Improvement of the CO_2 Balance of the Landside Accessibility of Brussels Airport Through Implementation of Electric Vehicles and General Policy Measures

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Abstract
When thinking about aviation and climate, researchers tend to focus on airborne operations. This aspect is obviously important, but the landside accessibility of an airport also results in climate impacting emissions. This paper analyses the current emissions balance originating from the passenger and employee transport to and from Brussels Airport. The CO_2 emissions related to the different landside access modes are inventoried and in a second step suggestions are made towards potential improvements of the situation. The measures suggested in this paper consist of a transition towards hybrid and battery electric vehicles, a modal shift away from internal combustion engine vehicles and some specific political interventions. When combined, it is calculated that the suggested measures can save more than 30% percent of the CO_2 emissions originating from the landside mobility of Brussels airport.

Keywords
emissions, mobility, public transport, environment, electric vehicle

1. INTRODUCTION
With 18.5 million passengers in 2008, Brussels Airport is a medium-sized passenger airport [The Brussels Airport Company, 2008]. Next to the passenger activity, an important amount of cargo is handled on the airport grounds as well and induces some additional mobility burden on the surrounding highways. Nevertheless, the focus of this paper is on the CO_2 emissions resulting from the landside transport of people (passengers and employees). As a result of the fact that the passenger numbers doubled between 1990 and 2008, the road traffic flows to and from the airport strongly increased. This traffic is currently mainly composed of internal combustion engine (ICE) passenger cars, and emits pollutants affecting climate and air quality. In this paper the focus is on CO_2 emissions but the suggested measures are expected to have rather positive effects on other emission levels and noise around the airport. This specific situation seems to be very appropriate for the introduction of hybrid and battery electric passenger vehicles and for the extension of the (electrically powered) public transport, as these two main options are valuable for the reduction of transport-related pollution [Wynen et al., 2008]. The latest large-scale enquiry concerning the mobility of employees and passengers of Brussels Airport is almost ten years old, therefore some assumptions had to be made based on intermediate reports and various information sources [The Brussels Airport Company, 2008; Tritel, 1998; Peersman, 2009; Iris 2, 2008; Lijn, 2006; IDEA Consult, 2006]. As a consequence, this paper can't be viewed as a general emissions inventory but should rather be looked at as a policy support tool providing qualitative and quantitative data.

2. THE CURRENT ACCESSIBILITY OF BRUSSELS AIRPORT
A number of large parking lots are located around the airport terminal and indicate the prime role of the passenger car over the other transport modes to reach the airport. The airport is currently also connected through electrified railways and through ICE public and private buses. For instance, the three main railway stations in Brussels are connected 4 times an hour, while a limited number of other cities in Belgium are also directly connected to the airport. Between 2002 and 2006, the amount of people (including passengers and employees) traveling to and from the airport by train has increased by 30 % from nearly 2.1 million to more than 2.7 million. Recently, a dedicated express public bus line has been introduced to connect the European district in the city center with the airport terminal.

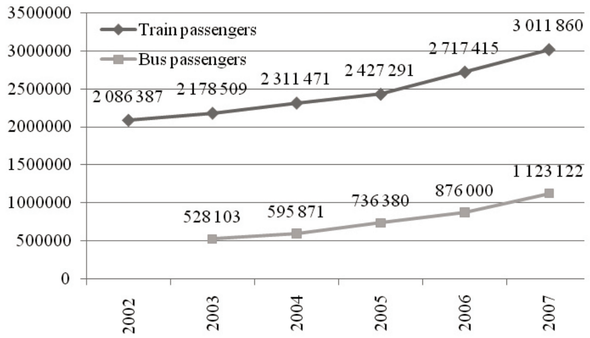

Fig. 1 Bus and train user statistics to and from Brussels Airport 2002-2007 [The Brussels Airport Company, 2008]

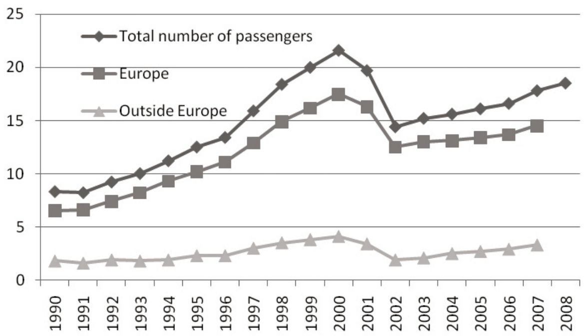

Fig. 2 The evolution of the annual total number of passengers (in millions) [The Brussels Airport Company, 2008]

Moreover 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) [The Brussels Airport Company, 2008]. The number of people using public transport to reach the airport has thus been growing over the years. Nevertheless, the public transport is still responsible for only a limited share in the airport connections. The latest available data show that approximately 20 % of the passengers coming from or going to the airport do that using public transport. On the other hand, the most recent data concerning employees' mobility show that only 11.9 % of them used public transport for their commuting trips to and from the airport. Although these numbers can certainly be improved, a slight modal shift has occurred in this period as the use of public transport increased much faster than the passenger and employee numbers [The Brussels Airport Company, 2008].

An explanation for the very important share of airport passengers and employees using individual passenger cars to reach the airport can be found in the following arguments: the airport is well-connected to the highway infrastructure, which is not (yet?) reaching full-time saturation. Meanwhile, extensive parking facilities are available around the terminal.

The total number of passengers (including transit passengers and Origin & Destination passengers) of Brussels Airport is currently lower than in the year 2000 (Figure 2). This drop is due to 9/11 and the bankruptcy of two Belgian carriers: Sabena and Citybird in 2001. Nevertheless, passenger numbers still more than doubled between 1990 and 2007. In 2007, approximately 16.7 million Origin & Destination (O&D) passengers generated a mobility burden on the roads and railroads to and from the airport [The Brussels Airport Company, 2008]. Only O&D passengers need to be taken into account in this context, as transit passengers don't generate this mobility burden, as they generally don't leave the airport building.

A well-to-wheel (WTW) is absolutely required to enable the comparison of the emissions of the different transport modes in an objective and exhaustive way. The WTW emissions needed for this paper are provided in Table 1. More specifically, the indirect and direct emissions are provided and correspond to the well-to-tank (WTT) and tank-to-wheel (TTW) emissions respectively.

Table 1 Overview of the direct and indirect CO_2 emissions for the different energy carriers [Timmermans et al., 2006]

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

The framework in which the airport includes a number of elements which need to be provided if one wants to have a good understanding of the mobility situation. The most important issues and assumptions made in this paper are listed below:

- The calculations are based on a yearly 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.
- Various vehicles are 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 (Timmermans J.-M. et al., 2006), 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 arise: 1) A passenger drives his/her vehicle to the airport, parks it and drives it back home after his/her return. 2) Two or more passengers share a car to/from the airport and leave the car there until their return. After the trip, these people perform the same trip in the other direction 3) One or more passengers are dropped-off at the airport by another person (driver). In this last case, the return trip of the vehicle is to be accounted for by the passenger(s). This situation is comparable to the current situation for a taxi trip. In this paper, the selected approach for the use of personal vehicles to reach the airport is the first one.
- Although it's unlikely that the passenger and employee numbers remain stable in the future (De Lijn [2006] predicts a strong growth in the coming years, while the economic crisis currently induces a downward trend on the air passenger numbers), it has been assumed these numbers remain 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.

Figure 3 provides an illustration of the ten provinces

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.

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

Table 3 Overview of the current average distances and CO2 emissions for the different transport modes to/from the airport (adapted from [Wynen et al, 2008]) 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[1]	15	n.a.
3b.	Leuven[1]	25	25
4.	East Flanders (Ghent)	68	68
5.	West Flanders (Bruges)	110	110
6.a	Charleroi[2]	70	70
6.b	Mons[2]	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[3]	150	150

1 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, these two regions are considered individually. Currently, the railway accessibility is very limited in this region. Therefore it is not considered in this phase.

2 In this study the employees of the Hainaut province are allocated either to the district of Charleroi (in the West of the Hainaut province) or Mons (in the East of the Hainaut province). This is due to the very different levels of the public transport connections of these cities with the airport. Currently there's a direct train from the airport to Mons, while there is no direct train to Charleroi.

3 As a compromise, a distance of 150 km is assumed for foreign passengers of the airport.

of Belgium, as well as the Brussels capital region and Brussels Airport. On the other hand, the distances between the most significant cities of the different provinces and the airport are shown in Table 3.

The distribution of passengers and the transport modes they use to reach the airport are provided in Table 5. The use of taxis is quite common for trips to Brussels, Halle-Vilvoorde and Antwerp. The existence of a private bus operator connecting the city with Brussels Airport results in a higher use of tour operators for

Table 4 Distribution of the landside origin/destination of the passengers of Brussels Airport [Tritel, 1998] (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[1]	4.94 %	73.4 %	18.3 %	6.4 %	1.8 %
3b.	Leuven[1]	4.67 %	72.8 %	9.7 %	11.7 %	.8 %5
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[2]	2.68 %	83.1 %	1.7 %	6.8 %	8.5 %
6.b	Mons[2]	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[3]	5.40 %	73.1 %	2.5 %	17.6 %	6.7 %
	Total		60.5 %	20.5 %	14.0 %	5.0 %

[1] 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, these two regions are considered individually. Currently, the railway accessibility is very limited in this region. Therefore it is not considered in this phase.

[2] In this study the employees of the Hainaut province are allocated either to the district of Charleroi (in the West of the Hainaut province) or Mons (in the East of the Hainaut province). This is due to the very different levels of the public transport connections of these cities with the airport. Currently there's a direct train from the airport to Mons, while there is no direct train to Charleroi.

[3] 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 %).

Table 5 Distribution of the residence of the employees working on the grounds of Brussels Airport (adapted from [Tritel, 1998; Peersman, 2009], 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 %

this region.

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 is provided in Table 5. The annual number of trips for employees is based on 230 working days per year. Assuming 2 trips are performed on a daily basis, this results in 460 trips per year per employee (Table 5). When employees have a comparatively easy public transport connection to the airport (e.g. Mons), it clearly appears that they 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 on a regular basis.

Table 6 provides a summary of the distribution of the emissions by transport mode. The assumption is made 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 connections were available, so all passengers were assumed to reach the airport by 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. INTERVENTIONS INFLUENCING TRAFFIC EMISSIONS

The previous paragraphs describe the current mobility and accessibility situation of the airport, including the evaluation of the WTW CO_2 emissions. Next, some suggestions are made with the aim to reduce the emissions due to the landside accessibility of Brussels Airport. Several working suggestions are made. Some are based on confirmed interventions being currently developed or under construction. Others are suggested by the authors and are consequently hypothetical at the moment. The different suggestions can be political, technological or infrastructural and can concern both public transport fleets and personal vehicles used to travel to and from the airport. A quantification of the potential emission reductions obtained through these interventions are quantified and described in this paragraph. The various suggestions are individually described below. However, this doesn't mean that several of these measures can't be implemented in parallel. A combined implementation could increase their beneficial effects, but do not necessarily simply add up. The emissions of the different transport modes are based on the ESTIMATE project [Wynen et al, 2008] and on the Ecoscore methodology [Timmermans et al., 2006].

3.1 Suggestion 1: Taxi operation agreement

As there is no agreement between the municipality of Zaventem -where the airport is located- and the Brussels Capital Region, a specific issue arises concerning taxis operating on Brussels Airport. As these authorities (Municipality of Zaventem and Brussels Capital Region) deliver 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 implies that one of the trips is always an empty trip, which obviously strongly reduces the ecological efficiency of the taxis operating these trips. Consequently, a passenger carried by taxi will be allocated twice the distance of 15 km, thus 30 km.

Accordingly, one of the measures to reduce the current emissions is to find an agreement between the Brussels capital region and the municipality of Zaventem. Developing a common license for both Zaventem and Brussels or coming to an agreement on the specific

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

operation of the taxis between the airport and the city center would drastically reduce the importance of this issue. This suggestion and analysis specifically concerns taxi operations between the airport and Brussels city. Although the situation is the same for the other municipalities outside of Zaventem, the most important taxi destination is from the airport is Brussels and should therefore be addressed with due priority.

When analysing the situation for 2007, it can be assumed that 2 561 246 taxi trips (38.0 % × 40.36 % × 16,700,000) were performed to Brussels (Table 4). If the distance of 30 km per passenger and the CO_2 emissions of 206.5 g /p.km are taken into account, this results in a total of 15,867 tons of CO_2 on a yearly basis. Without requiring any adaptation of the vehicle fleet or of the infrastructure, implementing this measure, is expected to reduce the emissions of CO_2 due to the taxi operations by half. Taking the assumptions described in the previous paragraph into consideration, this results in a reduction of the emissions by 7,933 tons on a yearly basis.

Although this measure will not solve the issue of CO_2 emissions as such (due to the limited number of passengers reaching the airport by taxi and the potential emission reduction), it shows the important advantage of not requiring any significant investments. Additionally, this agreement would have immediate results and it would have some beneficial effect on congestion and on the local air quality as well. Besides, it would be an exemplary, positive signal from the policy makers towards the citizens of whom they righteously ask some efforts in this matter.

This measure could be combined with a slight downsizing of the vehicles and with 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). In that case, the total CO_2 emissions due the taxi fleet would be reduced to just 4,533 tons per year (resulting in a potential reduction of 71% of the CO_2 emissions, reaching in total 11,334 tons per year).

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

Recently, the infrastructure works were started to build a new tram line connecting the NATO headquarters with central Brussels. These new tracks will 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. As an indication, the distance between the NATO headquarters and the airport is roughly 5 km.

Recent news reports [De Morgen, 2009] confirm the tram extension between the NATO headquarters and the airport (dashed line in Figure 4). The same reports even suggest that another tram line will connect the airport with the neighbouring municipalities of Machelen and Vilvoorde. Up to now, no concrete time frame has been communicated though.

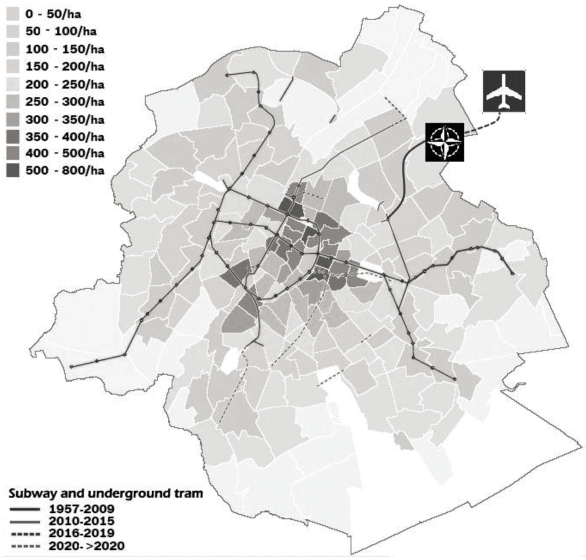

Fig. 4 Urban density of the Brussels Capital Region (adapted from [Iris 2, 2008])

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. As an illustration, 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 recommended extension of the tramline to the airport is shown as a dashed purple line. New interchange possibilities would also be created with this line as it crosses other existing tram (23, 24, 25 and 55) and bus lines (59, 63, 64, 65 and 69), hereby increasing the catchment area for users and thus increasing the revenue for the operator.

The electricity consumption of the trams, 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^2 [Barrero et al., 2008] corresponding with 7.6 g CO_2/p.km. The energy consumption with a reduced occupation of the tram during average operation (off-peak OR of approximately 30%) has been simulated as well and results in CO_2 emissions of 21.6 g /p.km.

In this paper, 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 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

Table 8 Scenario's for HEV and BEV fleet penetration and potential relative CO_2 emission reductions by 2025 and 2030 [MIRA-S, 2009]

	2025		2030	
	BAU scenario	EU scenario	BAU scenario	EU scenario
Share of HEV[1]	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 %

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

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

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

The average CO_2 TTW emission levels have been reduced significantly between 1995 and 2003 in Belgium (from 186 g/km to 158 g/km respectively). But since 2003 the average TTW emission level stagnated (from 158 g/km to 152 g/km). On average the WTW CO_2 emissions of the fleet in 2007 amounted to 166 g/km (Table 2).

As a result, 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, the implementation of hybrid electric vehicles (HEV) and battery electric vehicles (BEV) occurs according to the scenarios developed in [MIRA-S, 2009]. The WTW CO_2 emission level of the considered hybrid electric vehicles amounts to 118 g/km and would consequently result in an emission reduction of 30% per vehicle.km.

The electric consumption is based on the following empirical formula for the considered BEV: 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. This results in an energy consumption of 184.8 Wh/km 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 corresponding to a reduction of 69 % per vehicle.km compared to the current average emission level.

The Flemish environmental agency (VMM) produced some scenarios for the proportion of hybrid and battery electric vehicles by 2025 and by 2030 [MIRA-S, 2009] (Table 8). These scenarios include data according to a business as usual scenario (BAU scenario), as well as according to a more ambitious scenario (EU-scenario). A CO_2 emission reduction of 30 % per km is assumed for HEV and of 69 % per km for BEV. The technological composition of the vehicle fleet used to reach the airport is supposed to remain similar to the countrywide composition of the vehicle fleet. According to the potential CO_2 emissions reduction described above, this results in a reduction of the emissions compared to the average current fleet. If the suggested fleet penetrations of HEV and BEV are multiplied 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).

When 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 a total 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.

Of course, these CO_2 reductions are related to the electricity production mix mentioned above. Should this mix be greened, the reductions would evolve accordingly.

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

The “START plan” (regional development plan for the airport area) includes the objective to reach a modal shift away from personal vehicles towards public transport. A 60/40 distribution of personal vehicles and public transport respectively has been set as a target for the medium term (2020).

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 with the aim to reach these objectives,. The train station located on Brussels Airport is currently a dead-end train station. This situation not only reduces the capacity of the station, but also reduces the attractiveness of the trains calling at the airport station, as these waste time for passengers not going to the airport (because of the need of the train to change directions). To solve this issue, some important infrastructural works (under the project name ‘Diabolo’) have been started (Figure 5). These works include an additional railway curve (Nossegem curve), which has been completed recently (and eases the way to the East: Leuven, Liège, Hasselt); but also 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. The latter adaptations are all ongoing. Once these have been performed, connections to the West, which are currently already well-developed, will be improved to a smaller extent towards Kortrijk and Bruges. But the connections the North and the South of the country will be strongly improved. In view of this, and 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. It is likely that passengers originating from cities of which the accessibility has been improved most are more likely to perform a modal shift towards railways.

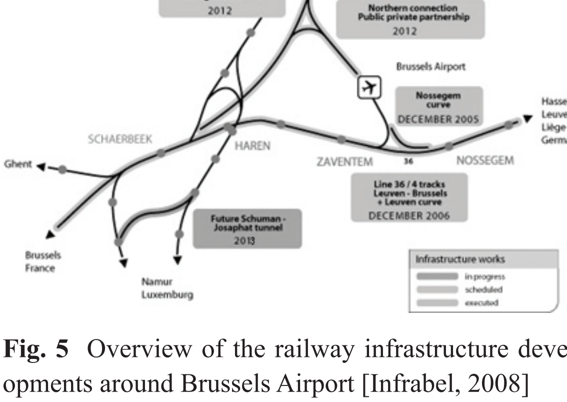

Fig. 5 Overview of the railway infrastructure developments around Brussels Airport [Infrabel, 2008]

If 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 paper, 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. As a consequence, 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 [De Lijn, 2006; IDEA Consult, 2006]. The other passengers (24 % of the passengers) are thus assumed to use 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.

It is considered that the goal to reach a 40 % share of shared transport (public transport and tour operators) is attained and that the part 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 reasons, it is considered that this transfer happens according to the current share of the personal vehicles (69.90 % of the trips) and taxis (13.00 % of the trips). The changed 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

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)

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

infrastructure works described above (Diabolo). This improved infrastructure increases the attractiveness of this connection while reducing its resulting (indirect) emissions at the same time.

Considering 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 shows that, according to the scenario resulting from suggestion 4, the total CO_2 emissions amount to 131,258 tons. This means that suggestion 4 (Table 11), would result in a total annual CO_2 emission reduction of 51,336 tons compared to the current situation (Table 6).

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

The improvement of the energy efficiency and the reduction of the ecological footprint of passenger transport can be reached through two main mechanisms. One of them consists of grouping passengers in higher capacity vehicles (typically through public transport). This was described in the previous suggestion. The

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

other mechanism is the introduction of alternative drive train technologies, such as hybrid and battery electric vehicles [Matheys et al., 2006]. Accordingly, 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 far-reaching 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 [Matheys et al., 2006] suggest a 30 % reduction in fuel consumption and thus CO_2 emissions for hybrid electric buses. Assuming 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. Should 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).

Implementing some adaptations in the mobility system, have some implications for the emissions of the system, but also have some other advantages and/or drawbacks. These influences 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 for the different suggested solutions.

4. CONCLUSIONS

Personal ICE vehicles currently have a prevailing position in the accessibility of the airport. These vehicles currently also form a major contribution to the total greenhouse gas emissions of the landside accessibility of Brussels Airport. Although some progress is being made towards the accessibility of the airport by

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 [Wynen et al, 2008; Matheys et al., 2006])

	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

public transport, 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. Therefore, 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. The different 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. These are included in a 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 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 is advisable to improve the accessibility of other parts of the city of Brussels to/from the airport. 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. This results in improved 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 perform 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. Moreover, as it's not to be expected that all of the passengers would reach the airport using public transport, it's also essential to encourage a significant shift of passenger vehicles towards electric and hybrid drives.

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 [Van den Bossche, 2003]. Also, 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). A greening of the electricity production would thus result in greening the whole transport system.

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