	872 322	8 282 008
Distribution of CO_2 emissions after construction of tram line (tons)	10 015	14 968	0	595	95	191	25 864

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3.3 Suggestion 3: Replacing a part of the vehicle fleet by hybrid electric and battery electric vehicles

Between 1995 and 2003 the average CO_2 TTW emission levels of newly registered personal cars in Belgium was significantly reduced (from 186 g/km to 158 g/km respectively). However, since 2003 the average TTW emission level stagnated (from 158 g/km to 152 g/km). The average WTW CO_2 emissions of the fleet in 2007 amount to 166 g/km (Table 2).
The total emissions resulting from the distance covered by car to reach the airport amounted to 137 787 tons in 2007 (Table 6).
In this suggestion or hypothesis, the implementation of hybrid electric vehicles (HEV) and battery electric vehicles (BEV) is performed according to the scenarios developed in [9]. The considered hybrid electric vehicles have a typical WTW CO_2 emission level of 118 g/km and would consequently result in an emission reduction of 30% per vehicle.km.
For the considered BEV, the electric consumption is based on the empirical formula: Electric consumption (in Wh/t.km) = 80 + 80/m (with the mass expressed in tons) and on a vehicle with a mass of 1 310 kg, an energy consumption of 184.8 Wh/km is obtained for BEV. Assuming an emission of 277.7 g CO_2/kWh for the Belgian electricity production mix in 2003, this results in an emission level of 51.1 g of CO_2/km which corresponds to a reduction of 69% per vehicle.km compared to the current average emission level.
In the scenarios described by the Flemish environmental agency (VMM) [9], the proportion of hybrid and battery electric vehicles by 2025 and by 2030 has been predicted (Table 8) according to a business as usual scenario (BAU scenario), as well as according to a more ambitious scenario (EU-scenario). It is assumed a CO_2 emission reduction of 30% per km is obtained for HEV and of 69% per km for BEV. It is assumed the technological composition of the vehicle fleet used to reach the airport is similar to the countrywide composition of the vehicle fleet. This reduces the emissions compared to the average current fleet according to the potential CO_2 emissions reduction described above. When multiplying the suggested fleet penetration of HEV and BEV with their emission reduction per km compared to the typical ICEV (30% and 69% respectively), the total reduction in CO_2 emissions for the personal vehicles coming from and going to the airport is obtained (Table 8).
Taking the distance covered by personal vehicles to reach the airport into account and assuming an equal amount of kilometers covered using personal vehicles in 2007 and in 2025/2030, this results in an absolute CO_2 emission reduction of 4 671 tons to 9 493 tons in 2025, and in a reduction of 9 934 to 19 511 tons in 2030.
These CO_2 reductions are consistent with the electricity production mix mentioned above. If this mix were to be greened, the reductions are likely to be more important.

Table 8: Scenario's for HEV and BEV fleet penetration and potential relative CO_2 emission reductions by 2025 and 2030 [9].

	2025		2030	
	BAU scenario	EU scenario	BAU scenario	EU scenario
Share of HEV[7]	10.5 %	18.3 %	19.1 %	35.2 %
Share of BEV	0.4 %	1.5 %	1.6 %	4.2 %
Relative CO_2 reduction for personal vehicles	3.36 % + 0.03 % = 3.39 %	5.86 % + 1.03 % = 6.89 %	6.11 % + 1.10 % = 7.21 %	11.26 % + 2.90 % = 14.16 %

[7]HEV includes plug-in HEV and non plug-in HEV, both diesel and gasoline fuelled.

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3.4 Suggestion 4: Development of the railway accessibility (Diabolo project) and significant modal shift towards public transport

One of the aims of the "START plan" (regional development plan for the airport area) is to reach a modal shift away from personal vehicles towards public transport. The goal is to reach a 60/40 distribution of personal vehicles and public transport respectively in the medium term (2020).

To reach these objectives, some of the shortcomings of the airport's public transport connection with its catchment area will be tackled through new rail infrastructure works in the coming years. Currently the train station located on Brussels Airport is a dead-end train station. This situation not only reduces the capacity of the station, but also results in a reduced attractiveness of the trains calling at the airport station, as these trains waste time changing directions. Therefore some important infrastructural works (under the project name 'Diabolo') have been started (Figure 5). These include an additional railway curve (Nossegem curve), which has been completed recently (and eases the way to the East: Leuven, Liège, Hasselt); the construction of a railroad tunnel under the airport terminal and grounds and the construction of new railroad infrastructure towards Mechelen and Antwerp in the North and to Brussels in the South (in the middle of the E19 motorway) and finally the Josaphat-Schuman tunnel in Brussels, which will increase the accessibility of the Brussels European district with the airport and will make straight connections between the airport on the one hand and Charleroi, Namur, Luxembourg and Walloon Brabant on the other hand. Connections to the West, which are currently already well-developed, will be improved to a smaller extent towards Kortrijk and Bruges. In view of this, if the objectives of the START-plan are to be met, the distribution of the origin of the passengers is not likely to be changed in a homogeneous manner. Passengers from cities of which the accessibility has been improved most are more likely to perform a modal shift towards railways.

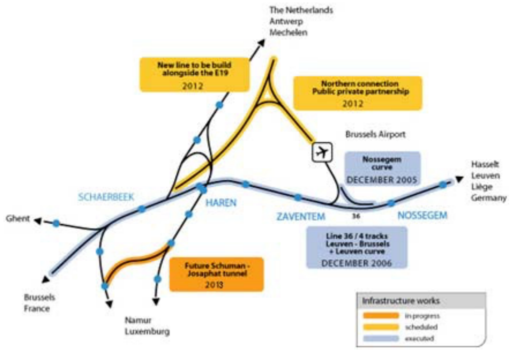

Figure 5: Overview of the railway infrastructure developments around Brussels Airport [10].

Assuming the modal shift occurs, and 40% of the movements to and from the airport are performed using public transport, these passengers still have to be distributed over the different transport modes. In this study, it is assumed that the bus mainly will be taken by people to/from the areas located close to the airport (Brussels city and Halle-Vilvoorde), while train traffic will mainly attract people along new convenient lines directly connecting the airport. Therefore it's assumed that the modal shift towards buses is obtained for short distances, while the modal shift towards train transport is mainly obtained through new lines/connections and thus from the cities connected by these lines.

This means that in this suggestion 40% of transport to/from the airport will be performed through public transport (expressed in numbers of trips). 16% should be performed by regional buses of 'De Lijn', as well as through the MIVB/STIB connection to Brussels city which will no longer be performed by bus, but by tram (see suggestion 2), as well as through tour operators [11,12]. This leaves 24% of the passengers using the train to reach the airport. In view of the above description and knowing the exact train schedules after the Diabolo project aren't yet confirmed to a full extent, the distribution shown in Table 9 is suggested, taking new rail tracks and connections into consideration.

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Table 9: Suggested distribution of the origin/destination city of the current train users and of the train users once the new train connections are implemented (after modal shift). In the left column, the potentially improved connections are shown between brackets.

	Province/city/district	Current fraction of rail users (trip numbers)	Potential fraction of rail users (trip numbers)
1.	Brussels city (EU-district)	10.5% (872 321)	25.0% (2 070 502)
2.	Antwerp (Antwerp, Mechelen)	6.2% (202 531)	30.0% (974 768)
3.a	Halle-Vilvoorde	0% (0)	15.0% (443 291)
3.b	Leuven	9.8% (281 439)	25.0% (718 001)
4.	East-Flanders (Ghent, Aalst)	18.0% (315 687)	20.0% (350 638)
5.	West-Flanders (Bruges, Kortrijk, Ostend)	24.0% (250 392)	25.0% (261 084)
6.a	Charleroi	9.8% (69 639)	27.5% (195 077)
6.b	Mons	25.5% (222 771)	27.5% (240 320)
7.	Liège (Liège)	13.9% (141 117)	20.0% (202 494)
8.	Limburg (Hasselt)	9.8% (71 522)	20.0% (146 166)
9.	Walloon Brabant (Ottignies, Nivelles)	5.7% (66 323)	27.5% (322 464)
10.	Namur (Namur)	22.2% (130 673)	25.0% (146 928)
11.	Luxembourg (Arlon)	39.8% (56 328)	40.0% (56 553)
12.	D,F,L,NL,UK	17.6% (158 717)	20.0% (180 180)
	Total	10.8% (2 839 459)	24.0% (6 308 463)

Assuming that the goal to reach a 40% share of common transport (public transport and tour operators) is attained and that the share of tour operators, walking and cycling remains stable, this means that a transfer from the personal vehicles and the taxi trips has to take place towards public transport. For simplicity, it is assumed that this transfer is to happen according to the current share of the personal vehicles (69.90% of the trips) and taxis (13.00% of the trips). The modal share after the transfer is shown in Table 10. In this scenario, the new railroad distance to be covered between Antwerp and Brussels Airport has been reduced to 34 km thanks to the new railroad infrastructure works described above (Diabolo). This increases the attractiveness of this connection while reducing its resulting (indirect) emissions at the same time.

Table 10: Modal shares before and after the suggested modal redistribution.

	Car	Taxi	Public transport	Tour operator	Walk/bike	Total
Current distribution of trips	69.90%	13.00%	13.31%	3.18%	0.61%	100%
Suggested distribution	50.08%	9.31%	36.82%	3.18%	0.61%	100%

Table 11: Distribution of the trips, covered p.km and CO_2 emissions by transport mode for both employees and passengers after the suggested modal shift occurs. On the right side, the share of the different modes of public transport are described in more detail (bus, tram and train).

After modal shift	Car	Taxi	Public transport	Of which bus	Of which train	Of which tram
Distribution of trips	50.08%	9.31%	36.82%	9.50%	24.00%	3.31%
Number of trips	13 163 616	2 447 150	9 678 201	2 496 382	6 308 463	872 322
Distribution of p.km	58.74%	9.30%	31.96%	3.81%	26.82%	1.33%
Number of covered p.km	577 298 943	91 443 283	314 117 874	37 445 733	263 587 311	13 084 830
Distribution of CO_2 emissions	74.17%	14.61%	11.21%	1.23%	9.83%	0.15%
CO_2 Emission quantities (tons)	95 832	18 883	14 489	1 593	12 705	191

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Taking the CO_2 emissions shown in Table 11 and adding them to the CO_2 emissions of tour operators, which remained stable at 2 054 tons, it appears that according to the scenario resulting from suggestion 4, the total CO_2 emissions amount to 131 258 tons. This means that, when comparing the current situation (Table 6) with suggestion 4 (Table 11), the total annual CO_2 emission reduction would amount to 51 336 tons.

3.5 Suggestion 5: Significant modal shift towards public transport combined with the introduction of hybrid and battery electric buses.

Improving the energy efficiency and reducing the ecological footprint of passenger transport can be performed through two main mechanisms. One of them is to group passengers in higher capacity vehicles (typically through public transport). This was described in the previous suggestion. The other one is the introduction of alternative drive train technologies, such as hybrid and battery electric vehicles [13]. Consequently, combining those two options is likely to result in the optimal on-road passenger transport solution. Therefore suggestion 5 is considered to be the most radical suggestion. Additionally to the modal shift described in suggestion 4, it proposes to replace the current ICE diesel bus fleet by a combined fleet of hybrid and battery electric buses.

The data provided by [13] results in a suggested 30% reduction in fuel consumption and thus CO_2 emissions for hybrid electric buses. Assuming that half of the fleet is replaced by hybrid electric buses and the other half of the fleet is replaced by battery electric buses, while the modal shift of suggestion 4 is maintained, would result in the emissions presented in Table 12. If the whole public bus fleet to reach the airport from Brussels and from Halle-Vilvoorde were to be replaced by a mixed fleet of 50% BEV and 50% HEV, the emissions reduction would amount to an extra 780 tons (difference between 1 593 tons in the case of a full ICE fleet and 813 tons assuming a mixed HEV-BEV fleet).

Table 12: Annual CO_2 emissions for different bus types.

	Annual CO_2 emissions (tons)
100% Conventional bus (ICEV)	1 593
100% Hybrid electric bus (HEV)	1 115
100% Battery electric bus (BEV)	511
50% BEV, 50% HEV	813

When implementing some adaptations in the mobility system, these have some implications for the emissions of the system, but also have some other advantages or drawbacks. These can be economical, ecological, political or technical. To put the suggestions discussed above into perspective, Table 13 provides some of the most important additional benefits or drawbacks.

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Table 13: Overview of the average distances and CO_2 emissions for the different transport modes to/from the airport considering the potential future adaptations (adapted from [5] and [13]).

	Annual reduction of the CO_2 emissions (tons) Percent of total	Additional Benefits	Disadvantages
Suggestion 1 Taxi operation agreement	7 933 (up to 11 334) 4.4% (up to 6.2%)	- Parallel reduction of other pollutants - Potentially very fast results - Increased economic efficiency of taxi operators - Reduction of congestion - No investment costs	- Limited influence on total emissions
Suggestion 2 Tram line	1 624 0.9%	- Parallel reduction of other pollutants - No local/diffuse emissions - Reduction of congestion - Users separated from road traffic (not affected by congestion) - Higher capacity compared to buses - Improved public transport in the Northeastern part of Brussels (not only airport-related passengers) - Limited infrastructure costs (compared with train infrastructure)	- Limited influence on total emissions - Only influences short trips to/from the airport (as opposite to train infrastructure)
Suggestion 3 Replacement of part of fleet by HEV and BEV	4 671 to 19 511 2.6 to 10.7%	- Parallel reduction of other pollutants - No additional investment costs (vehicles are assumed to be in the fleet already)	- No effect on congestion - Fleet replacement is a slow and gradual process
Suggestion 4 Diabolo and modal shift to public transport	51 336 28.0%	- Parallel reduction of other pollutants - No local/diffuse emissions - Reduction of congestion - Increased attractiveness of public transport on the whole line (not only airport related traffic)	- Very important infrastructure costs - Infrastructure works require important amount of time
Suggestion 5 Previous suggestion + HEV and BEV buses.	52 116 28.5%	- Parallel reduction of other pollutants - Potentially very fast results - Reduction of congestion - More important emission reduction than for shift towards conventional ICE public buses	- Investment in new material exceeds the investment cost for conventional ICE public buses

4 Conclusions

Currently, private ICE vehicles have a dominant position in the accessibility of the airport. These vehicles currently form a major contribution to the total greenhouse gas emissions of the landside accessibility of Brussels Airport. Some progress is being made towards the accessibility of the airport by public transport, however, if the most reasonable goals concerning O&D passengers and the use of public transport objectives are to be achieved, it would mean that the number of users of public transport is expected to triplicate by 2025. Consequently, the currently planned developments are not expected to be sufficient to absorb this number of commuters and to reduce the pollution resulting from their landside mobility.

Therefore, several suggestions to reduce the environmental and mobility burden of the landside accessibility of the airport have been made in this paper. These suggestions have been evaluated on the basis of their potential CO_2 emissions reductions, but all of them are likely to result in the reduction of the emissions of other pollutants as well.

All of the suggestions result in CO_2 reductions which range between 0.9% (Suggestion 2 - Connection of the airport with a tram line) and 28.5% (suggestion 5 - Significant modal shift towards public transport combined with the introduction of hybrid and battery electric buses) of the total CO_2 emissions. This doesn't mean suggestion 2 is to be discarded. The limited CO_2

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reduction, which is due to the limited distance covered by the trams is one aspect of this suggestion, but the potentially, relatively high number of personal vehicle trips which can be avoided through this suggestion is important as well regarding the mobility issues in the area. In the long run, and looking at the number of users of the tram line, it should be evaluated if the tram line needs to be replace by a more heavy, light rail or metro line. This aspect is important when designing the potentially needed bridges, tunnels and other infrastructure works for the tram line.
Knowing that the connection from the European district to the airport will be improved in the near future and that the connection to the three main train stations is well-developed, it would be advisable to improve the accessibility of other parts of the city of Brussels. This is also tackled through suggestion 2.
Concerning rail based transport modes (trains and trams), an additional asset to their high efficiency and capacity, is that they operate on their own tracks, which results in higher punctuality (as they are not hampered by road congestion) as well as in the avoidance of any additional mobility burden on the already heavily congested road system in and around the city and the airport.
It's not only important to reach a modal shift away from personal vehicles, it's also advisable that the public transport bus fleet used to access the airport shifts towards the more sustainable electric or hybrid drive trains instead of the current ICE. As it's not to be expected that all of the passengers would reach the airport using public transport, it's also essential to push for a significant shift of passenger vehicles towards electric and hybrid drives as well.
In urban traffic, due to their beneficial effect on environment, electric vehicles are an important factor for improvement of traffic and more particularly for a healthier environment [14]. More generally, all of the electrically propelled vehicles (BEV, trams, trains,…) not only show the advantage of having a higher energy efficiency, they also result in local emission sources (at the power plants), which are more easily tackled than diffuse emission sources (such as ICEV). Additionally, a subsequent greening of the electricity production results in greening the whole transport system.

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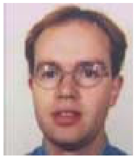

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