



Study on urban mobility – Assessing and improving the accessibility of urban areas

Annexe 3: Task 3 Report – Relative efficiency of urban
passenger transport modes



Ricardo
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Annexe 3: Task 3 Report – Relative efficiency of urban
passenger modes

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Executive summary

Study overview

The European Commission (Directorate General for Mobility and Transport) launched this study to improve the understanding of urban accessibility and road congestion in Europe. The study aims to advance the understanding of urban accessibility in order to improve the functioning of urban areas and make the transport system in Europe's urban areas more efficient. The study includes five key tasks:

- Task 1 – State of the Art Review
- Task 2 – Estimation of European urban congestion costs;
- Task 3 – Relative efficiency of urban passenger transport modes;
- Task 4 – Best practice examples for increasing urban accessibility; and
- Task 5 – Policy proposals.

This report is the Task 3 report on the assessment of the relative performance of different urban transport modes under a range of different operating conditions. These data will aid cities in understanding the performance of different modes in their local situation with the aim of supporting improved functioning of urban areas and better urban accessibility.

In the context of this study the performance of urban transport modes has been assessed in relation to:

- *Capacity* – defined in terms of passengers per vehicle and passengers per hour in relation to the capacity of the infrastructure
- *Energy use* – defined in terms of MJ per passenger km
- *CO₂ emissions* – defined in terms of CO₂ per passenger km
- *Cost* – defined in terms of Euros per passenger km.

The metrics have been assessed for private modes (car and motorcycle) and public transport modes (bus and rail). Basic modes have been further divided into sub-modes for example midi bus, large bus and bus rapid transit (BRT). With the road categories key fuel technologies have also been considered covering petrol, diesel, compressed natural gas (CNG), liquid petroleum gas (LPG), petrol-electric hybrid and battery electric. The focus is on motorised modes but some commentary is also provided on active modes such as walking and cycling.

In addition, each of the metrics have been assessed for different 'real world' conditions covering metropolitan areas and medium cities, and peak (or congested) traffic and off-peak (or uncongested) traffic.

Key conclusions

The performance of different transport modes is dependent on a range of factors including the capacity of the infrastructure and vehicles, occupancy levels and traffic conditions. In addition, the different modes may perform differently depending on which metrics are being considered. Therefore, comparing modes across the four different metrics and different city conditions presents a complex picture.

However, looking across all the results a few key trends emerge:

- During peak periods the capacity, cost and environmental performance per passenger of public transport is generally better than that of private modes (cars and motorcycles). However, during off peak periods the picture is much more complex.
- Costs are generally lower for public transport than private transport in all conditions.

- Overall capacity, including infrastructure, is greatest for the rail modes. For the road modes capacities are much more similar for both private and public transport (bus-based) and during off-peak periods the effective capacity of private modes is often greater given the lower occupancy levels of public transport.
- Energy and CO₂ emissions per passenger are generally lower for public transport modes than private modes at peak periods, though metro and light rail system seem relatively energy intensive with bus-based modes being the most efficient. However, during off peak periods private modes can have lower energy use and emissions per passenger.
- Electric and hybrid cars can have an environmental performance similar to public transport modes, but are more costly than convention petrol and diesel vehicles. Similarly, hybrid and electric buses have better environmental performance than their diesel or CNG counterparts.

In terms of active modes the energy use, CO₂ emissions and costs are all substantially less than for the motorised modes. The capacity of these modes is not necessarily directly comparable with that of motorised modes, but in essence the capacity of cycling will be similar to mopeds and the capacity of walking will depend on the pedestrian infrastructure. Active modes, especially walking, are also part of an effective multi-modal public transport system.

Overall there is a role for all transport modes in an efficient urban transport system. Public transport should be the primary mode for volume movement of people at peak times, with rail modes providing high capacity for key routes. To maximise the environmental performance of public transport systems electric and hybrid systems are favoured. Private modes have a role particularly in off-peak periods when there is insufficient passenger loading to give high occupancy factors on public transport. Again electric and hybrid technologies will improve the environmental performance of private modes, especially during peak periods as they are less affected by slow traffic conditions. Active modes have a key role in shorter journeys and as part of the multi-modal transport system supporting other modes.

The detailed data provide in the appendices to this report is an information resource that can be used by cities to assess the performance to transport modes relevant to their local condition.

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1 Introduction

Ricardo Energy & Environment (UK) and Transport e Territorio (TRT, Italy) have been commissioned by the European Commission to undertake a study on urban mobility and assessing and improving the accessibility of urban areas. This is the third deliverable for the study.

1.1 Study objectives and overview

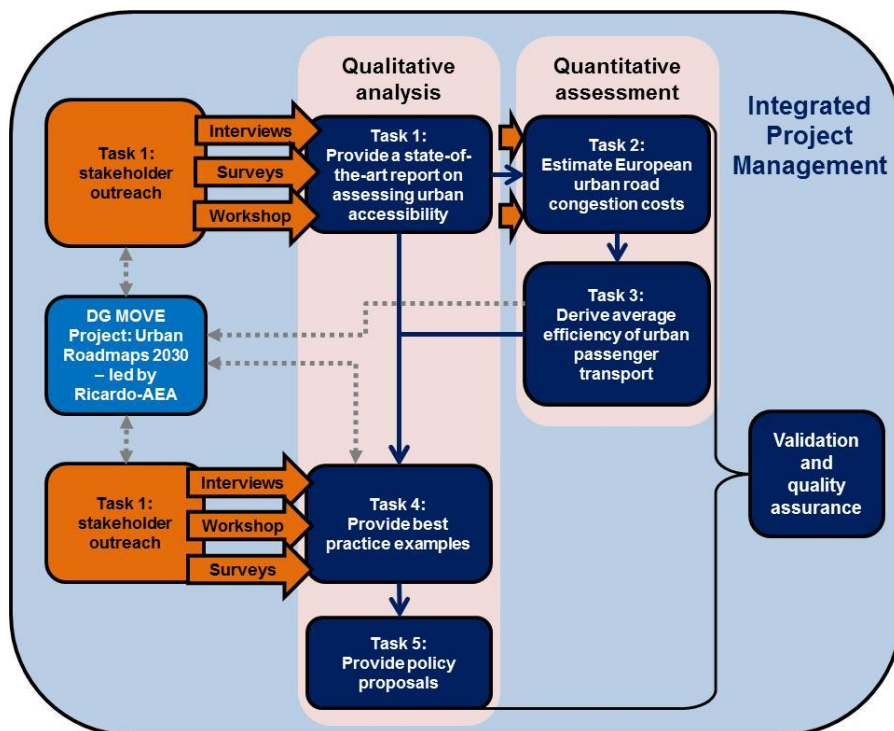
This study in urban accessibility has been designed to advance the understanding of urban accessibility and how it may be improved in order to promote better functioning of urban areas and make the transport system in Europe's urban areas more efficient.

The study consists of five key tasks, which are as follows:

- Task 1: State of the art report – urban accessibility
- Task 2: Estimation of European urban road congestion costs
- **Task 3: Relative efficiency of urban passenger transport modes**
- Task 4: Best practice examples – increasing accessibility
- Task 5: Policy proposals.

Figure 1.1 provides an overview of how the different tasks fit together within the project.

Figure 1.1: Overview of study tasks and methodology



The state of the art review in Task 1 made clear that accessibility differs from mobility, which just refers to the movement of people and goods, in that it involves consideration of the opportunities enabled by mobility. It also identified four key dimensions of accessibility:

- *Transport* – covering the various aspects of transport options available for passenger or freight movement, and is essentially the mobility element of accessibility.

- *Land-use* – the distribution and quality of destinations that passengers and goods need to access;
- *Individual* – the personal needs in terms of travel options or destinations;
- *Temporal* – the time constraints in relation to when destinations are open or transport services operate.

The key dimensions that can be influenced by urban policy are the transport and land-use dimensions, which together can be considered the factors that should be integrated within a Sustainable Urban Mobility Plan. Within the transport dimension the level of urban congestion and the efficiency of urban transport modes are key considerations in improving both mobility and accessibility. These two aspects are considered in a more quantitative assessment in Tasks 2 and 3, to provide data to help cities understand and improve these aspects of their urban transport system.

Tasks 4 and 5 go on to look at measures and policies that can help to improve accessibility. Task 4 considers the range of measures available at the city level and examples of best practice in applying them. Task 5 pulls together the lessons from all the other tasks and consider action at the national and European level that can support cities in delivering improvements to accessibility.

Tasks 1 to 4 will result in a stand-alone, final publishable report. Task 5 will pull together the outputs from the project and will be used to provide clear guidance on how urban accessibility can be improved.

1.2 Task 3: Relative efficiency of urban passenger transport modes

This report provides an assessment of the relative performance of different urban transport modes under a range of different operating conditions. These data will help cities in understanding the performance of different modes in their local situation with the aim of improving the transport dimension of urban accessibility. The work is output of Task 3 of the DG MOVE study on urban mobility (MOVE/C1/SER/2014-368/SI2.696637) "Assessing and improving urban accessibility". The general objective of the study is *"to improve understanding of urban accessibility and road congestion, and support a debate on understanding and improving urban accessibility in order to improve the functioning of urban areas and make the transport system more resource efficient."*

In the context of this study the performance of urban transport modes has been assessed in relation to:

- *Capacity* – defined in terms of passengers per vehicle and passengers per hour in relation to the capacity of the infrastructure
- *Energy use* – defined in terms of MJ per passenger km
- *CO₂ emissions* – defined in terms of CO₂ per passenger km
- *Cost* – defined in terms of Euros per passenger km

Costs and capacity of a transport mode are not concepts that have single, universally understood definitions; both can be defined from a number of different perspectives: therefore, suitable definitions have been identified for the purposes of this study. In addition, when considering energy use and emissions both direct (or tank to wheel) and indirect (well to tank) estimates have been made. This is important for electric vehicles where all of the emissions and a portion of the energy use is associated with the downstream generation of the electricity.

These metrics have been estimated for a range of urban transport modes and fuels as set out in Table 1-1 below. Capacity has only been assessed for the main modes and sub-modes, but the energy consumption, CO₂ emissions and costs have also been

assessed for each of the fuel types. The focus is on these motorised modes and fuels, however, commentary is also provided in relation to the metrics for the walking and cycling as key active modes for urban journeys and as part of the wider transport system.

Table 1-1 Urban transport modes and fuels assessed in the study

Main mode	Sub modes	Fuels
Passenger Car		Petrol Diesel Gas (CNG and LPG) Hybrid Electric (petrol only) Battery Electric
Motorcycle	Moped Motorcycle	Petrol
Bus	Midi Large Bus rapid transit	Diesel Gas (CNG) Hybrid electric (diesel) Battery electric
Rail	Tram/light rail Metro Heavy rail	Electric Diesel (heavy rail only)

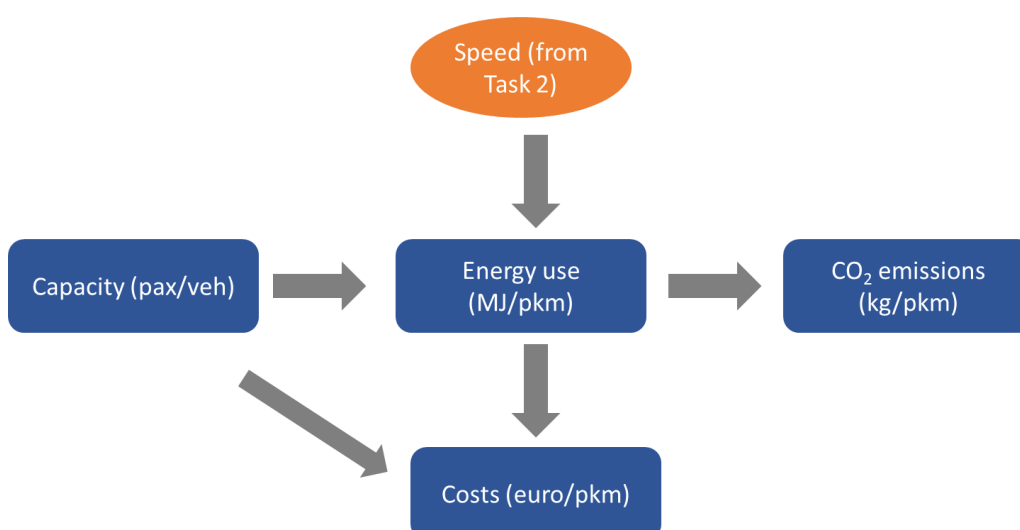
The metrics have also been calculated in relation to four different urban situations covering:

- Large metropolitan areas
- Medium cities
- Congested peak traffic conditions
- Un-congested off-peak traffic conditions.

These differing operating conditions will effect a range of factors that influence the operating performance of different transport modes such as service frequency, occupancy load factors and vehicle speeds.

There is a clear relationship between these different performance metrics as illustrated in Figure 1-2 below. In addition there is a link with the congestion assessment carried out in Task 2 of this study which has provided input into the average traffic speeds in peak and off-peak times for the two different city types.

Figure 1-2 Relationship between the different performance metrics



In the following sections (2, 3 and 4) we set out which data sources, literature and methodologies have been used in order to derive metric values. We also describe the potential limitations of the derived values and will furthermore summarise which other data sources have been consulted (and the reasons for not using them further in our analysis).

In Section 5 we provide some summary discussion and conclusions from the results. In addition the detailed results tables for each metric are provided in the Annexes to the report for use by cities.

2 Capacity of the transport modes

With reference to the capacity of transport modes, this term can have different meanings. For private transport, capacity is usually considered in terms of road capacity (although vehicles also have a capacity), while for road public transport vehicle size and frequency of service are much more relevant than physical capacity of infrastructure.

This difference has been considered in the data analysis and estimation of average figures taking into account on one hand the “theoretical” capacity of each transport mode, mainly based on physical infrastructures characteristics, on the other hand the “actual” capacity, representative of the performances in EU urban contexts. In fact, although a common definition of capacity is identified as the number of passengers which are transported in a unit of time by the different modes of transport, different factors can influence this measure, as shown in Table 2-1.

Table 2-1: Elements affecting capacity of different urban transport modes

Transport mode	Theoretical capacity				Actual capacity		
	Vehicle capacity (pass./ vehicle)	Road infr. capacity (vehicles/ hour)	Passenger Car Unit (PCU) factor (PCUs/ vehicle)	Theoretical Frequency of service (vehicles/ hour)	Occupancy rate (%)	Demand profile impact	Frequency of service (vehicles/ hour)
Private car	✓	✓			✓	✓	
Motorbike	✓	✓	✓		✓	✓	
Bus/ Trolleybus	✓			✓	✓		✓
Tram/ Metro/ LTR/ Heavy Rail	✓			✓	✓		✓

In summary, measures of both theoretical and actual capacity of urban transport modes have been estimated, as described in detail in the following paragraphs.

The estimation is based on a review of both literature and real-world conditions, although the latter are not the same in all cities and countries (e.g. occupancy rates or frequency of services). Nevertheless, some of the relevant elements required to estimate capacity are not really site-dependent, e.g. the capacity of a representative urban road, of an average bus, or of a typical metro system is relatively similar across the Union’s urban areas. Therefore, the literature survey considered two different types of sources:

- Technical literature concerning the theoretical capacity of transport modes
- Information on real world elements, although this aspect is challenging. In principle in any different urban area conditions can be different but evidence is often limited. We collected as much information as possible and organised the data in order to represent different conditions.

2.1 Cars

For private cars the theoretical capacity results from the vehicle capacity and the road infrastructure capacity. Vehicle capacity is assumed to be five passengers, while road infrastructure capacity depends on the road characteristics. For the purpose of this task, the reference value for urban road capacity in terms of traffic vehicle flow per hour has

been taken from Technical Note 10 of Transport for London's Roads Task Force¹, providing values of capacity for different urban road types.

We assumed as representative a two-way single carriageway road with two lanes (one per direction), with a carriageway width of 6.75 meters and a speed limit of about 50 km/h, representing a busy high street carrying predominantly local traffic with frontage activity including loading and unloading. For this road type the traffic vehicle flow per hour is 900 Passenger Car Units equivalent (PCUs) per hour. As a result, the theoretical capacity of average cars on this type of road is of 4,500 passengers per hour.

When assessing average capacity under "common, real-world conditions" some other factors have to be taken into account. First, under such conditions the occupancy rate of cars is generally much lower than five. Furthermore, in real-world conditions the traffic flow during off-peak period is lower than during peak, therefore a lower amount of vehicles per hour are travelling.

In order to estimate the influence of these factors, various sources have been taken into account. The average number of passengers in a car vehicle have been estimated on the basis of (JRC-IPTS, 2015)², (EMISIA, INFRAS, IVL, 2013)³, (Regione Lombardia, 2014)⁴.

Data have been analysed taking into account the differentiation by urban type (metropolitan area, medium city) and time period (peak, off-peak). Nevertheless, the analysis revealed that differences are not significant (around 1%) and therefore the differentiation has not been considered. Since values are different from country to country, the average EU28 value of 1.7 passenger per car (from JRC travel survey) has been used, i.e. about 34% of vehicle capacity.

As mentioned above, in real-world conditions the traffic flow during off-peak period is lower than during peak. Therefore a lower number of vehicles per hour are travelling. Based on the analysis of urban traffic counts in Italy, France⁵ and the UK⁶, the average hourly traffic flow during off-peak period is about 55% of road infrastructure capacity in Italy, 60% in France and 85% in the UK. Nevertheless, data in UK refers to Class A Trunk roads in urban area, which are larger than the type of road considered in the analysis. In all cases, peak period refers to traffic between 7am and 9am (morning peak) and 5pm and 7pm (evening peak), the rest of the day is considered off-peak. In the end, the representative share of off-peak road traffic has been set to 60% of road infrastructure capacity and applied to both urban types (metropolitan area, medium city) due to the restricted sample of data.

Therefore, in the real-world passenger car capacity on representative urban roads is much less than 4,500 passengers/hour:

- During **peak period**, actual capacity is about 1,530 passengers/hour (considering 34% of vehicle capacity)
- During **off-peak period**, actual capacity is about 920 passengers/hour (considering 34% of vehicle capacity and 60% of road infrastructure capacity).

¹<http://www.tfl.gov.uk/cdn/static/cms/documents/technical-note-10-what-is-the-capacity-of-the-road-network-for-private-motorised-traffic.pdf>

² <http://publications.jrc.ec.europa.eu/repository/handle/JRC96151>

³ <http://traccs.emisia.com/download.php>

⁴ <https://www.dati.lombardia.it/browse?category=Mobilit%C3%A0+e+trasporti>

⁵<http://www.enroute.ile-de-france.developpement-durable.gouv.fr/les-comptages-a174.html>

⁶ <http://www.dft.gov.uk/traffic-counts/>

Table 2-2: Theoretical and actual capacity of car mode

Urban type	Time period	Vehicle capacity (pass/veh)	Road infr. Capacity (veh/h)	Theoretical capacity (pass/h)	Occupancy rate (%)	Demand profile impact	Actual capacity (pass/h)
Metropolitan area	Peak	5	900	4,500	34%	1	1,530
	Off-peak					0.6	920
Medium city	Peak					1	1,530
	Off-peak					0.6	920

Source: TRT estimation

2.2 Mopeds and motorcycles

Mopeds and motorcycles are similar to cars. However, on the one hand they occupy less space (thus the same road can host more motorbikes than cars) while, on the other hand, their vehicle capacity is limited to one or two passengers. The theoretical capacity of mopeds/motorcycles is therefore the results of vehicle capacity, road infrastructure capacity and the coefficient of equivalence of vehicles in terms of Passenger Cars Unit (PCU). Vehicle capacity is assumed to be two passengers for motorcycle and one for moped⁷, while the reference value for urban road capacity is the same estimated for cars, i.e. 900 PCU per hour (see Table 2.1).

The coefficient of equivalence of vehicles in terms of Passenger Cars Unit (PCU) for mopeds and motorcycles has been set to 0.5, as generally estimated from road occupancy analysis e.g. from Lee et Al. (2010), where it is stated that "in a single-lane saturation flow, the lane width does not affect the PCUs significantly and the PCU value measured is 0.46"⁸. As a result, the theoretical capacity of motorcycles is of 3,600 passengers per hour and 1,800 passengers per hour for mopeds.

As already mentioned for cars, under real-world conditions some other factors have to be taken into account. The same aspects have been considered: the occupancy rate is generally lower than two for motorcycle and traffic flow during off-peak period is lower than during peak.

The average number of passengers on a motorcycle have been estimated on the basis of the TRACCs project (2013) database, reporting data by country. The average EU28 value of 1.1 passengers per motorcycle has been used, i.e. about 55% of vehicle capacity. No information was available on differentiation by urban type (metropolitan area, medium city) and time period (peak, off-peak). For moped, the occupancy rate is obviously 100% of vehicle capacity, since it is set to one.

The impacts on actual capacity related to reduced demand during off-peak have been assumed to be the same as car mode (see Table 2.1), i.e. 60% of road infrastructure capacity. Therefore, in the real-world motorcycle capacity on representative urban roads is much reduced:

- During **peak periods**, actual capacity of motorcycles is about 1,980 passengers/hours (considering 55% of vehicle capacity) and 1,800 passengers/hours for moped;
- During **off-peak periods**, actual capacity of motorcycles is about 1,180 passengers/hours (considering 55% of vehicle capacity and 60% of road infrastructure capacity) and 1080 passengers/hours for moped (considering 60% of road infrastructure capacity).

⁷ Although in several countries 2 passengers are allowed to travel on mopeds under specific circumstances, e.g. age of the drivers or years of driving licence.

⁸ (Tzu-Chang Lee John W. Polak Michael G. H. Bell Mar, 2010)

Table 2-3: Theoretical and actual capacity of motorcycle mode

Urban type	Time period	Vehicle capacity (pass/veh)	Road infr. Capacity (veh/h)	Theoretical capacity (pass/h)	Occupancy rate (%)	Demand profile impact	Actual capacity (pass/h)
MOTORCYCLE							
Metropolitan area	Peak	2	1,800	3,600	55%	1	1,980
	Off-peak					0.6	1,180
Medium city	Peak					1	1,980
	Off-peak					0.6	1,180
MOPED							
Metropolitan area	Peak	1	1,800	1,800	100%	1	1,800
	Off-peak					0.6	1,080
Medium city	Peak					1	1,800
	Off-peak					0.6	1,080

Source: TRT estimation

2.3 Buses

For buses (and trolleybus) in theory one could assume to compute the capacity in the same way as for cars, whilst taking into consideration that a bus has a higher passenger capacity than a car i.e. it is equivalent to more than 1 PCU. However, in the real world, the “supply-side” limit of capacity is not the infrastructure but the frequency of service. Therefore the estimation of the theoretical capacity of the frequency of service and vehicle capacity has been taken into account.

In terms of vehicle capacity, the following assumptions have been made according to the specific sub-mode:

- Midi: 60 passenger per vehicle (10 meter bus, e.g. Plaxton pointer)
- Large: 100 passenger per vehicle (12 meter bus)
- BRT: 140 passenger per vehicle (18 meter bus).

Data have been estimated from UK bus length categories for the estimation of emission factors and on the basis of bus manufacturers’ information.

With reference to the frequency of service for the estimation of theoretical capacity, the maximum realistic frequency has been assumed equal to 20 vehicles per hour, i.e. with a 3-minute headway, without any differentiation by urban type or time period.

As a result, the following value of theoretical capacity are estimated for bus sub-modes:

- Midi: 1,200 passengers per hour
- Large: 2,000 passengers per hour
- BRT: 2,800 passengers per hour.

When assessing bus average capacity under “common, real-world conditions” it should be considered that on the demand side the occupancy rate is lower than vehicle capacity and varies significantly on the basis of time period. Furthermore, also the frequency of service varies during the day and is generally lower than the maximum realistic frequency mentioned above.

In order to estimate the occupancy rate of bus vehicles, the following data sources have been used as reference: (EMISIA, INFRAS, IVL , 2013), (TRT, Frahunofer-ISI, 2013)⁹, EEA, Indicator factsheet TERM29 for occupancy rates in passenger transport (bus, train), UK annual bus statistics¹⁰.

Unfortunately data are not available with the required level of detail and therefore assumptions have been made in order to provide a realistic picture of real-world conditions. Firstly, it has been assumed that the bus occupancy rate during peak period is the same for all sub-modes in the same urban context. With reference to off-peak, higher occupancy rates are assumed for large buses and Bus Rapid Transit (BRT) which are expected to be in service on main routes (with higher demand).

The occupancy rate during peak period is supposed to be higher than 75%, otherwise the surplus capacity within the system wouldn't be economically affordable by the transport company¹¹. Furthermore, it has been assumed that occupancy rate in metropolitan area is higher than in medium city.

Since average daily occupancy rate data are available from data sources, the occupancy rate during off-peak period has been estimated in order to fit the data on average occupancy rate considering the whole day (and the whole network). I.e. with occupancy rate of 75% in peak period and 10% in off-peak period the daily average is 26% ($75\% * 0.25 + 10\% * 0.75$, assuming 4 peak hours out of 16 hours of service).

In the end, the following value of occupancy rate has been estimated:

- Metropolitan area:
 - Midi bus: peak 86%, off-peak 12% (daily average 30%)
 - Large bus: peak 86%, off-peak 46% (daily average 56%)
 - BRT: peak 86%, off-peak 46% (daily average 56%)
- Medium city:
 - Midi bus: peak 75%, off-peak 10% (daily average 26%)
 - Large bus: peak 75%, off-peak 40% (daily average 49%)
 - BRT: peak 75%, off-peak 40% (daily average 49%)

From the supply-side point of view, data on frequency of service has been estimated on the basis of the following sources:

- Public transport service timetables in various EU cities (Brescia, Oslo, Genova, Milano, Glasgow, Copenhagen, Helsinki, Lyon, Seville, Nantes and Edinburgh)
- (TCRP, 2007)
- (Cantarella).

The following values of frequency of service has been estimated:

- Metropolitan area:
 - Midi bus: peak 8 vehicles per hour (approximately 8-minute headway), off-peak 6 vehicles per hour (10-minute headway)
 - Large bus: peak 12 vehicles per hour (5-minute headway), off-peak 7 vehicles per hour (9-minute headway)
 - BRT: peak 17 vehicles per hour (4-minute headway), off-peak 10 vehicles per hour (6-minute headway)
- Medium city:

⁹ http://www.astra-model.eu/doc/ASSIST_D4-2_ASTR-EC_Model.pdf

¹⁰

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/11854/annual-bus-statistics-2011-12.pdf

¹¹

<http://www.ppiaf.org/sites/ppiaf.org/files/documents/toolkits/UrbanBusToolkit/assets/1/1c/1c13.html>

- Midi bus: peak 6 vehicles per hour (10-minute headway), off-peak 4 vehicles per hour (15-minute headway)
- Large bus: peak 8 vehicles per hour (8-minute headway), off-peak 5 vehicles per hour (12-minute headway)
- BRT: peak 17 vehicles per hour (4-minute headway), off-peak 10 vehicles per hour (6-minute headway).

Therefore, in the real world bus capacity is heavily dependent on time period and much lower than theoretical capacity, as reported in the following table.

Table 2-4: Theoretical and actual capacity of bus mode

Urban type	Time period	Vehicle capacity (pass/veh)	Th. Service frequency (veh/h)	Theoretical capacity (pass/h)	Occupancy rate (%)	Service frequency (veh/h)	Actual capacity (pass/h)
MIDI BUS							
Metropolitan area	Peak	60	20	1,200	86%	8	410
	Off-peak				12%	6	40
Medium city	Peak				75%	6	270
	Off-peak				10%	4	20
LARGE BUS							
Metropolitan area	Peak	100	20	2,000	86%	12	1,040
	Off-peak				46%	7	320
Medium city	Peak				75%	8	600
	Off-peak				40%	5	200
BRT							
Metropolitan area	Peak	140	20	2,800	86%	17	2,070
	Off-peak				46%	10	640
Medium city	Peak				75%	17	1,800
	Off-peak				40%	10	560

Source: TRT estimation

2.4 Rail

For trams and metro services (and heavy rail), capacity is theoretically a matter of infrastructure and vehicle capacity. In the real world occupancy rates are again lower than 100% and the frequency of service can often be below the theoretical maximum frequency. Therefore for the estimation of the theoretical capacity the frequency of service and vehicle capacity has been taken into account, following the same approach used for the bus mode (see Table 2.3).

In terms of vehicle capacity, the following assumptions have been made depending on the specific sub-mode:

- Tram/light rail:
 - Metropolitan area: 285 passenger per vehicle

- Medium city: 170 passenger per vehicle
- Metro:
 - Metropolitan area: 1,200 passenger per vehicle
 - Medium city: 550 passenger per vehicle
- Heavy rail: 1000 passenger per vehicle.

Data have been estimated from a sample of tram and metro services in various cities (Brescia, Oslo, Genova, Milano, Glasgow, Copenhagen, Helsinki, Lyon and Seville).

With reference to the frequency of service, for the estimation of theoretical capacity, the maximum realistic frequency has been assumed equal to 20 vehicles per hour (3-minute headway) for tram, 30 vehicles per hour (2-minute headway) for metro and 15 vehicles per hour (4-minute headway) for heavy rail. Differentiation by urban type or time period are not considered in this case.

As a result, the following value of theoretical capacity are estimated for rail sub-modes:

- Tram/light rail
 - Metropolitan area: 5,700 passengers per hour
 - Medium city: 3,400 passengers per hour
- Metro:
 - Metropolitan area: 36,000 passengers per hour
 - Medium city: 16,500 passengers per hour
- Heavy rail: 15,000 passengers per hour.

As already mentioned for buses, under real-world conditions it should be considered that on the demand-side the occupancy rate is lower than vehicle capacity and varies significantly on the basis of time period. Furthermore, the frequency of service varies during the day and is generally lower than the maximum realistic frequency mentioned above. In order to estimate the occupancy rate of rail vehicles, the following data sources have been used as reference: (TRT, Fraunhofer-ISI, 2013), EEA Indicator factsheet TERM29 for occupancy rates in passenger transport (bus, train).

Unfortunately data are not available with the required level of detail. Therefore assumptions have been made in order to provide a realistic picture of real-world conditions. For tram/light rail mode and heavy rail it has been assumed that the occupancy rates are the same as estimated for large bus / BRT (see Table 2.3).

For metro the occupancy rate during peak period is assumed to be higher than the other urban modes, assuming that this service is provided along main routes with higher demand. In line with the other modes, it has been assumed that occupancy rate in metropolitan area is higher than in medium city. During off-peak it has been assumed that occupancy rate are the same estimated for large bus / BRT.

In the end, the following value of occupancy rate has been estimated:

- Metropolitan area:
 - Tram/light rail: peak 86%, off-peak 46% (daily average 56%)
 - Metro: peak 99%, off-peak 46% (daily average 59%)
 - Heavy rail: peak 86%, off-peak 46% (daily average 56%)
- Medium city:
 - Tram/light rail: peak 75%, off-peak 40% (daily average 49%)
 - Metro: peak 86%, off-peak 40% (daily average 52%)
 - Heavy rail: peak 75%, off-peak 40% (daily average 49%).

From the supply-side point of view, data on frequency of service has been estimated on the basis of the following sources:

- Public transport service timetable in various EU cities (Brescia, Oslo, Genova, Milano, Glasgow, Copenhagen, Helsinki, Lyon, Seville, Nantes and Edinburgh)

- (Cantarella)

The following values of frequency of service have been estimated:

- Metropolitan area
 - Tram/light rail: peak 13 vehicles per hour (5-minute headway), off-peak 7 vehicles per hour (9-minute headway)
 - Metro: peak 20 vehicles per hour (3-minute headway), off-peak 12 vehicles per hour (5-minute headway)
 - Heavy rail: peak 6 vehicles per hour (10-minute headway), off-peak 3 vehicles per hour (20-minute headway)
- Medium city
 - Tram/light rail: peak 9 vehicles per hour (7-minute headway), off-peak 7 vehicles per hour (9-minute headway)
 - Metro: peak 12 vehicles per hour (5-minute headway), off-peak 10 vehicles per hour (6-minute headway)
 - Heavy rail: peak 3 vehicles per hour (20-minute headway), off-peak 1 vehicles per hour (60-minute headway)

Therefore, in the real world urban rail capacity is heavily dependent on time period and much lower than theoretical capacity, as reported in the following table.

Table 2-5: Theoretical and actual capacity of urban rail mode

Urban type	Time period	Vehicle capacity (pass/veh)	Th. Service frequency (veh/h)	Theoretical capacity (pass/h)	Occupancy rate (%)	Service frequency (veh/h)	Actual capacity (pass/h)
TRAM/ LRT							
Metropolitan area	Peak	285	20	5,700	86%	13	3,200
	Off-peak				46%	7	920
Medium city	Peak	170		3,400	75%	9	1,150
	Off-peak				40%	7	480
METRO							
Metropolitan area	Peak	1200	30	36,000	99%	20	23,810
	Off-peak				46%	12	6,620
Medium city	Peak	550		16,500	86%	12	5,690
	Off-peak				40%	10	2,200
HEAVY RAIL							
Metropolitan area	Peak	1000	15	15,000	86%	6	5,180
	Off-peak				46%	3	1,380
Medium city	Peak				75%	3	2,250
	Off-peak				40%	1	400

Source: TRT estimation

2.5 Active modes

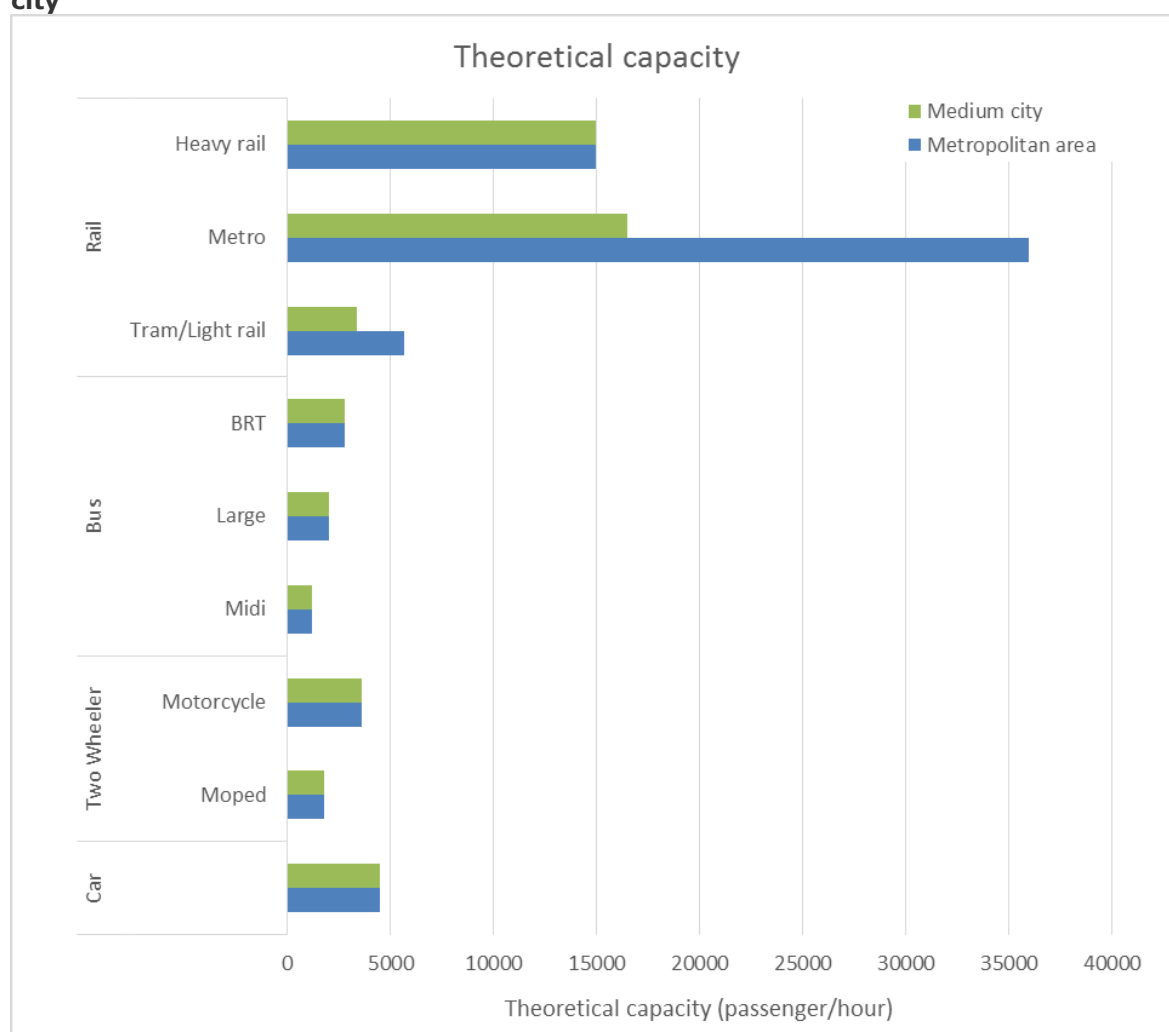
Active modes, primarily walking and cycling, are an important urban transport mode in themselves but also as a link between the public transport system and the full door-to-door journey. The capacity of active modes is not necessarily directly comparable with that of the other modes discussed above. The capacity of walking as an urban transport mode is very dependent on the pedestrian area and its use, from small side streets with narrow pavements where flows will be very low to large pedestrian areas where flows will be very high. Also pedestrian areas and sidewalks are used for other social purposes. Therefore, no direct comparison is given here.

With regards cycling a simple assumption can be made that the capacity for cycling on a typical road is the same as for a moped as they are both single person two-wheeled vehicles.

2.6 Results

In this section the outcome of the estimations made using the data and the assumption explained above are revealed. In terms of theoretical capacity (**Figure 2-1**), metro services provide the highest capacity in metropolitan areas as well as in medium cities (where heavy rail also plays a significant role).

Figure 2-1: Theoretical capacity (passenger/hour) in a metropolitan area and medium city



Source: TRT estimation

At a first sight, it might be surprising to notice that cars and motorcycles provide higher values of theoretical capacity in comparison to buses. Nevertheless, these values are explained when considering that a full utilisation of vehicle capacity is assumed (i.e. 5 passengers for cars and 2 passengers for motorcycle) and that even theoretical bus capacity is constrained by frequency of service.

Among public transport modes, as expected, BRT and large bus services provide better performances than midi buses in terms of theoretical capacity. Tram/light rail services are comparable to BRT in medium cities, while in metropolitan areas it is assumed that larger vehicles are used and therefore the theoretical capacity is higher than for the other modes.

If average capacity under "common, real-world conditions" is considered rather than the theoretical capacity, the results show a different picture. In particular, the time of the day considered makes a huge difference. During peak periods public transport modes generally provide higher capacity than private modes, while during off-peak periods the opposite is expected.

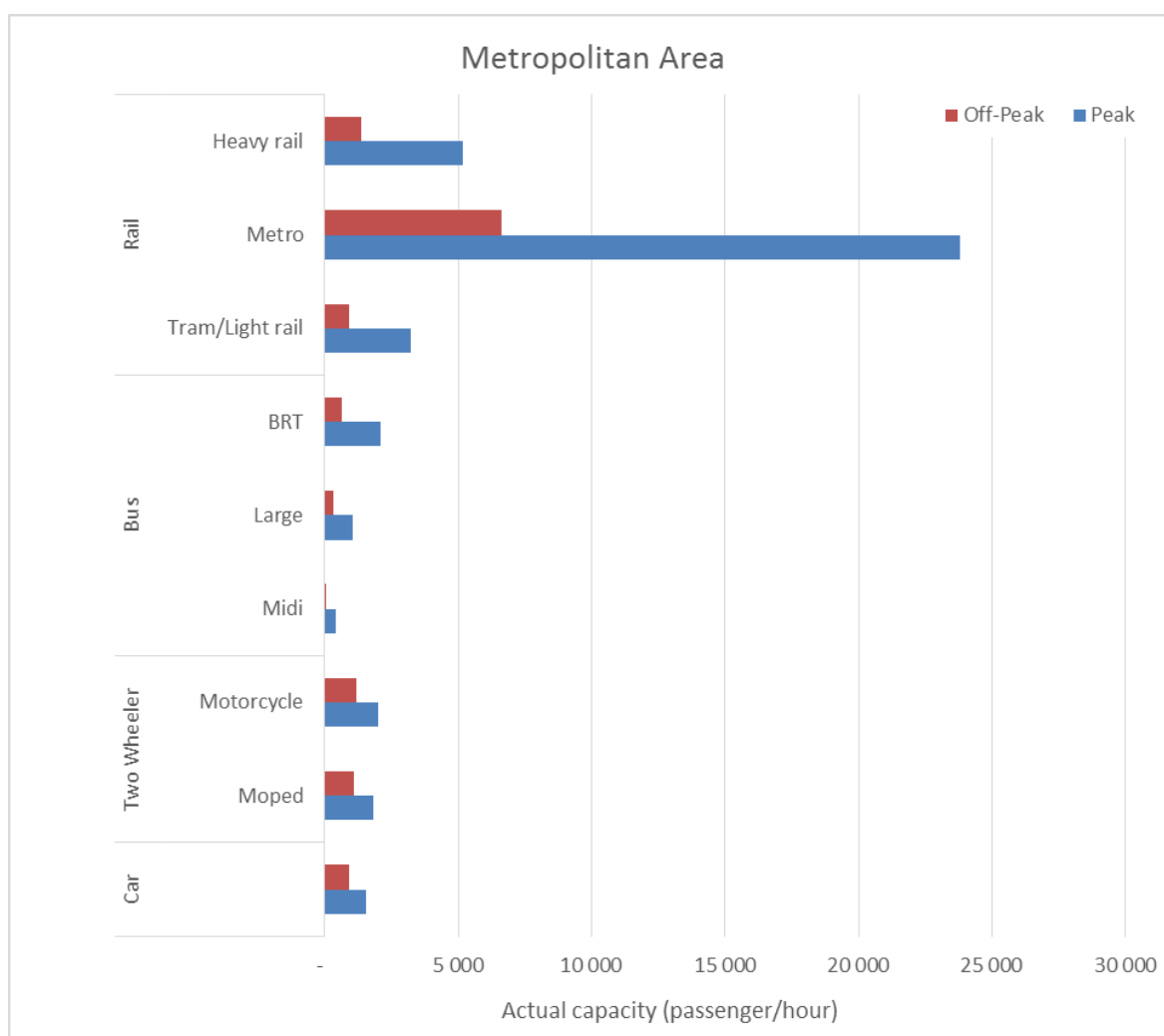
In metropolitan areas (see Figure 2-2), metro services again provide the greatest capacity during both peak and off-peak periods, although with very different values (about 24,000 and 6,600 passenger per hour respectively).

During peak periods, heavy rail and tram/light rail provide higher capacity values with respect to bus, i.e. about 5,200 and 3,200 passenger per hour respectively. BRT capacity is close to 2,000 passenger per hour, large and midi bus service provides lower performances, i.e. about 1,000 and 400 passenger per hour respectively.

The capacity of cars and moped/motorcycle (1,500 and 1,800 passengers per hour) is below that of heavier public transport modes but higher than bus capacity.

During off-peak periods, private road modes provide better or at least similar performances in comparison to most public transport services. For cars, mopeds and motorcycles values are estimated in a range of 900 to 1,100 passengers per hour - the same as tram/light rail. Only heavy rail (and metro) has a higher capacity of about 1,400 passengers per hour.

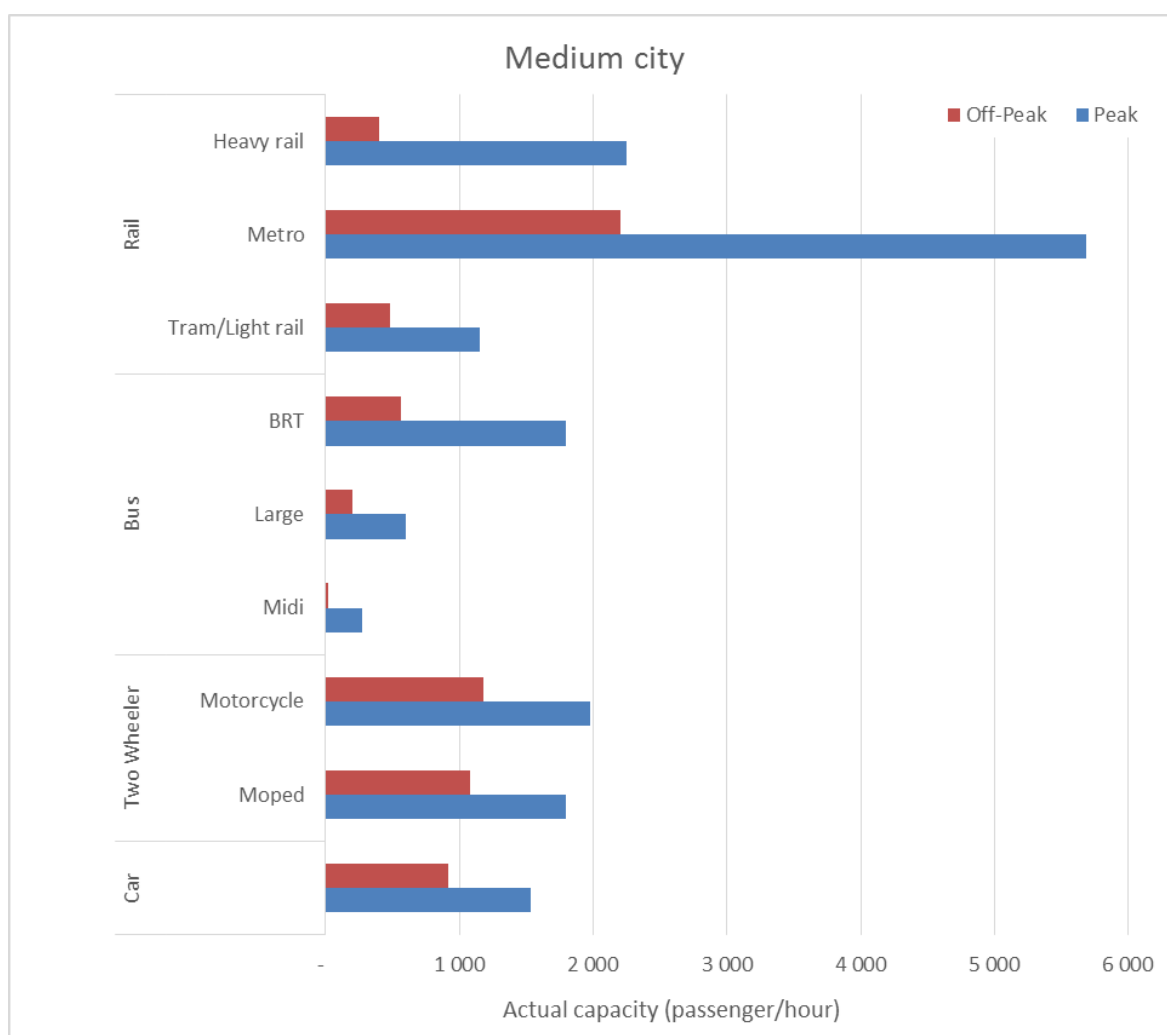
The actual capacity of bus public transport services in actual conditions is strongly affected by low frequencies and low occupancy factors. For BRT and large bus service values are estimated as 600 and 300 passenger per hour respectively, while for midi buses it is less than 50 passenger per hour. Of course these actual conditions are average ones and might not reflect specific circumstances.

Figure 2-2: Actual capacity (passenger/hour) in a metropolitan area

Source: TRT estimation

In medium cities (see Figure 2-3) the estimated actual capacity by mode is lower than in metropolitan areas for public transport modes (because of lower frequencies) while for private modes the capacity is the same or even slightly higher (for motorcycles) because of lower congestion.

The comparison by mode provides very similar conclusions to those observed for metropolitan areas.

Figure 2-3: Actual capacity (passenger/hour) in a medium city

Source: TRT estimation

3 Energy consumption and CO₂ emissions

This section describes the approach used to derive average energy consumption figures (per pkm) and average CO₂ emission figures (per pkm) for a range of urban passenger transport modes (shown in Table 1-1) that are representative of transport systems across the European Union (EU). Energy consumption and CO₂ emissions are two closely related metrics that can be used to assess the **environmental performance** of urban transport options.

The average energy consumption was calculated for four urban passenger transport modes (car, powered two wheelers, bus and rail) and presented in terms of megajoules per passenger kilometre (MJ/pkm) in this project for both direct energy use (tank to wheel) and total life cycle energy use (well to wheel). These metrics are representative of the average environmental performance of transport systems across the EU; by presenting the results in terms of pkm, the figures can be used to develop comparisons between different modes of transport, which may be useful to a broad range of audiences.

Data concerning the average energy consumption for each transport mode (in terms of MJ per vehicle km) was first collected. Where applicable, data was gathered by sub-mode and by fuel type (as shown in Table 1-1). Using the vehicle capacity and occupancy factors derived in Subtask 3.1 of this project (see Section 2), average energy consumption figures could then be calculated in terms of MJ/pkm depending on the type of urban area (metropolitan area or medium city) and the time of the journey (peak or off-peak).

The CO₂ emissions per pkm are derived from the energy use results using CO₂ emissions factors related to both direct emissions (from combustion of the fuel) and indirect emissions from production of the fuel. This provides CO₂ emissions results on a well to wheel (WTW) basis. The detailed methodology and data sources used for each mode are described in the following sections.

3.1 Cars

The EU passenger car fleet comprises a diverse mixture of vehicles with varying characteristics. For example, cars may vary in terms of their size, fuel type, or age, all of which are factors that influence environmental performance. The objective of this subtask was to calculate the fuel consumption of an **average** passenger car in the EU fleet for **six fuel types** (petrol, diesel, LPG, CNG, hybrid vehicles and battery electric vehicles) and **four urban transport scenarios** (metropolitan area peak, metropolitan area off-peak, medium city peak and medium city off-peak). The definition of an average vehicle requires information relating to the fleet composition; this was obtained from the TRACCS project, which provides data for 2010 (EMISIA, INFRAS, IVL, 2013). Fuel consumption data was obtained from COPERT 4 v11 (EMISIA, 2014).

As outlined in Figure 3-1 (and described in further detail below), a six-step process was used to determine the average direct or tank-to-wheel (TTW) and lifecycle or wheel-to-wheel (WTW) fuel consumption in terms of megajoules per passenger kilometre (MJ/pkm) for each fuel type.

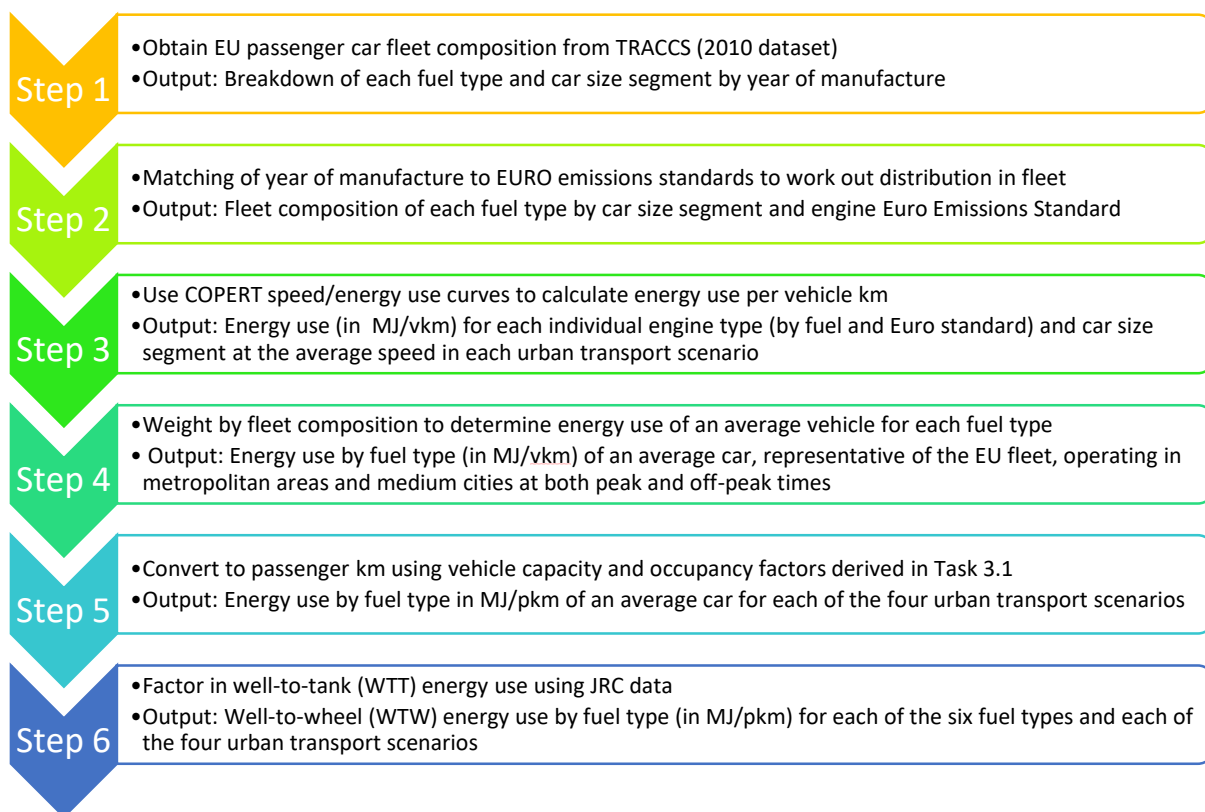
Step 1: Obtain EU passenger car fleet composition by fuel type from TRACCS

The first step of the process was to obtain information concerning the EU passenger car fleet and the share of vehicle sizes and efficiencies within each fuel type. The TRACCS dataset provides a breakdown of the 2010 EU passenger car fleet by fuel type (petrol, diesel, LPG, CNG), size segment (small, lower-medium, upper-medium, and executive) and year of manufacture. As no data relating to the hybrid and electric vehicle fleet in

the EU was available (from TRACCS, nor from alternative sources), the same size distribution as for Euro 5 petrol cars was assumed.

The output of this first step was a breakdown of each fuel type by car size segment and year of manufacture. An example data point here would be the percentage (of all the petrol cars in the TRACCS 2010 dataset) of lower-medium segment cars that were manufactured in 2009.

Figure 3-1: Overview of the methodology used to calculate energy consumption figures



Step 2: Matching of year of manufacture to Euro Emissions Standards to calculate a breakdown of vehicles by fuel type, vehicle size segment and Euro Emissions Standard

A breakdown of vehicles by year of manufacture/age of the vehicle allowed the categorisation of vehicles by Euro Emissions standard. This was achieved by matching of year of manufacture to the Euro standard requirements for that year. Vehicles with different Euro standard engines show differences in fuel consumption, therefore understanding the fleet composition allows for a more accurate definition of an average European passenger car. A breakdown of the fleet in this way was also required because COPERT energy use data can be calculated by engine size, fuel type and Euro Emissions Standard.

The output of this step was a breakdown of each fuel type by car size segment and by Euro standard. For example, Table 3-1 shows the breakdown for small, petrol cars.

Table 3-1: Example output from Step 1 showing the breakdown of petrol small passenger cars

Fuel	Segment	Euro standard	% of fuel type
Petrol	Small	Pre-Euro	5.22%
Petrol	Small	Euro 1	7.72%
Petrol	Small	Euro 2	12.97%
Petrol	Small	Euro 3	16.19%
Petrol	Small	Euro 4	11.38%
Petrol	Small	Euro 5	1.99%

Source: Ricardo Energy & Environment analysis of TRACCS data

Step 3: Use COPERT fuel consumption curves to calculate energy consumption per vkm

The energy usage of a vehicle varies depending on the operating conditions for a vehicle, for example the average speed travelled. As such, speed-emission/energy consumption curves have been developed to calculate the average emissions/fuel consumption at different speeds. Passenger car fuel consumption data was derived from COPERT 4 v11 (EMISIA, 2014) for petrol, diesel, LPG and CNG vehicles. For CNG vehicles, the same curves as for petrol vehicles were used since they essentially use the same spark ignition technology and the so the energy use in MJ/km will essentially be the same. For hybrid and electric vehicles, data was based on a study carried out by Ricardo Energy & Environment for the UK Department for Transport on speed emission/energy curves for ultra-low emission vehicles (Ricardo-AEA, 2015) but with uplift to reflect new data on real world performance of EVs. These energy curves are based on those from COPERT 4. All passenger car hybrid vehicles were assumed to be petrol hybrids.

Prior to using the COPERT energy curves, the TRACCS size segments were matched to the equivalent category in COPERT. For example, a small, Euro 4 petrol vehicle in TRACCS was assumed to be equivalent to a Euro 4 petrol vehicle with an engine size <0.8 litres in COPERT.

Four urban transport scenarios are covered in this project: two types of urban area (metropolitan area or medium city) and two travel times (peak or off-peak). Different average speeds are applicable depending on whether travel is taking place in a metropolitan area or medium city and whether the journey takes place at peak time, or at off-peak time. These are shown in Table 3-2.

Table 3-2: Average speeds used in the analysis for cars

Metropolitan area		Medium city	
Peak	Off-Peak	Peak	Off-peak
25 km/h	40 km/h	30 km/h	45 km/h

Source: TRT estimation

The output of this third step was a list of energy consumptions in each of the four urban transport situations for all passenger car types considered in this project.

Step 4: Weight by fleet composition to obtain energy usage of an average vehicle

The next step was to take the fuel consumption calculated for each of the individual vehicle types in Step 3 and to weight these based on the fleet composition calculated in

Step 2. This resulted in an average energy consumption figure for each fuel type (in MJ/vkm) that is representative of the EU fleet.

For LPG passenger cars only a single speed-energy curve was available in COPERT, therefore fleet composition was not taken into consideration. Furthermore, no data relating to the EU hybrid and electric vehicle fleet was available (from TRACCS, nor from alternative sources), therefore the same size distribution as for Euro 5 petrol cars was assumed when weighting the energy consumption.

Step 5: Convert to pkM using vehicle capacity and occupancy factors

To convert from energy usage per vehicle kilometre to energy usage per passenger kilometre, the vehicle capacities and occupancy factors described in Section 2 were utilised. For all cars, the vehicle capacity was 5 passengers per vehicle, while the occupancy factor was 34% for all journeys. The following formula was used:

$$\frac{\text{Energy use per vehicle in MJ per vkm}}{(\text{Vehicle capacity} \times \text{occupancy factor})}$$

Step 6: Inclusion of well-to-tank energy usage

The energy usage associated with the production and distribution of a fuel prior to its use in a vehicle is an important consideration when comparing the efficiency of different transport options. The energy usage associated with these processes is often referred to as well-to-tank (WTT) emissions. The WTT factors (in terms of MJ energy used per MJ of fuel produced) used in this project were obtained from the most recent JRC WTT Report Version 4.a (JRC, 2014). These are reproduced in Table 3-3 below, along with the specific JRC code and description in the comments column.

Table 3-3: WTT emission factors used in this project

Fuel	WTT energy use (MJ/MJ)	Comments
Petrol	0.1842	Code: COG1 - Gasoline fuel - Crude oil from typical EU supply, transport by sea, refining in EU (marginal production), typical EU distribution and retail.
Diesel	0.2042	Code: COD1 - Diesel fuel - Crude oil from typical EU supply, transport by sea, refining in EU (marginal production), typical EU distribution and retail.
LPG	0.1184	Code: LRLP1 - LPG - LPG from remote natural gas field, purification and liquefaction at source, long-distance sea transport, distribution by road to retail point.
CNG	0.1653	Code: GMCG1 - CNG - EU-mix natural gas, transport to EU by pipeline (2500 km), distribution through gas trunk lines and low pressure grid, compression to CNG at retail point.
Petrol Hybrid	0.1842	Assumed same as petrol
Electric	2.2616	Code: EMEL - EU-mix - EU-mix electricity (Low voltage)

Source: (JRC, 2014)

The final results for passenger cars are presented in Section 3.6.

3.2 Mopeds and motorcycles

For mopeds and motorcycles the same overall methodology as for cars was used (see Figure 3-1). Specific assumptions for mopeds and motorcycles in relation to the methodology are described below.

Steps 1 and 2: Fleet data from TRACCS and Euro Emissions Standards

TRACCS fleet data for powered two wheelers was divided into two categories for mopeds (2-stroke and 4-stroke) and two categories for motorcycles (2-stroke and 4-stroke). As for cars, these were matched to the appropriate Euro Emissions Standards based on the year of manufacture. A breakdown by Euro standard is shown in Table 3-4 for mopeds and Table 3-5 for motorcycles.

Table 3-4: Moped fleet composition based on TRACCS data

Fuel	Segment	Euro standard	% of fuel type
Petrol	Mopeds - 2-stroke	Pre-Euro	37.99%
Petrol	Mopeds - 2-stroke	Euro 1	25.61%
Petrol	Mopeds - 2-stroke	Euro 2	10.44%
Petrol	Mopeds - 2-stroke	Euro 3	19.97%
Petrol	Mopeds - 4-stroke	Pre-Euro	2.54%
Petrol	Mopeds - 4-stroke	Euro 1	1.61%
Petrol	Mopeds - 4-stroke	Euro 2	0.54%
Petrol	Mopeds - 4-stroke	Euro 3	1.28%

Source: Ricardo Energy & Environment analysis of TRACCS data

Table 3-5: Motorcycle fleet composition

Fuel	Segment	Euro standard	% of fuel type
Petrol	Motorcycles - 2-stroke	Pre-Euro	4.99%
Petrol	Motorcycles - 2-stroke	Euro 1	3.75%
Petrol	Motorcycles - 2-stroke	Euro 2	2.33%
Petrol	Motorcycles - 2-stroke	Euro 3	2.68%
Petrol	Motorcycles - 4-stroke	Pre-Euro	29.17%
Petrol	Motorcycles - 4-stroke	Euro 1	22.19%
Petrol	Motorcycles - 4-stroke	Euro 2	12.13%
Petrol	Motorcycles - 4-stroke	Euro 3	22.77%

Source: Ricardo Energy & Environment analysis of TRACCS data

Steps 3 and 4: Calculation of energy consumption using COPERT energy curves and weighting by fleet composition to obtain energy usage of an average vehicle

For the purposes of this project, the average speed of mopeds and motorcycles were assumed to be the same as for cars; these are shown in Table 3-6. However, in reality, it is possible that mopeds and motorcycles may travel at increased speeds in some urban areas by moving between queued traffic. This is particularly likely in heavily congested areas.

Table 3-6: Average speeds used in the analysis for mopeds and motorcycles

Metropolitan area		Medium city	
Peak	Off-Peak	Peak	Off-peak
25 km/h	40 km/h	30 km/h	45 km/h

Source: TRT estimation

To define an EU average moped and average motorcycle, the fuel consumption data obtained in Step 3 was then weighted according to the fleet composition shown in Table 3-4 and Table 3-5 above. This resulted in average energy use values for mopeds and motorcycles in terms of MJ/vkm.

Steps 5 and 6: Vehicle capacity and occupancy factors and inclusion of well-to-tank energy usage

Vehicle capacity and occupancy factors were used to convert the MJ/vkm energy use values obtained in Step 4 into energy use metrics in terms of passenger kilometres. As described in 2.2, vehicle capacity and occupancy factors were calculated as part of Task 3.1 of this project and are as follows:

- Mopeds: vehicle capacity of 1, occupancy factor of 100% in all urban scenarios
- Motorcycles: vehicle capacity of 2, occupancy factor of 55% in all urban scenarios

The WTT factors shown in Table 3-3 in 3.1 were then used to account for energy usage associated with the production and distribution of fuels.

3.3 Buses

For buses the same overall methodology as for cars was used (see Figure 3-1). Specific assumptions for buses in relation to the methodology are discussed below.

Steps 1 and 2: Fleet data from TRACCS and Euro Emissions Standards

As for cars, mopeds and motorcycles, fleet data was obtained from TRACCS. This dataset contained data relating to only one category of urban bus (called 'urban bus' in the TRACCS dataset), whereas the objective of this project is to consider three sub-modes (midi bus, large urban bus and bus rapid transit). It is assumed that the fleet composition is similar for each type of bus, therefore the same fleet composition and consequently the same Euro standard distribution was applied across all sub-modes in Step 4.

Steps 3 and 4: Calculation of energy consumption using COPERT energy curves and weighting by fleet composition to obtain energy usage of an average vehicle

COPERT provides energy use curves for diesel buses for bus sizes equivalent to midi buses, large buses and BRT. In contrast to cars and powered two wheelers, the average speeds used for buses were lower, which represents typical bus journeys in urban areas. The speeds used in the analysis are shown in Table 3-7.

Table 3-7: Average speeds used in the analysis for buses

Metropolitan area		Medium city	
Peak	Off-Peak	Peak	Off-peak
14 km/h	17 km/h	16 km/h	19 km/h

Source: TRT estimation

As for cars and powered two wheelers, the energy consumption of the individual types of buses (e.g. Euro standard and size) was then weighted according to the TRACCS

data. This resulted in an average energy consumption (in MJ/vkm), representative of the EU fleet, for each of the bus sub-modes. In the weighting step, the same fleet distribution was used for all categories of diesel buses.

For other fuel types (diesel hybrid, CNG and electric) speed/energy curves were not available from COPERT, therefore conversion factors were used. These were obtained from a recent Ricardo Energy & Environment study for Transport for London (TfL) (Ricardo-AEA, 2014) and are shown in Table 3-8.

Table 3-8: Conversion factors used to scale from energy consumption of diesel buses to other fuels

Fuel Type	Conversion factor
CNG	1.25
Diesel Hybrid	0.61
Electric	0.31

Source: (Ricardo-AEA, 2014)

Steps 5 and 6: Vehicle capacity and occupancy factors and inclusion of well-to-tank energy usage

To convert from energy usage per vehicle kilometre to energy usage per passenger kilometre, the vehicle capacities and occupancy factors described in Section 2 were utilised. For buses, these varied depending on the type of bus (midi, large or BRT), urban area (metropolitan area, medium city) and time of journey (peak or off-peak). In order for well-to-tank energy consumption to be included, the factors listed in Table 3-3 in Section 3.1 were used. These are the same factors used as for other transport modes. For diesel hybrid vehicles, the same factor as for diesel was assumed.

3.4 Rail

Availability of rail data

For the transport modes already discussed in this report (cars, two wheelers and buses) detailed, high quality data concerning the EU fleet mix is available, in addition to speed-dependent energy usage information for distinct categories of vehicles. Research carried out in this task found that information concerning the typical energy consumption of urban passenger trains is more limited. For example, COPERT provides only a single speed-energy curve for rail transport, with no further detail on the sub-modes (e.g. light rail/tram, metro, heavy rail). The overall lack of data for rail may be because it is difficult to define a typical train as passenger rail systems tend to be customised according to local needs (in terms of the size of trains, number of carriages, average speed travelled, capacity, distance between stops).

Due to the lack of data, an alternative methodology was therefore followed for rail transport (instead of following the methodology detailed in Figure 3-1). A literature review was carried out to gain an understanding of the typical efficiencies of urban rail transport across the EU. In most cases, data was only available in terms of energy use per passenger kilometre, although figures were collected for a range of metrics (e.g. fuel/energy use per vehicle kilometre, CO₂ emissions per km) and were compared on an energy use per passenger km basis wherever possible.

Average energy consumption of rail transport sub-modes (in MJ/pkm)

The final energy usage statistics for this project were obtained from the STREAM project (Study on the Transport Emissions of All Modes) carried out by CE Delft (CE Delft, 2008). This was one of the only data sources to include environmental performance metrics for all rail sub-modes considered in this project. It was judged to be more appropriate to use a single source, rather than to take figures from multiple sources, as different

assumptions (such as those concerning vehicle capacities and occupancy factors) have a direct influence on results reported in terms of energy usage per passenger kilometre. Furthermore, the aims of this study were very similar to this project, with the authors aiming to provide a comprehensive review of the emissions of transport modes per unit performance. The figures from the CE Delft study are reproduced in Table 3-9.

Table 3-9: Average energy use of passenger rail transport modes (MJ/pkm)

Mode name in source	Sub-mode	Fuel type	Average energy use MJ/pkm
Electric Tram	Tram	Electric	0.53
Electric Metro	Metro	Electric	0.50
Electric stop	Heavy rail	Electric intercity	0.12
Diesel stop	Heavy rail	Diesel intercity	0.22

Source: (CE Delft, 2008)

Using the vehicle capacity and occupancy factors for metropolitan areas described in Section 2.4 and assuming 25% operating time during peak hours and a 75% operating time at off-peak hours, the figures in Table 3-9 were then used to estimate the average energy consumption of a vehicle in both metropolitan areas and medium cities. This resulted in the values shown in Table 3-10. These figures were then used in combination with the vehicle capacities and occupancy factors to calculate the average energy use for peak and off-peak journeys in terms of MJ/pkm.

Table 3-10: Estimated energy usage figures for rail sub-modes used in this project (MJ/vkm)

Submode	Fuel type	Metropolitan area Energy use MJ/vkm	Medium city Energy use MJ/vkm
Tram/Light rail	Electric	84.7	43.9
Metro	Electric	355.8	141.8
Heavy rail	Electric intercity	62.9	62.9
Heavy rail	Diesel intercity	115.3	115.3

Source: Ricardo Energy & Environment calculation

Comparison with other data sources

Light rail/tram

Data published in the UK by the Department of Energy and Climate Change (DECC) shows that the average energy consumption of light rail/trams in the UK is 0.39 MJ/pkm (DECC, 2015), while the International Association of Public Transport (UITP) shows an average figure of 0.11 kWh/pkm (equivalent to 0.40 MJ/pkm) for the EU (UITP, 2014)¹². Both these data sources are comparable to the CE Delft source selected for use in this project.

Metro

¹² In addition to the data source referenced, which states an average energy consumption of 0.12 kWh/pkm for urban rail (including light rail/tram and metro), UITP provided data specifically for this project.

The 2015 UK Government GHG Conversion Factors for Company Reporting (published by DECC) shows an average energy consumption of 0.41 MJ/pkm for the London Underground. Data from the UITP shows that the average energy consumption of EU metro systems is 0.13 kWh/pkm, which is equivalent to 0.47 MJ/pkm (UITP, 2014). Again, these figures are comparable to the value stated in the CE Delft study, which has been selected for use in this project.

Heavy rail – electric intercity

Based on data from Ricardo Energy and Environment's SULTAN tool (which was developed for EU level analysis for the European Commission) and the vehicle capacity and occupancy factors described in Section 2.4, an average energy usage of 0.04 MJ/pkm at peak time and 0.08 MJ/pkm at off-peak time were calculated (Ricardo-AEA et al., 2012). However, the SULTAN figure is an average of all passenger electric rail transport, including long-distance travel which is typically more efficient.

Data for the EU from the International Union of Railways (UIC) Railway Handbook, shows that (UIC, IEA, 2012) average CO₂ associated with electric rail are 39 gCO₂/pkm. These were estimated to equate to an average energy consumption of 0.04 MJ/pkm. Again, these values are not specific to urban rail. The Office for Road and Rail in the UK on the other hand only provides a single figure of 48.4 gCO₂/pkm for passenger rail transport, which is an average of electric and diesel travel (ORR, 2015). This equates to an average energy consumption of 0.05 MJ/pkm, which compares well to other sources.

Heavy rail – diesel intercity

Based on data from Ricardo Energy & Environment's SULTAN tool and the vehicle capacity and occupancy factors described in Section 2.4, an average energy usage of 0.05 MJ/pkm at peak time and 0.09 MJ/pkm at off-peak time were calculated (Ricardo-AEA et al., 2012). However, the SULTAN figure is an average of all passenger diesel rail transport, including long-distance travel which is typically more efficient. Data for the EU from the International Union of Railways (UIC) Railway Handbook, shows that (UIC, IEA, 2012) average CO₂ associated with electric rail are 59 gCO₂/pkm. These were estimated to equate to an average energy consumption of 0.06 MJ/pkm. Again, these values are not specific to urban rail.

Overall more detailed data on the energy consumption of urban rail systems (in terms of MJ/vkm) across Europe is required for an improved understanding of energy efficiency. This project has assumed that the energy consumption will be the same in both metropolitan areas and medium cities, which may not be the case in reality.

Inclusion of WTT energy usage

In order for well-to-tank energy consumption to be included, the factors listed in Table 3-3 in Section 3.1 were used. These are the same factors used as for other transport modes.

3.5 Conversion of energy consumption figures to CO₂ emissions

Energy usage figures (in terms of MJ/vkm) were converted into carbon dioxide emissions per passenger kilometre via the use of emissions factors (in conjunction with the vehicle capacity and occupancy factors described in Section 2). This project presents CO₂ emissions in terms of well-to-wheel (WTW) emissions. This takes into account the well-to-tank (WTT) emissions, which include the emissions associated with producing, transforming, transporting and distributing a fuel, and also the tank-to-wheel (TTW) emissions, which are related to the combustion of the fuel. The WTT emissions used in this project are shown in Table 3-11, while the TTW emissions are shown in Table 3-12. Both sets of figures are taken from the most recent JRC WTT Report Version 4.a (JRC, 2014). For petrol hybrids, emission factors are assumed to be the same as for petrol, while for diesel hybrids, emission factors are assumed to be the same as for diesel.

Table 3-11: Well-to-tank CO₂ emission factors used in this project

Fuel	WTT CO ₂ emissions (kg CO _{2eq} / MJ _{fuel})
Petrol	0.0138
Diesel	0.0154
LPG	0.0080
CNG	0.0130
Petrol Hybrid	0.0138
Diesel Hybrid	0.0154
Electric	0.1501

Source: (JRC, 2014)

Table 3-12: Tank-to-wheel CO₂ emission factors used in this project

Fuel	TTW CO ₂ emissions (kg CO _{2eq} / MJ _{fuel})
Petrol	0.0734
Diesel	0.0732
LPG	0.0657
CNG	0.0562
Petrol Hybrid	0.0734
Diesel Hybrid	0.0732
Electric	0.0000

Source: (JRC, 2014)

3.6 Active modes

Walking and cycling are generally simply assumed to have zero energy use and CO₂ emissions when compared to other transport modes. However, this is not strictly true as individuals who walk and cycle compared to a motorised transport user have been found to have higher dietary intakes and there is a CO₂ impact of this additional food production (Coley, 2002).

In relation to cycling a study for the European Cycling Federation¹³ estimated that the additional food energy intake to be 11 kilocalories per km of cycling (0.046 MJ/km). Using the same approach and walking energy use data from a US study (McArdle, 2000) we estimate that at 4km/h the typical additional food intake would be around 25 kilocalories per km (0.1 MJ/km). This suggests that the mechanical advantage provided by a bicycle allows it to be about twice as energy efficient as walking as an urban transport mode.

If the CO₂ related to the production of the additional food required is considered, then the ECF study estimates that the marginal CO₂ emission from cycling are 0.016 kg/km. Again using the same approach for walking this would be about double that for cycling at 0.035 kg.km.

When compared to the results for motorised modes shown in the following section these active modes are significantly lower in terms of energy use and CO₂ emissions, but are not zero.

¹³ 'Cycle more Often 2 cool down the planet ! Quantifying CO₂ savings of cycling', ECF, Nov 2011

3.7 Results

As discussed in Section 1, results were calculated for four scenarios:

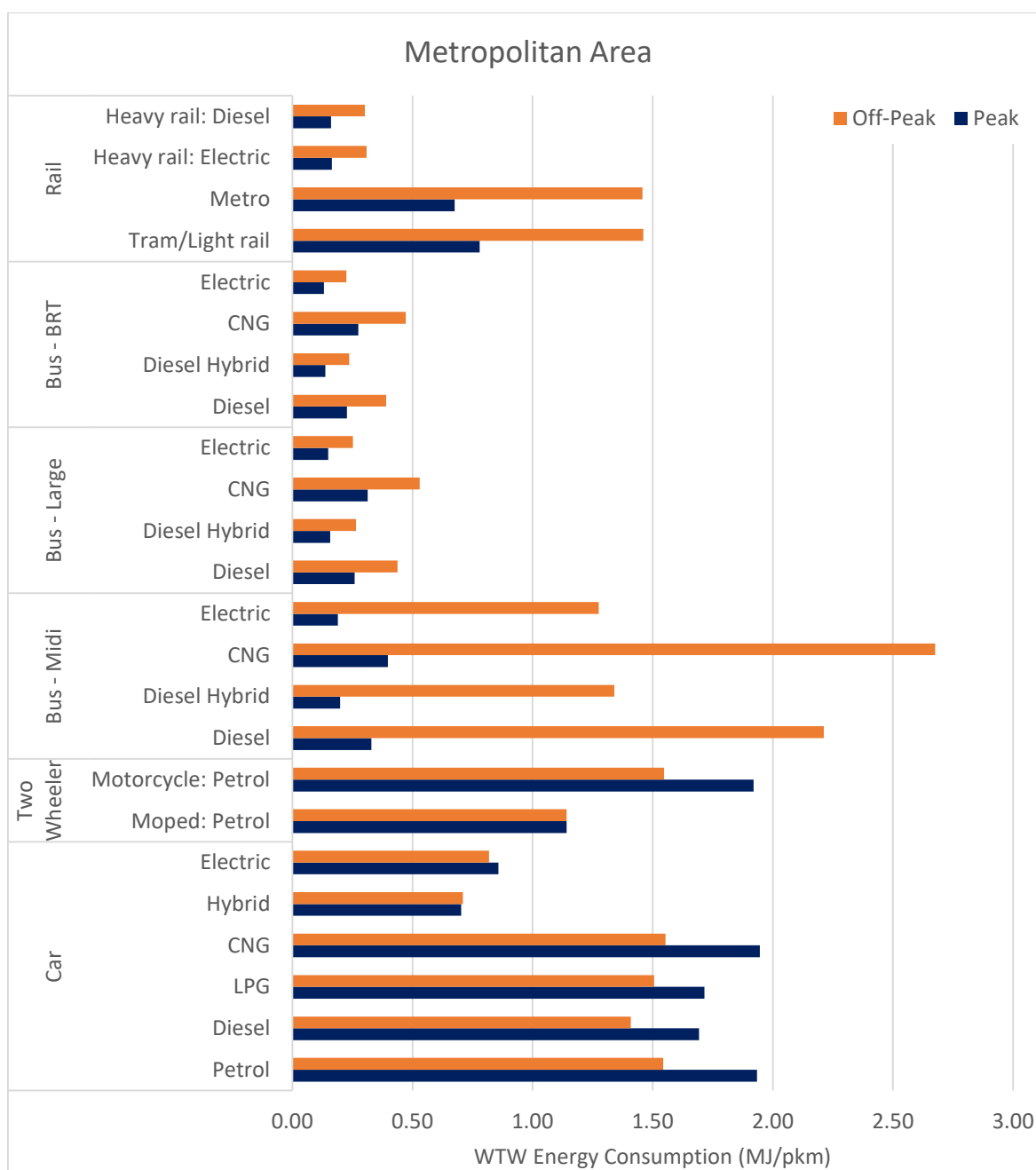
- Metropolitan areas
- Medium city
- Peak (congested periods)
- Off-peak (uncongested periods).

A description of the results along with charts showing the average energy consumption and CO₂ emissions per passenger kilometre are shown in the following sections. All results in this section are reported in terms of the well-to-wheel (WTW) energy consumption/CO₂ emissions.

Metropolitan areas

In metropolitan areas, the energy consumption of private transport modes (passenger cars, mopeds and motorbikes) is mainly dependent on the fuel type and the speed travelled (i.e. whether travel occurs at peak or off-peak time). Vehicle occupancy factors for private transport modes are considered to be the same at both peak and off-peak times (see Section 2) and therefore do not have an impact on the results.

For passenger cars the average energy consumption of petrol, diesel, LPG and CNG fuelled passenger cars is relatively similar, while for hybrids and electric vehicles energy use is substantially lower (on average, less than half the energy use). As shown in Figure 3-2, the energy consumption of petrol, diesel, LPG and CNG vehicles ranges from 1.69-1.95 MJ/pkm at peak time and from 1.41-1.55 MJ/pkm during off-peak hours. Fuel consumption is slightly higher for these vehicles at peak time due to the lower average speed and frequent stopping and starting. Within these fuel types, the energy consumption of petrol and CNG cars is marginally higher than diesel and LPG fuelled cars. For hybrid and electric vehicles, energy consumption is almost identical at peak and off-peak times; for example, for hybrid cars energy consumption was calculated to be 0.70 MJ/pkm at peak time and 0.71 MJ/pkm at off peak time. This is due to the use of technologies such as regenerative braking. For electric vehicles, energy consumption ranges between 0.82 MJ/pkm and 0.86 MJ/pkm depending on whether travel is at off-peak or peak time.

Figure 3-2: Average WTW energy consumption (MJ/pkm) in a metropolitan area

Source: Ricardo Energy & Environment calculations

For mopeds, the energy consumption curve is not speed dependent, therefore it is assumed that the energy use is the same at off peak and at peak time. At 1.14 MJ/pkm, the fuel consumption per passenger kilometre is lower than for passenger cars fuelled by petrol, diesel, LPG and CNG, but higher than for hybrid and electric vehicles.

On the other hand, motorcycles were calculated to have a similar energy consumption per passenger kilometre to petrol cars. The energy use curve for motorcycles is speed dependent, so fuel consumption figures show differences at peak/off-peak time (1.92 MJ/pkm at peak time and 1.55 MJ/pkm at off peak time). In reality, these may not be observed as motorcycles may be able to move between queued traffic and travel at a more constant speed compared to cars.

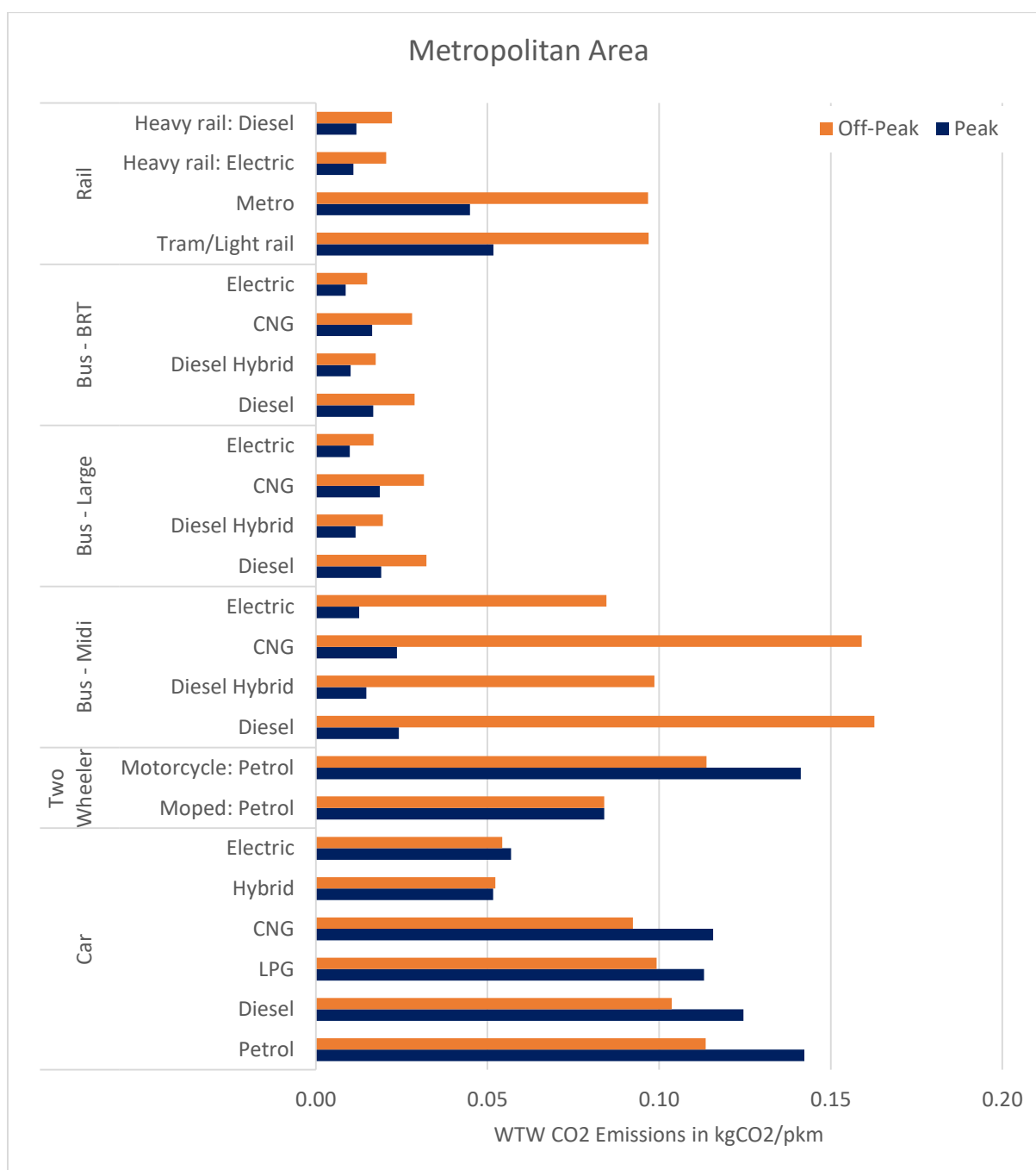
Similarly to private transport modes, the results for public transport (buses and trains) are also dependent on the vehicle fuel type. However, compared to private transport modes, the energy consumption per passenger kilometre is more heavily dependent on the time of travel (whether the journey occurs at peak or off-peak time). This is mainly due to significant differences in occupancy factors at peak and off-peak times (for private transport modes, occupancy is estimated to be constant regardless of journey time). For example, in the case of large buses travelling in metropolitan areas, vehicle occupancy has been calculated to be 86% at peak time, compared to 46% at off-peak time. The average speed travelled also has a very minor effect for buses due to the slight difference in speed at peak and at off-peak time. As noted in the methodology, the calculation of energy usage for trains did not consider the speed travelled, therefore energy consumption per pkm is only dependent on fuel type and occupancy factor.

At peak times, energy consumption for public transport modes is generally significantly lower than at off-peak time, particularly for sub-modes where there is a large difference in occupancy factor depending on when the journey is made (for example midi buses). The most efficient modes at peak time are seen to be large and BRT buses (0.13 – 0.31 MJ/pkm, depending on fuel type) and heavy rail (0.16 MJ/pkm for both diesel and electric). On the other hand, the least efficient modes are tram/light rail and metro systems, with energy usage of 0.72 and 0.61 MJ/pkm respectively. Compared to private transport modes, public transport modes are generally significantly more efficient (except if compared to hybrid and electric cars, which have an average energy consumption of 0.70 and 0.86 MJ/pkm).

At off-peak times, the most efficient sub-modes for public transport were calculated to be large and BRT buses. These had energy usage values of 0.23-0.53 MJ/pkm, depending on the fuel type. In particular, diesel hybrid and electric buses are the most efficient. Heavy rail was also seen to be one of the more efficient modes during off-peak times. Diesel and electric trains were calculated to have an average energy usage of 0.30-0.31 MJ/pkm.

Another notable observation is that for midi buses, there is a large increase (over 500%) in average energy consumption (in MJ/pkm) for travel at off-peak time, compared to peak time. This is due to the significant difference in occupancy factor, which was calculated to be 12% at off-peak time and 86% at peak time. This resulted in average off-peak energy consumption of 1.28-2.68 MJ/pkm depending on the fuel type. For comparison, the average energy consumption for car travel at off-peak time was calculated to be between 0.71 MJ/pkm and 1.55 MJ/pkm depending on the fuel type.

The average WTW CO₂ emissions (in kg CO₂e/pkm) in metropolitan areas are shown in Figure 3-3. The trends seen in this chart are the same as for energy consumption.

Figure 3-3: Average WTW CO₂ emissions (kg CO₂e/pkm) in a metropolitan area

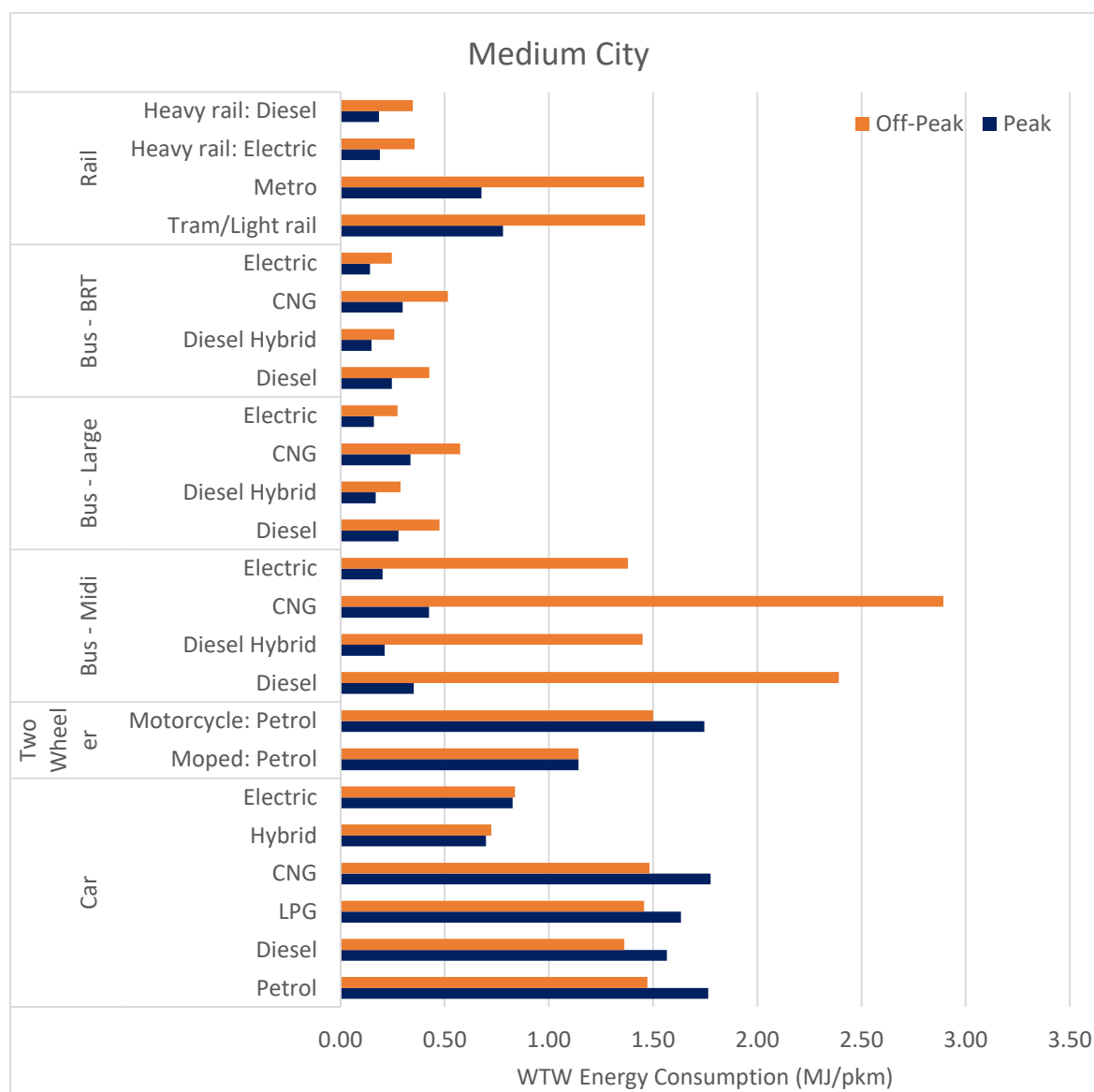
Source: Ricardo Energy & Environment calculations

Medium city

The average energy consumption of private transport modes in medium cities are shown in Figure 3-4, while the CO₂ emissions are shown in Figure 3-5. Overall, the trends are similar to those observed in metropolitan areas, with only slight differences in average fuel consumption calculated due to the higher average speed of travel in urban areas. This higher average speed represents a less congested urban environment with more free flowing traffic and fewer stopping and starting manoeuvres, which have a detrimental impact on fuel economy.

At peak time in a medium city the average speed for private transport modes has been estimated to be 30 km/h, compared to 25 km/h in metropolitan areas. As the vehicle capacity and occupancy factors do not change, this leads to a lower energy consumption per passenger km. For example, for petrol cars the energy consumption at peak time in a medium city has been calculated to be 1.76 MJ/pkm, compared to 1.93 MJ/pkm in metropolitan areas.

Figure 3-4: Average WTW energy consumption (MJ/pkm) in a medium city



Source: Ricardo Energy & Environment calculations

The only private transport sub-mode that does not follow this trend is mopeds, for which energy consumption is assumed to not be speed dependent. The energy consumption per passenger kilometre has therefore been calculated to be the same in both medium cities and metropolitan areas.

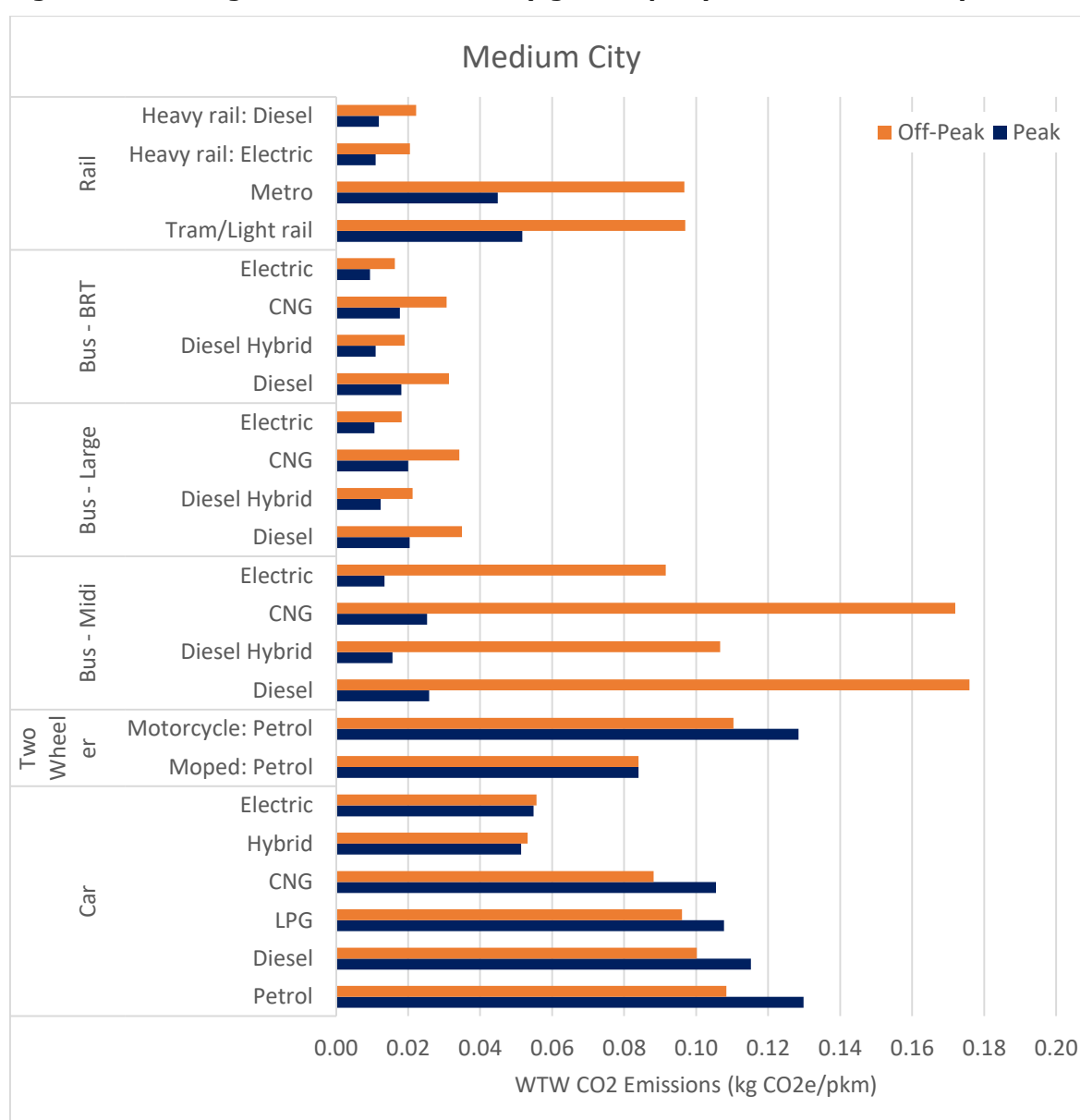
For public transport in medium cities, different vehicle capacities and occupancy factors were assumed for some sub-modes, compared to the same vehicle types in metropolitan areas. These generally resulted in a slight increase to the average energy consumption per passenger kilometre. For example, in some cases vehicle capacities were assumed

to be lower in medium cities, while in some cases occupancy factors were estimated to be lower. The average speed of buses also had a slight effect on energy consumption, however the impact is minimal due to the similarity of speeds in medium cities/metropolitan areas at peak/off-peak time (see Table 3-7).

The average energy consumption for public transport modes in a medium city is shown in Figure 3-4. As for metropolitan areas, large buses, BRT buses and heavy rail have been calculated to be the most efficient, however the energy consumption is marginally higher in medium cities. For example, for a large diesel bus operating in a medium city, the average energy consumption has been calculated to be 0.28 MJ/pkm, compared to 0.26 MJ/pkm in a metropolitan area.

The average WTW CO₂ emissions (in kg CO₂e/pkm in medium cities are shown in Figure 3-5. The trends seen in this chart are the same as for energy consumption.

Figure 3-5: Average WTW CO₂ emissions (kg CO₂e/pkm) for in a medium city



Source: Ricardo Energy & Environment calculations

4 Cost of the transport modes

With regards to costs, data was used to address the question: “*what are the costs per passenger kilometre associated with the transport mode when it is able to transport the number of passengers equivalent to its capacity?*” This question can be asked from two perspectives. One is the perspective of users, which includes the relevant costs that are those incurred by individuals. In particular, this means that for public transport modes the costs to be considered are fares/tariffs. However, the overall cost to run public transport modes is the full production cost, including the components not covered by fare revenues. In order to undertake a fair comparison with private transport, full costs are considered (and that for passenger cars, the fixed costs referred to previously are also accounted for).

Therefore a societal point of view has been adopted and full operating costs of both private and public transport has been estimated. Externality costs have not been considered as the quantification of some of external effects such as CO₂ emissions has been addressed in Section 3.

The estimation of urban transport costs is based on a review of both literature and real-world conditions, although often the latter are not the same in all cities and countries (e.g. operating costs of cars or public transport production costs). Therefore, the literature survey considered two different types of sources:

- Technical literature concerning the costs of transport modes
- Information on real world elements related to cost components of urban transport modes.

4.1 Car cost per vehicle-km

With reference to car private mode, the estimation of relevant costs is performed from the perspective of users which includes:

- Variable costs related to the energy use, i.e. fuel consumption
- Variable costs not related to the energy use, i.e. tyres, lubricants, maintenance etc.
- Fixed cost, i.e. amortisation of vehicles purchase, ownership taxes (registration and circulation), and insurance.

These costs have been estimated for the following car technology/fuel types: petrol, diesel, LPG, CNG, hybrid electric, battery electric.

Energy cost

The average energy cost per vehicle category have been estimated on the basis of the outcome of estimation of energy consumption described in Section 3 (with appropriate conversion factors) in combination with average European energy prices by fuel type.

The estimation of energy consumption by vehicle category is provided in terms of MJ/vkm, therefore the appropriate factors have been applied to convert the values in terms of litre/vkm or kg/vkm or kWh/vkm.

Average energy price across Europe have been taken from:

- Eurostat statistics on energy price (gasoline, diesel and LPG)¹⁴
- Eurostat statistics on electricity price¹⁵

¹⁴ http://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_price_statistics

¹⁵ http://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_price_statistics

- CNG stations location and energy price in Europe.¹⁶

As a result, the estimation of average EU energy cost per vehicle type, urban type and time period is reported in the following table.

Table 4-1: Energy cost per vehicle of car mode

Car category	Urban type	Time period	Energy cost (Euro/vkm)	Conversion factor	Energy price	Energy consumption (MJ/vkm)
Petrol	Metropolitan area	Peak	0.122	31.5 (MJ/l)	1.38 (Euro/l)	2.777
		Off-peak	0.097			2.216
	Medium city	Peak	0.111			2.534
		Off-peak	0.093			2.114
Diesel	Metropolitan area	Peak	0.083	36.3 (MJ/l)	1.26 (Euro/l)	2.390
		Off-peak	0.069			1.989
	Medium city	Peak	0.077			2.211
		Off-peak	0.067			1.922
LPG	Metropolitan area	Peak	0.071	23.7 (MJ/l)	0.64 (Euro/l)	2.608
		Off-peak	0.062			2.288
	Medium city	Peak	0.067			2.484
		Off-peak	0.060			2.216
CNG	Metropolitan area	Peak	0.064	48.0 (MJ/kg)	1.08 (Euro/kg)	2.840
		Off-peak	0.051			2.266
	Medium city	Peak	0.058			2.590
		Off-peak	0.048			2.164
Hybrid electric	Metropolitan area	Peak	0.044	31.5 (MJ/l)	1.38 (Euro/l)	1.008
		Off-peak	0.045			1.020
	Medium city	Peak	0.044			1.002
		Off-peak	0.045			1.038
Electric	Metropolitan area	Peak	0.029	3.6 (MJ/kWh)	0.21 (Euro/kWh)	0.644
		Off-peak	0.028			0.615
	Medium city	Peak	0.028			0.621
		Off-peak	0.029			0.630

Source: TRT estimation (TRACCs and JRC conversion factors)

Other fixed and variable cost (not energy related)

The average cost per vehicle category (not energy related) have been estimated on the basis of the following data source: (EMISIA, INFRAS, IVL, 2013), (CE DELFT, 2011)¹⁷. The cost components included in the analysis are: maintenance, amortisation of vehicles purchase, ownership taxes (registration and circulation) and insurance.

For petrol, diesel, LPG and CNG vehicles data related to the year 2010 from TRACCs project by country has been selected, referring to a 5 year old vehicle for ownership tax, maintenance, insurance and mileage per vehicle. TRACCs data are differentiated by

¹⁶ www.cngprices.com

¹⁷ http://cedelft.eu/publicatie/impact_of_electric_vehicles/1153

propulsion and vehicle type (Small, Lower-Medium, Upper-Medium, Executive): in order to estimate data by propulsion category the average values weighted on car fleet composition by country (also available in TRACCs) have been used.

The amortisation cost and registration tax per vehicle-km have been estimated considering that the useful life of a vehicle is 10 years for all categories and estimating annual mileage based on country data from TRACCs.

Finally, the representative values by category are estimated based on the average EU28 data by country. However, outliers were not considered when estimating the representative average values (e.g. registration tax in Denmark is very high and therefore has been excluded from the average as it considered not representative of current costs).

For electric and hybrid vehicles data from the CE DELFT¹⁸ study has been used, assuming respectively a medium-size full-electric vehicle and a medium-size hybrid-electric vehicle with internal combustion engine. In both cases a low level of incentives in terms of circulation and registration taxes has been assumed. The amortisation cost and registration tax per vehicle-km have been estimated considering that the useful life of the vehicles is 10 years and estimating annual mileage as average between petrol and diesel data reported in the CE DELFT study.

As a result, the following values of cost per vehicle-km have been estimated by category.

Table 4-2: Other cost per vehicle of car mode

Car category	Total non-energy cost (Euro/vkm)	Maintenance cost (Euro/vkm)	Amortisation cost (Euro/vkm)	Insurance cost (Euro/vkm)	Ownership taxes (Euro/vkm)	Annual mileage (km/year)
Petrol	0.29	0.03	0.19	0.05	0.02	15,000
Diesel	0.23	0.02	0.15	0.04	0.02	24,800
LPG	0.24	0.02	0.16	0.04	0.02	28,000
CNG	0.20	0.02	0.13	0.04	0.01	24,200
Hybrid electric	0.23	0.06	0.08	0.08	0.01	15,600
Electric	0.38	0.03	0.22	0.12	0.01	15,600

Source: TRT estimation

The following table reports minimum and maximum values of data considered in the analysis.

¹⁸ http://cedelft.eu/publicatie/impact_of_electric_vehicles/1153

Table 4-3: Other cost per vehicle of car mode: minimum and maximum values*

Car category	Total non-energy cost (Euro/vkm)	Maintenance cost (Euro/vkm)	Amortisation cost (Euro/vkm)	Insurance cost (Euro/vkm)	Ownership taxes (Euro/vkm)	Annual mileage (km/year)
Petrol	0.17 – 0.61	0.02 – 0.05	0.12 – 0.47	0.03 – 0.09	0 – 0.05	10,700-21,800
Diesel	0.12 – 0.49	0.01 – 0.03	0.07 – 0.40	0.02 – 0.06	0 – 0.04	11,100-43,800
LPG	0.09 – 0.40	0.01 – 0.04	0.06 – 0.27	0.02 – 0.08	0 – 0.06	11,700-57,600
CNG	0.13 – 0.28	0.02 – 0.03	0.08 – 0.18	0.03 – 0.05	0 – 0.02	17,400-31,000

Source: TRT estimation

* excluding outliers in the data

4.2 Motorcycle cost per vehicle-km

The estimation of relevant costs is performed from the perspective of users for moped and motorcycle as well and includes:

- Variable costs related to the energy use, i.e. fuel consumption
- Variable costs not related to the energy use, i.e.: tyres, lubricants, maintenance etc.
- Fixed cost, i.e. amortisation of vehicles purchase, ownership taxes (registration and circulation), and insurance.

Energy cost

The average energy cost per vehicle category has been estimated on the basis of the outcome of estimation of energy consumption described in Section 3 (with the appropriate conversion factor) in combination with the average European energy price for gasoline. The estimation of energy consumption by vehicle category is provided in terms of MJ/vkm, therefore the appropriate factor has been applied to convert the values in terms of liter/vkm.

The average energy price of gasoline across Europe has been taken from Eurostat statistics on gasoline price¹⁹. As a result, the estimation of average EU energy cost per vehicle type, urban type and time period is reported in the following table.

¹⁹ http://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_price_statistics

Table 4-4: Energy cost per vehicle of powered two wheeler mode

Vehicle type	Urban type	Time period	Energy cost (Euro/vkm)	Conversion factor	Energy price	Energy consumption (MJ/vkm)
Moped	Metropolitan area	Peak	0.042	31.5 (MJ/l)	1.38 (Euro/l)	0.964
		Off-peak				
	Medium city	Peak				
		Off-peak				
Motorcycle	Metropolitan area	Peak	0.078	31.5 (MJ/l)	1.38 (Euro/l)	1.784
		Off-peak	0.063			1.437
	Medium city	Peak	0.071			1.621
		Off-peak	0.061			1.393

Source: TRT estimation (TRACCs conversion factors)

Other fixed and variable cost (not energy related)

The average cost has been estimated on the basis of data from the TRACCs project (2013) database, considering mopeds and motorcycles separately. TRACCs data are also differentiated by vehicle type (2-stroke, 4-stroke). In order to estimate a generalised value for motorcycle and moped respectively the average values weighted on fleet composition by country (also available in TRACCs) have been used.

The amortisation cost and registration tax per vehicle-km have been estimated considering that the useful life of a vehicle is 10 years for all categories and the annual mileage based on country data from TRACCs.

The representative estimated values by vehicle type for the average of EU28 are shown below in Table 4-5 and estimated maximum and minimum values in Table 4-6.

Table 4-5: Other cost of motorcycle mode

Mode	Total non-energy cost (Euro/vkm)	Maintenance cost (Euro/vkm)	Amortisation cost (Euro/vkm)	Insurance cost (Euro/vkm)	Ownership taxes (Euro/vkm)	Annual mileage (km/year)
Moped	0.16	0.03	0.08	0.04	0.01	3,900
Motorcycle	0.21	0.04	0.11	0.05	0.01	6,200

Source: TRT estimation

Table 4-6: Other cost of motorcycle mode: minimum and maximum values

Mode	Total non-energy cost (Euro/vkm)	Maintenance cost (Euro/vkm)	Amortisation cost (Euro/vkm)	Insurance cost (Euro/vkm)	Ownership taxes (Euro/vkm)	Annual mileage (km/year)
Moped	0.03 - 0.38	0.01 - 0.07	0.01 - 0.18	0.01 - 0.11	0 - 0.08	1,100-13,600
Motorcycle	0.06 - 0.36	0.01 - 0.07	0.02 - 0.27	0.02 - 0.10	0 - 0.12	2,500-20,400

Source: TRT estimation

4.3 Bus cost per vehicle-km

With regards to the bus mode, the overall cost of running the service for different bus types (diesel, hybrid, CNG, electric) has been considered in the analysis, including the components not covered by fare revenues. Therefore, the estimated costs include factors such as personnel wages, maintenance, fuel, vehicle purchase, etc.

Three components have been considered separately for the estimation: energy cost, amortisation of vehicle purchase, and other costs (personnel wage, maintenance, etc.).

Data on the overall cost for conventional bus (diesel) is available from literature, while detailed information for other bus types hasn't been found. Therefore, we assumed that energy and purchase cost depends on vehicle type (electric buses purchase cost is significantly higher but their energy consumption cost is significantly lower) whereas the 'other cost' component (mainly influenced by personnel wages and other fixed cost) is the same for all vehicle types.

Energy cost

Fuel cost has been estimated on the basis of the outcome of the estimation of energy consumption as described in Section 3 (with appropriate conversion factors) in combination with average European energy prices by fuel type.

The estimation of energy consumption by vehicle category is provided in terms of MJ/vkm, therefore the appropriate factors have been applied to convert the values in terms of litre/vkm or kg/vkm or kWh/vkm.

Average energy price across Europe have been taken from:

- Eurostat statistics on energy price (diesel)²⁰
- Eurostat statistics on electricity price for industrial use²¹
- CNG stations location and energy price in Europe.²²

The result of the estimation in terms of average EU energy cost per vehicle type, urban type and time period is reported in the following table.

Table 4-7: Energy cost per vehicle-km of bus mode

Bus category	Urban type	Time period	Energy cost (Euro/vkm)	Conversion factor	Energy price	Energy consumption (MJ/vkm)
Midi – diesel	Metropolitan area	Peak	0.491	36.3 (MJ/l)	1.26 (Euro/l)	14.138
		Off-peak	0.440			12.672
	Medium city	Peak	0.455			13.110
		Off-peak	0.414			11.916
Midi – Diesel hybrid	Metropolitan area	Peak	0.298	36.3 (MJ/l)	1.26 (Euro/l)	8.570
		Off-peak	0.267			7.682
	Medium city	Peak	0.276			7.947
		Off-peak	0.251			7.223

²⁰ http://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_price_statistics

²¹ http://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_price_statistics

²² www.cngprices.com

Midi - CNG	Metropolitan area	Peak	0.396	48.0 (MJ/kg)	1.08 (Euro/kg)	17.672
		Off-peak	0.355			15.840
	Medium city	Peak	0.367			16.387
		Off-peak	0.334			14.895
Midi - Electric	Metropolitan area	Peak	0.145	3.6 (MJ/kWh)	0.12 (Euro/kWh)	4.341
		Off-peak	0.130			3.891
	Medium city	Peak	0.134			4.025
		Off-peak	0.122			3.659
Large - diesel	Metropolitan area	Peak	0.644	36.3 (MJ/l)	1.26 (Euro/l)	18.562
		Off-peak	0.581			16.740
	Medium city	Peak	0.600			17.287
		Off-peak	0.548			15.785
Large - Diesel hybrid	Metropolitan area	Peak	0.391	36.3 (MJ/l)	1.26 (Euro/l)	11.252
		Off-peak	0.352			10.147
	Medium city	Peak	0.364			10.479
		Off-peak	0.332			9.569
Large - CNG	Metropolitan area	Peak	0.520	48.0 (MJ/kg)	1.08 (Euro/kg)	23.203
		Off-peak	0.469			20.924
	Medium city	Peak	0.484			21.609
		Off-peak	0.442			19.731
Large - Electric	Metropolitan area	Peak	0.190	3.6 (MJ/kWh)	0.12 (Euro/kWh)	5.699
		Off-peak	0.171			5.140
	Medium city	Peak	0.177			5.308
		Off-peak	0.162			4.846
BRT - diesel	Metropolitan area	Peak	0.792	36.3 (MJ/l)	1.26 (Euro/l)	22.811
		Off-peak	0.725			20.880
	Medium city	Peak	0.745			21.471
		Off-peak	0.688			19.827
BRT - Diesel hybrid	Metropolitan area	Peak	0.480	36.3 (MJ/l)	1.26 (Euro/l)	13.828
		Off-peak	0.439			12.658
	Medium city	Peak	0.452			13.015
		Off-peak	0.417			12.019
BRT - CNG	Metropolitan area	Peak	0.639	48.0 (MJ/kg)	1.08 (Euro/kg)	28.514
		Off-peak	0.585			26.101
	Medium city	Peak	0.601			26.839
		Off-peak	0.555			24.784

BRT - Electric	Metropolitan area	Peak	0.233	3.6 (MJ/kWh)	0.12 (Euro/kWh)	7.004
		Off-peak	0.214			6.411
	Medium city	Peak	0.220			6.592
		Off-peak	0.203			6.088

Source: TRT estimation (TRACCs and JRC conversion factors)

Amortisation of vehicle purchase

Another element explicitly considered in the estimation has been the amortisation of vehicle purchase. Data on vehicle purchase costs are reported in the following table and has been estimated on the basis of (Clean Fleets, 2014), (CIVITAS, 2013), (TfL, 2010)

It is assumed that the average cost of a midi bus is about 75% of the average cost of large buses / BRT vehicles.

The amortisation cost per vehicle-km have been estimated considering that the useful life of a bus is 15 years for all categories and estimating annual mileage of 45,000 km based on (ASSTRA, 2013).

Table 4-8: Amortisation cost per vehicle-km of bus mode

Mode	Fuel type	Amortisation cost (Euro/vkm)	Lifetime (years)	Annual mileage (km/year)	Vehicle purchase cost (Euro/vehicle)
Midi bus	Diesel	0.30	15	45,000	202,500
	Diesel hybrid	0.38			255,000
	CNG	0.39			262,500
	Electric	0.56			375,000
Large bus / BRT	Diesel	0.40	15	45,000	270,000
	Diesel hybrid	0.50			340,000
	CNG	0.52			350,000
	Electric	0.74			500,000

Source: TRT estimation

Other costs

As mentioned above, it has been assumed that the 'other cost' component (mainly influenced by personnel wages and other fixed cost) is the same for all vehicle types. The total cost of conventional bus has been used to estimate the 'other cost' component from the difference between the total cost of a conventional bus and the energy and purchase costs calculated here. This has then been applied to all other bus types.

The overall cost for delivering a bus service in terms of cost per vehicle-km is estimated on the basis of the following data sources: (ASSTRA, 2013), (Bain & Company, 2012), (UK Department for Transport statistics, 2015), (American Public Transportation Association, 2013).

Bus service delivery costs depend on local conditions (e.g. commercial speed) which may vary from city to city, no matter the size of the city. Therefore data for metropolitan and medium cities have not been differentiated. For midi and large buses the same delivery costs are assumed, while BRT services are treated separately.

For midi and large buses the value estimated is the average of data for Italy and United Kingdom of 3.5 Euro/vehicle-km (ranging from 2.7 to 4.2). Based on a US report, BRT operating costs are about 23% higher than those of buses. Therefore the average representative value is estimated as 4.3 Euro/vehicle-km (ranging from 3.3 to 5.2).

According to (ASSTRA, 2013) the share of fuel/energy and vehicle purchase cost is about 20% of service delivery cost at urban level. Therefore, the following values of residual costs have been estimated: 2.8 Euro/vkm for midi and large bus and 3.4 Euro/vkm for BRT.

The total production cost is the sum of energy cost, amortisation cost and other cost.

Looking at the average total production cost in Table 4-9, it is interesting to notice that the range of values for each mode among different fuel type is quite similar, with difference of about 0.1-0.15 Euro per vehicle-km (i.e. 3%). Nevertheless, this result comes from quite different values of energy and amortisation costs: electric and hybrid vehicles have of course higher amortisation costs, which are however counterbalanced by low energy cost. This result opens the possibility of various political choices when taking into account also energy consumption and CO₂ emission of these alternative vehicles.

Table 4-9: Delivery cost of bus services

Mode	Fuel type	Range of energy cost (Euro/vkm)	Amortisation cost (Euro/vkm)	Other production cost (Euro/vkm)	Average total production cost (Euro/vkm)
Midi bus	Diesel	0.41 – 0.49	0.32	2.8	3.52
	Diesel hybrid	0.25 – 0.30	0.40		3.42
	CNG	0.33 – 0.40	0.41		3.52
	Electric	0.12 – 0.14	0.59		3.44
Large bus	Diesel	0.55 – 0.64	0.40	2.8	3.77
	Diesel hybrid	0.33 – 0.39	0.50		3.64
	CNG	0.44 – 0.52	0.52		3.77
	Electric	0.16 – 0.19	0.74		3.67
BRT	Diesel	0.69 – 0.79	0.40	3.4	4.55
	Diesel hybrid	0.42 – 0.48	0.50		4.36
	CNG	0.55 – 0.64	0.52		4.52
	Electric	0.20 – 0.23	0.74		4.35

Source: TRT estimation

4.4 Rail cost per vehicle-km

For rail public transport services, all the components for running the service (even if not covered by fare revenues) have been considered in the analysis. Therefore, as explained for buses, the estimated costs include e.g. personnel wage, maintenance, fuel, vehicle purchase, etc.

For heavy rail the average total cost could be estimated in principle differentiating diesel and electric services. Nevertheless, several analysis have been performed before

proceeding in this sense for this task. In fact, it is reported in literature²³ that the energy cost for running train services are about 5% to 10% of total cost for running the service.

When energy costs are estimated using energy consumption described in Section 3 (with appropriate conversion factors and in combination with average European energy prices), the following values are observed.

Table 4-10: Energy cost per vehicle-km of heavy rail mode

Heavy rail category	Energy cost (Euro/vkm)	Conversion factor	Energy price	Energy consumption (MJ/vkm)
Electric	2.096	3.6 (MJ/kWh)	0.12 (Euro/kWh)	62.888
Diesel	2.802	36.3 (MJ/l)	0.88 (Euro/l)	115.294

Source: TRT estimation

The estimation of energy consumption by vehicle category is provided in terms of MJ/vkm, therefore the appropriate factors have been applied to convert the values in terms of litre/vkm or kg/vkm or kWh/vkm. Average energy price across Europe have been taken from:

- Eurostat statistics on energy price (diesel)²⁴, assuming the price for railways operator is discounted by 70% with respect to the pump-price
- Eurostat statistics on electricity price²⁵ for industrial use.

The difference in terms of Euro/vkm between electric and diesel trains is about 0.7 euro/vehicle-km (2.1 to 2.8 Euro/vkm). This difference applies to maximum 10% of total cost, which means the difference between electric and diesel trains (considering all the other cost components equal) would be marginal. Therefore, this differentiation has been excluded in our estimation and total cost for heavy rail services have been considered the same for diesel and electric in the context of analysis (metropolitan and medium city).

The overall cost for delivering a rail public transport service in terms of cost per vehicle-km is estimated on the basis of (TRT, 2011), (Office of Rail Regulation, 2012), (Coppola), (American Public Transportation Association, 2013), (Civity management consultant, 2012)²⁶.

In line with bus modes, rail service delivery costs have not been differentiated for metropolitan and medium cities.

For tram / light rail mode the value estimated is based on data of SITRAM project of 5.7 euro/vehicle-km.

It has been found in literature that metro operating costs are about 2.5 times those of trams. Therefore the average representative value is estimated as 14.2 Euro/vehicle-km.

Finally, based on the review of costs and performances in seven EU countries²⁷, heavy rail operating costs for commuter services are estimated on average as 16 Euro/train-

²³ (Civity management consultant, 2012), UIC data (1999)

²⁴ http://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_price_statistics

²⁵ http://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_price_statistics

²⁶ https://mpira.ub.uni-muenchen.de/67799/1/MPRA_paper_67799.pdf

²⁷ United Kingdom, Ireland, Germany, Belgium, France, Denmark, Netherlands

km. This value is the average of the total cost per train-km (including overhead, rolling stock amortisation cost and maintenance cost, operation management, train staff, customer management and energy cost). The values are variable from country to country, ranging from 5 Euro/train-km to about 30 Euro/train-km.

Table 4-11: Production cost of rail services

Mode	Total production cost (Euro/vkm)	Range of production cost (Euro/vkm)
Tram / light rail	5.7	4.2 – 7.5
Metro	14.2	12.4 – 16.0
Heavy rail	16.0	5.2 – 29.2

Source: TRT estimation

4.5 Cost per passenger-km by mode

In order to allow for the comparison between the cost of private and public transport modes, the values estimated above in terms of cost per vehicle-km have been normalised to the amount of passengers related to each mode. This gives the final cost metric in terms of cost per passenger km. In line with the approach used in Section 2 for capacity, two types of cost metrics have been estimated in order to take into account the “theoretical” capacity of each transport mode (i.e. vehicle capacity), mainly based on physical infrastructures characteristics, on the other hand the “actual” capacity (i.e. occupancy rate), representative of the performances in EU urban contexts.

For **car** and **motorcycle** the estimation has been performed in two steps. Firstly, total cost per vehicle has been computed considering both energy and non-energy costs. Secondly the ratio between total cost and vehicle capacity (or respectively occupancy factor) has been calculated. The values are different for urban type and time period because energy costs are different depending on speed circumstances (while occupancy factors are unchanged). The results are shown in Section 4.6 (Tables are in the Annex).

With reference to the **bus** mode, service delivery costs per passenger-km are estimated with the application of vehicle capacity and occupancy factors resulting from the analysis in Section 2.3 by mode (midi, large, BRT), urban type (metropolitan area, medium city) and time period (peak, off-peak). The results are shown in Section 4.6.

For **rail** mode production costs per passenger-km are estimated with the application of vehicle capacity and occupancy factors resulting from the analysis in Section 2.4 by mode (tram, metro, heavy rail), urban type (metropolitan area, medium city) and time period (peak, off-peak). The estimated values in each context are reported in Section 4.6.

4.6 Active modes

The comparison of costs with active modes can only be done on a simple level. With regards walking, although there is potentially a fuel cost in terms of additional food intake this has not been considered. There is also assumed to be no capital costs related to walking. Therefore, the cost associated with walking is essentially zero compared to the other modes.

In terms of cycling although we can assume no fuel cost there will be the capital cost of the bicycle in the same way as a car or moped. The average cost of a new bicycle is estimated at 345 Euro²⁸. If this is combined with an 8 year life and an average cycling

²⁸ www.statista.com

distance of 2,400 km per year²⁹ this gives a capital cost of cycling as 0.018 Euro/km. Although not zero this is still much lower than any other the results for the motorised modes as set out in the following section.

4.7 Results

As described in Sections 4.1 to 4.4, results were calculated for four scenarios:

- Metropolitan areas
- Medium city
- Peak (congested periods)
- Off-peak (uncongested periods).

A description of the results along with charts showing the average actual and theoretical cost per passenger kilometre are shown in the following sections.

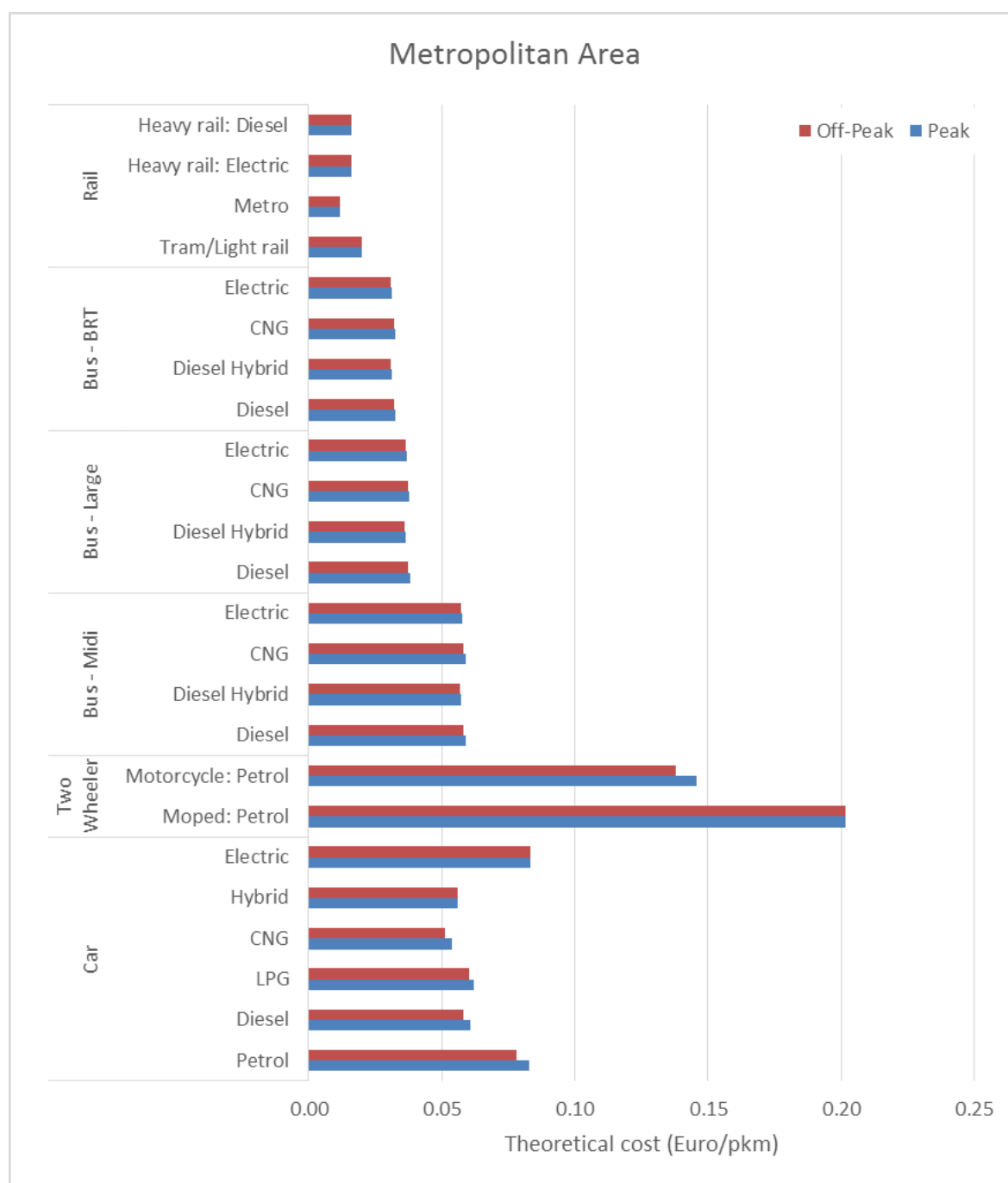
Theoretical cost

From a theoretical point of view (Figure 4-1 and Figure 4-2) the highest average cost per passenger-km is related to two-wheelers (0.15 to 0.20 Euro/pkm), while rail modes show the lower values (0.02 Euro/pkm) together with BRT and large buses (0.03 and 0.04 Euro/pkm respectively).

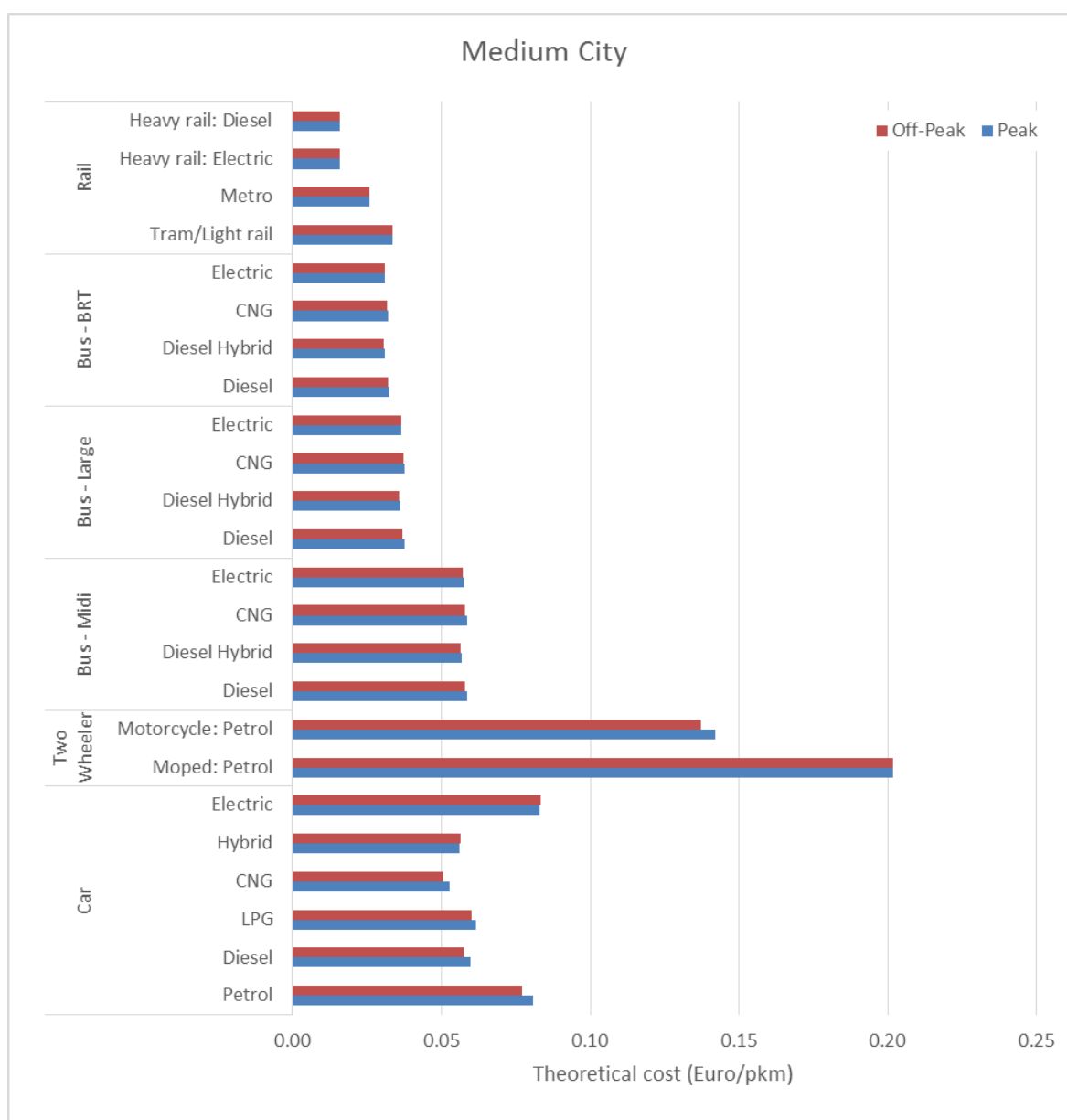
The average costs for midi bus and cars show similar values, in a range between 0.06 to 0.08 Euro/pkm. Of course, some differences are observed between cars by fuel type. The most expensive are petrol and electric (the first due to energy cost, the later basically due to non-energy cost, e.g. amortisation cost), while hybrid and CNG are the cheapest (about 0.055 Euro/pkm).

Similar results are observed for peak and off-peak period for both metropolitan areas and medium cities.

²⁹ Average cycle life and mileage taken from the ECF report 'Cycle more Often 2 cool down the planet ! Quantifying CO2 savings of cycling', ECF, Nov 2011

Figure 4-1: Theoretical cost (Euro/pkm) in a metropolitan area

Source: TRT estimation

Figure 4-2: Theoretical cost (Euro/pkm) in a medium city

Source: TRT estimation

Actual cost in a metropolitan area

The analysis of average cost under “common, real-world conditions” shows a somewhat different picture, especially depending on the time period of the day.

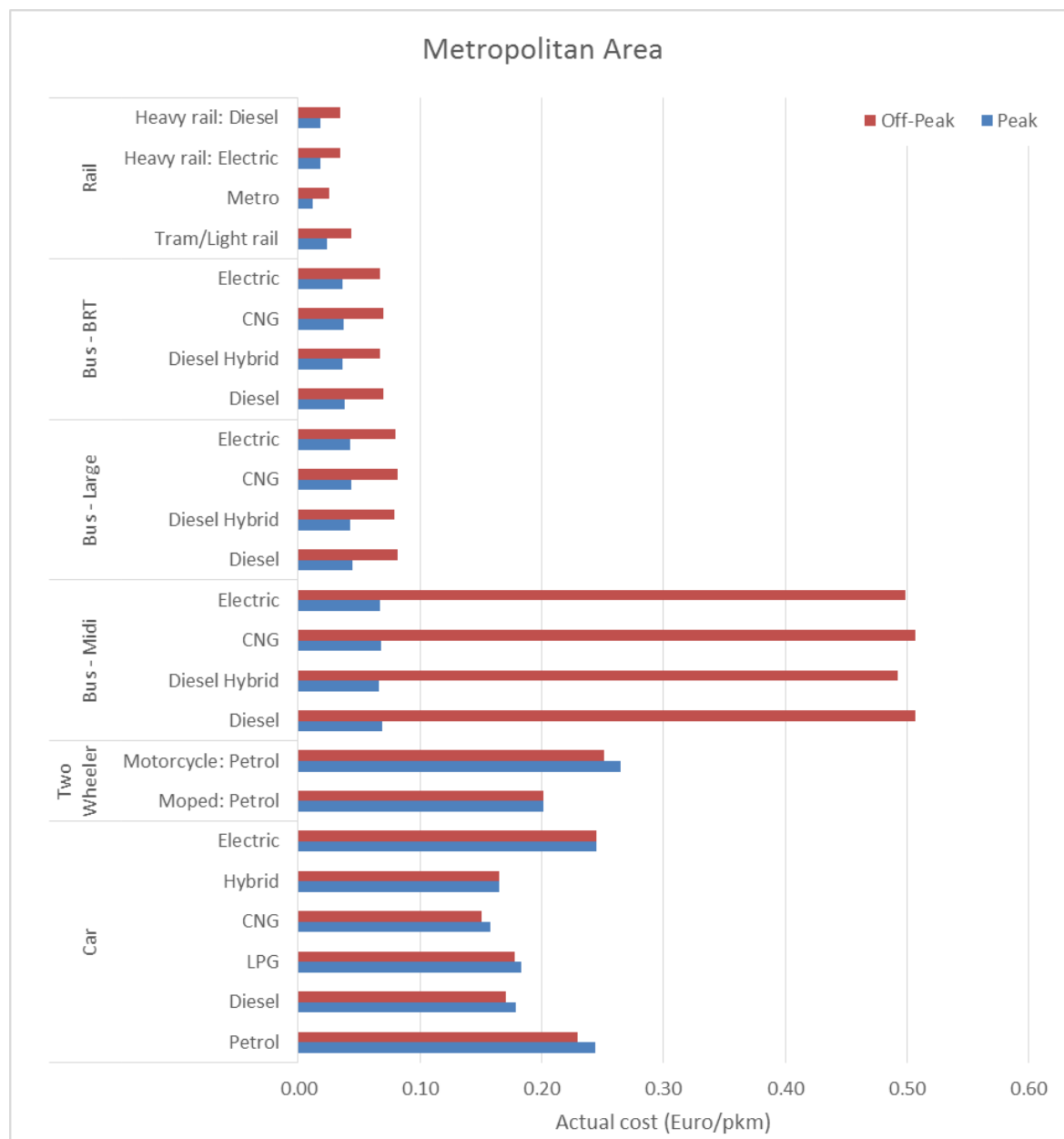
During peak period private road modes (car and two-wheelers) show the highest average cost per passenger-km (0.15 to 0.26 Euro/pkm). Some car fuel types provide better performances, but always higher than the other public transport modes.

The average cost of rail modes is the lowest (0.02 Euro/pkm) together with BRT and large buses (both about 0.04 Euro/pkm). Midi bus are slightly more expensive, with 0.07 Euro/pkm.

During off-peak periods, due to a low level of occupancy rate, the average cost for some public transport mode increase consistently - it is particularly the case for midi bus services, becoming the most expensive mode (0.5 Euro/pkm). The average actual cost of the other public transport modes (rail and bus) during peak time is basically doubled

during off-peak. As a result, the difference between private modes and public transport services is reduced. Nevertheless bus and rail are still less expensive (0.03 to 0.08 Euro/pkm for public transport instead of 0.15 to 0.25 Euro/pkm for car and two-wheelers).

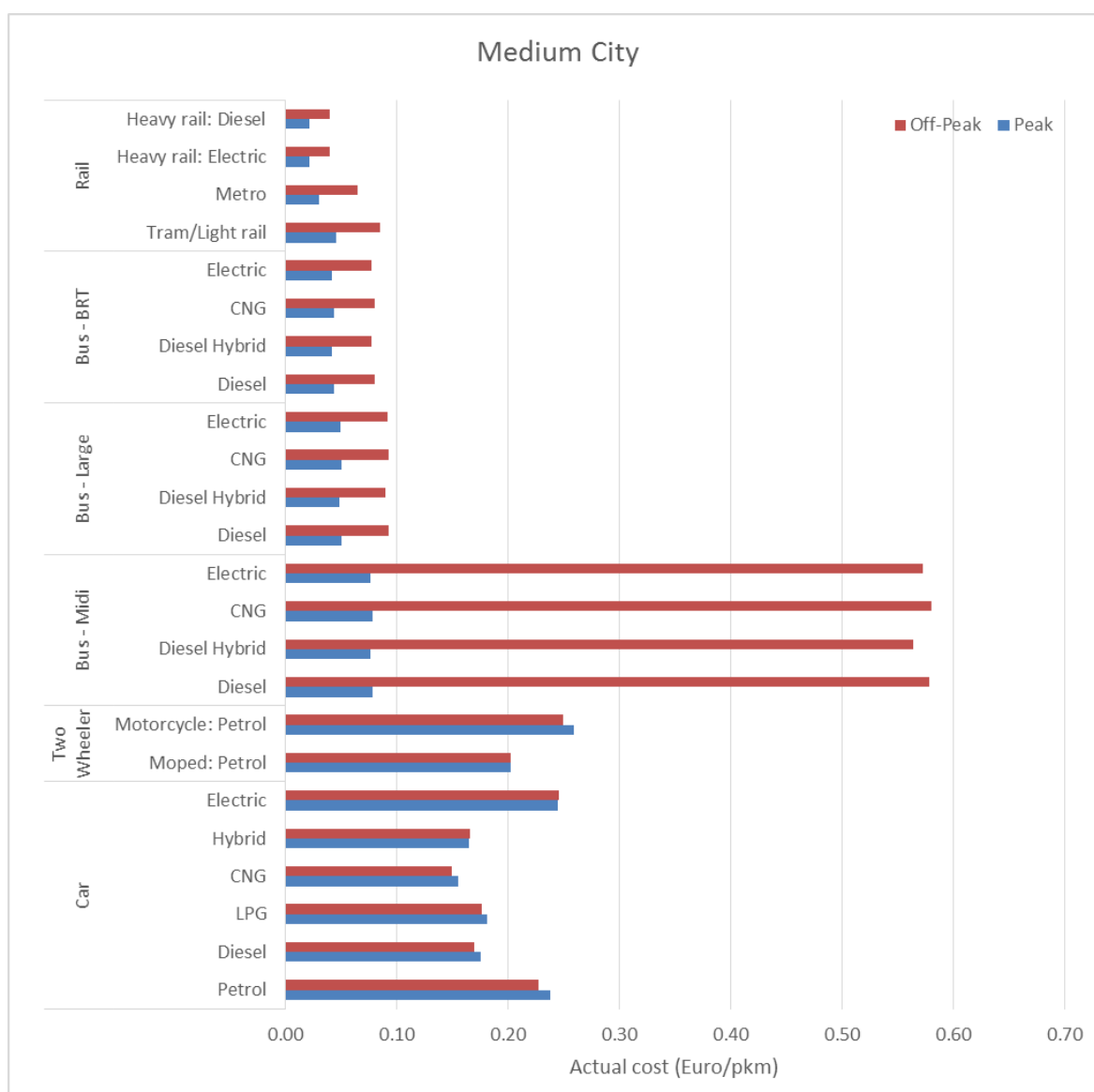
Figure 4-3: Actual cost (Euro/pkm) in a metropolitan area



Source: TRT estimation

Actual cost in a medium city

The trends of average cost in medium cities are similar to those observed in metropolitan areas, although public transport modes are slightly more expensive.

Figure 4-4: Actual cost (euro/pkm) in a medium city

Source: TRT estimation

5 Conclusions

This report has assessed the performance of a range of urban transport modes in relation to capacity, energy use, CO₂ emissions and cost. The data has been estimated as generic averages for European cities in relation to four basic conditions: metropolitan areas, medium cities, peak (congested) traffic and off-peak (uncongested) traffic. These data are intended to support cities in understanding different urban passenger modes and how to contribute to the efficient operation of the city and improving urban access.

Key conclusions from the analysis carried out are set out below, with detail data on each performance metric and mode provided in the Annexes.

Capacity results

- Metro services have the highest results in terms of both theoretical and actual capacity as might be expected.
- In terms of theoretical capacity, private modes (cars, mopeds and motorcycles) challenge or outperform buses assuming that vehicle capacity of all modes is fully used and considering that public transport is limited by frequency of service.
- Actual capacity in real-world conditions changes according to the time of the day: while metro and heavy rail are always the highest capacity alternatives, tram/light rail, BRT and especially buses can provide less capacity than private modes because of very low occupancy factors, which typically affect public transport services in non-congested or off-peak periods.

Energy use and CO₂ emission results

- The average per passenger energy usage (and therefore the CO₂ emissions) of private transport modes (cars, mopeds and motorcycles) is primarily dependent on the average speed travelled. Higher average speeds represent less congested urban environments with smoother traffic flow and fewer stopping and starting manoeuvres. Consequently, energy efficiency is better.
- On the other hand, the average per passenger energy use of public transport modes (bus and rail) is mainly dependent on the vehicle capacity and occupancy factor. This is because the speed of travel via public transport was estimated to not vary considerably depending on the urban environment (medium city or metropolitan area) and whether the journey occurs at peak or off-peak time.
- Private transport modes are more efficient at off-peak times due to reduced congestion. This is in contrast to public transport modes, which show a lower energy consumption per passenger kilometre during peak time. This is because the occupancy factors for private transport modes were assumed to remain constant at peak and off-peak times, while for public transport modes, occupancy is significantly higher at peak time.
- At peak times, the most efficient transport modes were calculated to be large buses, BRT buses and heavy rail. At off-peak times, these were also the most efficient transport modes. In relation to the fuel type, electric and hybrid vehicles were found to be the most efficient on a well-to-wheel basis for these modes, while CNG vehicles were calculated to be the least efficient.
- Overall during peak periods public transport is more energy efficient and less polluting per passenger km than private vehicles. The only exception to this is for electric and hybrid vehicles which have a similar energy use to some of the more energy intensive public transport modes such as metros.
- However during off-peak times, the energy consumption per passenger km of private and public modes is much closer and in some cases, such as diesel midi buses, the public transport modes have higher energy use.

- Consequently, in some urban transport situations (for example, at off-peak times), it can be more energy efficient to travel by some private transport modes, in particular electric or hybrid cars, than some public transport modes.
- From an energy efficiency perspective it is therefore important to consider the level of utilisation of public transport modes at different times of day when deciding service provision. As illustrated by the calculated energy usage of midi buses at off-peak times (which have very low occupancy factors), it is very inefficient to run large public transport vehicles that are mostly empty.
- The difference between modes show a very similar picture between metropolitan areas and medium cities. The key differences are that in metropolitan areas cars have poorer energy consumption than in medium cities due to lower traffic speeds, whereas public transport has better energy efficiency than in medium cities due to high occupancy factors.

Cost results

- From a theoretical point of view the highest average cost per passenger-km is related to two-wheelers, while rail modes show the lower values together with BRT and large buses.
- The cost of cars depend on fuel type: the most expensive are petrol and electric (the former due to energy cost, the latter basically due to non-energy cost, e.g. amortisation cost), while hybrid and CNG are the cheapest.
- The average cost of bus services is instead quite similar comparing different fuel types, even if this result comes from quite different values of energy and amortisation costs. Higher amortisation costs for electric and hybrid buses are, counterbalanced by low energy cost.
- In real-world conditions, private road modes are generally always more expensive than public transport services but the difference is less during off-peak time due to the low level of occupancy rates in public transport modes.

Overall conclusions

The performance of different transport modes is dependent on a range of factors including the capacity of the infrastructure and vehicles, occupancy levels and traffic conditions. In addition the different modes may perform differently depending on which metrics are being considered. Therefore comparing modes across the four different metrics and different city conditions presents a complex picture.

However, looking across all the results a few key trends emerge:

- During peak periods the capacity, cost and environmental performance per passenger of public transport is generally better than that of private modes (cars and motorcycles). However, during off peak periods the picture is much more complex.
- Costs are generally lower for public transport than private transport in all conditions.
- Overall capacity, including infrastructure, is greatest for the rail modes. For the road modes capacities are much more similar for both private and public transport (bus-based) and during off-peak periods the capacity of private modes is often greater given the lower occupancy levels of public transport.
- Energy and CO₂ emissions per passenger are generally lower for public transport modes than private modes at peak periods, though metro and light rail system seem relatively energy intensive with bus-based modes being the most efficient. However, during off peak periods private modes can have lower energy use and emissions per passenger.

- Electric and hybrid cars can have an environmental performance similar to public transport modes, but are more costly than convention petrol and diesel vehicles. Similarly hybrid and electric buses have better environmental performance than there diesel or CNG counterparts.

In terms of active modes the energy use, CO2 emissions and costs are all substantially less than for the motorised modes. The capacity of these modes is not necessarily directly comparable with that of motorised modes, but in essence the capacity of cycling will be similar to mopeds and the capacity of walking will depend on the pedestrian infrastructure. Active modes, especially walking, are also part of an effective multi-modal public transport system.

Overall there is a role for all transport modes in an efficient urban transport system. Public transport should be the primary mode at peak times, with rail modes providing high capacity for key routes. To maximise the environmental performance of public transport systems electric and hybrid systems are favoured. Private modes have a role particularly in off-peak periods when there is insufficient passenger loading to give high occupancy factors on public transport. Again electric and hybrid technologies will improve the environmental performance of private modes, especially during peak periods as they less affected by slow traffic conditions.

The detailed results provided in the appendixes are designed as an information resource to allow cities to assess the efficiency of different transport modes relevant to their local situation. These data can then be used by cities to consider strategies to work towards an optimum mix of transport modes to support improved accessibility in relation to the capacity and costs of use, and their environmental impacts.

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Annexes

Annex 1: Capacity results tables

Annex 2: Energy and CO₂ emission results tables

Annex 3: Cost results tables

Annex 1: Capacity results tables

Table A1: Full results for capacity assessment. Source: TRT calculations

Mode	Sub-mode	Urban type	Time period	Infrastructure capacity / maximum frequency	Service frequency	Vehicle capacity	Occupancy factor	Daily traffic profile impact	Actual Capacity	Theoretical Capacity
				(veh/hour)	(veh/hour)	(Pass/veh)	%		(Pass/hour)	(Pass/hour)
Car		Metropolitan area	Peak	900		5	34.0%	1.00	1530	4500
		Metropolitan area	Off-peak				34.0%	0.60	920	4500
		Medium city	Peak				34.0%	1.00	1530	4500
		Medium city	Off-peak				34.0%	0.60	920	4500
Moped			Peak	1800		1	100%	1.00	1800	1800
			Off-peak					0.60	1080	1800
Motorcycle		Metropolitan area	Peak	1800		2	55%	1.00	1980	3600
		Metropolitan area	Off-peak					0.60	1180	3600
		Medium city	Peak					1.00	1980	3600
		Medium city	Off-peak					0.60	1180	3600
Bus	Midi	Metropolitan area	Peak	20	8.0	60	86.3%		410	1200
		Metropolitan area	Off-peak		6.0		11.5%		40	1200
		Medium city	Peak		6.0		75.0%		270	1200
		Medium city	Off-peak		4.0		10.0%		20	1200

	Large	Metropolitan area	Peak	20	12.0	100	86.3%		1040	2000
		Metropolitan area	Off-peak		7.0		46.0%		320	2000
		Medium city	Peak		8.0		75.0%		600	2000
		Medium city	Off-peak		5.0		40.0%		200	2000
	BRT	Metropolitan area	Peak	20	17.1	140	86.3%		2070	2800
		Metropolitan area	Off-peak		10.0		46.0%		640	2800
		Medium city	Peak		17.1		75.0%		1800	2800
		Medium city	Off-peak		10.0		40.0%		560	2800
Rail	Tram/Light rail	Metropolitan area	Peak	20	13.0	285	86.3%		3200	5700
		Metropolitan area	Off-peak		7.0		46.0%		920	5700
		Medium city	Peak		9.0	170	75.0%		1150	3400
		Medium city	Off-peak		7.0		40.0%		480	3400
	Metro	Metropolitan area	Peak	30	20.0	1200	99.2%		23810	36000
		Metropolitan area	Off-peak		12.0		46.0%		6620	36000
		Medium city	Peak		12.0	550	86.3%		5690	16500
		Medium city	Off-peak		10.0		40.0%		2200	16500
	Heavy rail	Metropolitan area	Peak	15	6.0	1000	86.3%		5180	15000
		Metropolitan area	Off-peak		3.0		46.0%		1380	15000
		Medium city	Peak		3.0	1000	75.0%		2250	15000
		Medium city	Off-peak		1.0		40.0%		400	15000

Annex 2: Energy and CO₂ emission results tables

Energy results

Table A2: Full results for energy consumption. Source: Ricardo Energy & Environment calculations

Mode	Sub-mode	Fuel Type	Urban type	Time period	Energy use per vehicle	WTT energy use	Vehicle capacity	Occupancy factor	Energy use per passenger	WTW energy use
					MJ/ vkm	MJ/ MJ	(Pass/ veh)	%	MJ/pkm	MJ/ pkm
Car		Petrol	Metropolitan area	Peak	2.78	0.1842	5	34%	1.63	1.93
			Metropolitan area	Off-peak	2.22	0.1842	5	34%	1.30	1.54
			Medium city	Peak	2.53	0.1842	5	34%	1.49	1.76
			Medium city	Off-peak	2.11	0.1842	5	34%	1.24	1.47
		Diesel	Metropolitan area	Peak	2.39	0.2042	5	34%	1.41	1.69
			Metropolitan area	Off-peak	1.99	0.2042	5	34%	1.17	1.41
			Medium city	Peak	2.21	0.2042	5	34%	1.30	1.57
			Medium city	Off-peak	1.92	0.2042	5	34%	1.13	1.36
		LPG	Metropolitan area	Peak	2.61	0.1184	5	34%	1.53	1.72
			Metropolitan area	Off-peak	2.29	0.1184	5	34%	1.35	1.51
			Medium city	Peak	2.48	0.1184	5	34%	1.46	1.63
			Medium city	Off-peak	2.22	0.1184	5	34%	1.30	1.46
		CNG	Metropolitan area	Peak	2.84	0.1653	5	34%	1.67	1.95
			Metropolitan area	Off-peak	2.27	0.1653	5	34%	1.33	1.55
			Medium city	Peak	2.59	0.1653	5	34%	1.52	1.78

Mode	Sub-mode	Fuel Type	Urban type	Time period	Energy use per vehicle	WTT energy use	Vehicle capacity	Occupancy factor	Energy use per passenger	WTW energy use
			Medium city	Off-peak	2.16	0.1653	5	34%	1.27	1.48
		Petrol Hybrid	Metropolitan area	Peak	1.01	0.1842	5	34%	0.59	0.70
			Metropolitan area	Off-peak	1.02	0.1842	5	34%	0.60	0.71
			Medium city	Peak	1.00	0.1842	5	34%	0.59	0.70
			Medium city	Off-peak	1.04	0.1842	5	34%	0.61	0.72
		Electric	Metropolitan area	Peak	0.64	2.2616	5	34%	0.38	0.86
			Metropolitan area	Off-peak	0.62	2.2616	5	34%	0.36	0.82
			Medium city	Peak	0.62	2.2616	5	34%	0.37	0.83
			Medium city	Off-peak	0.63	2.2616	5	34%	0.37	0.84
Mopeds + Motorcycles	Moped	Petrol	Metropolitan area	Peak	0.96	0.1842	1	100%	0.96	1.14
			Metropolitan area	Off-peak	0.96	0.1842	1	100%	0.96	1.14
			Medium city	Peak	0.96	0.1842	1	100%	0.96	1.14
			Medium city	Off-peak	0.96	0.1842	1	100%	0.96	1.14
	Motorcycle	Petrol	Metropolitan area	Peak	1.78	0.1842	2	55%	1.62	1.92
			Metropolitan area	Off-peak	1.44	0.1842	2	55%	1.31	1.55
			Medium city	Peak	1.62	0.1842	2	55%	1.47	1.75
			Medium city	Off-peak	1.39	0.1842	2	55%	1.27	1.50
Bus	Midi	Diesel	Metropolitan area	Peak	14.14	0.2042	60	86%	0.27	0.33

Mode	Sub-mode	Fuel Type	Urban type	Time period	Energy use per vehicle	WTT energy use	Vehicle capacity	Occupancy factor	Energy use per passenger	WTW energy use
			Metropolitan area	Off-peak	12.67	0.2042	60	12%	1.84	2.21
			Medium city	Peak	13.11	0.2042	60	75%	0.29	0.35
			Medium city	Off-peak	11.92	0.2042	60	10%	1.99	2.39
		Diesel Hybrid	Metropolitan area	Peak	8.57	0.2042	60	86%	0.17	0.20
			Metropolitan area	Off-peak	7.68	0.2042	60	12%	1.11	1.34
			Medium city	Peak	7.95	0.2042	60	75%	0.18	0.21
			Medium city	Off-peak	7.22	0.2042	60	10%	1.20	1.45
		CNG	Metropolitan area	Peak	17.67	0.1653	60	86%	0.34	0.40
			Metropolitan area	Off-peak	15.84	0.1653	60	12%	2.30	2.68
			Medium city	Peak	16.39	0.1653	60	75%	0.36	0.42
			Medium city	Off-peak	14.89	0.1653	60	10%	2.48	2.89
		Electric	Metropolitan area	Peak	4.34	2.2616	60	86%	0.08	0.19
			Metropolitan area	Off-peak	3.89	2.2616	60	12%	0.56	1.28
			Medium city	Peak	4.03	2.2616	60	75%	0.09	0.20
			Medium city	Off-peak	3.66	2.2616	60	10%	0.61	1.38
	Large	Diesel	Metropolitan area	Peak	18.56	0.2042	100	86%	0.22	0.26
			Metropolitan area	Off-peak	16.74	0.2042	100	46%	0.36	0.44
			Medium city	Peak	17.29	0.2042	100	75%	0.23	0.28
			Medium city	Off-peak	15.78	0.2042	100	40%	0.39	0.48

Mode	Sub-mode	Fuel Type	Urban type	Time period	Energy use per vehicle	WTT energy use	Vehicle capacity	Occupancy factor	Energy use per passenger	WTW energy use
		Diesel Hybrid	Metropolitan area	Peak	11.25	0.2042	100	86%	0.13	0.16
			Metropolitan area	Off-peak	10.15	0.2042	100	46%	0.22	0.27
			Medium city	Peak	10.48	0.2042	100	75%	0.14	0.17
			Medium city	Off-peak	9.57	0.2042	100	40%	0.24	0.29
		CNG	Metropolitan area	Peak	23.20	0.1653	100	86%	0.27	0.31
			Metropolitan area	Off-peak	20.92	0.1653	100	46%	0.45	0.53
			Medium city	Peak	21.61	0.1653	100	75%	0.29	0.34
			Medium city	Off-peak	19.73	0.1653	100	40%	0.49	0.57
		Electric	Metropolitan area	Peak	5.70	2.2616	100	86%	0.07	0.15
			Metropolitan area	Off-peak	5.14	2.2616	100	46%	0.11	0.25
			Medium city	Peak	5.31	2.2616	100	75%	0.07	0.16
			Medium city	Off-peak	4.85	2.2616	100	40%	0.12	0.27
	BRT	Diesel	Metropolitan area	Peak	22.81	0.2042	140	86%	0.19	0.23
			Metropolitan area	Off-peak	20.88	0.2042	140	46%	0.32	0.39
			Medium city	Peak	21.47	0.2042	140	75%	0.20	0.25
			Medium city	Off-peak	19.83	0.2042	140	40%	0.35	0.43
		Diesel Hybrid	Metropolitan area	Peak	13.83	0.2042	140	86%	0.11	0.14
			Metropolitan area	Off-peak	12.66	0.2042	140	46%	0.20	0.24

Mode	Sub-mode	Fuel Type	Urban type	Time period	Energy use per vehicle	WTT energy use	Vehicle capacity	Occupancy factor	Energy use per passenger	WTW energy use
			Medium city	Peak	13.02	0.2042	140	75%	0.12	0.15
			Medium city	Off-peak	12.02	0.2042	140	40%	0.21	0.26
		CNG								
			Metropolitan area	Peak	28.51	0.1653	140	86%	0.24	0.28
			Metropolitan area	Off-peak	26.10	0.1653	140	46%	0.41	0.47
			Medium city	Peak	26.84	0.1653	140	75%	0.26	0.30
			Medium city	Off-peak	24.78	0.1653	140	40%	0.44	0.52
		Electric	Metropolitan area	Peak	7.00	2.2616	140	86%	0.06	0.13
			Metropolitan area	Off-peak	6.41	2.2616	140	46%	0.10	0.23
			Medium city	Peak	6.59	2.2616	140	75%	0.06	0.14
			Medium city	Off-peak	6.09	2.2616	140	40%	0.11	0.25
Rail	Tram/Light rail	Electric	Metropolitan area	Peak	84.68	2.2616	285	86%	0.34	0.78
			Metropolitan area	Off-peak	84.68	2.2616	285	46%	0.65	1.46
			Medium city	Peak	43.92	2.2616	170	75%	0.34	0.78
			Medium city	Off-peak	43.92	2.2616	170	40%	0.65	1.46
	Metro	Electric								
			Metropolitan area	Peak	355.78	2.2616	1200	99%	0.30	0.68
			Metropolitan area	Off-peak	355.78	2.2616	1200	46%	0.64	1.46
			Medium city	Peak	141.80	2.2616	550	86%	0.30	0.68
			Medium city	Off-peak	141.80	2.2616	550	40%	0.64	1.46

Mode	Sub-mode	Fuel Type	Urban type	Time period	Energy use per vehicle	WTT energy use	Vehicle capacity	Occupancy factor	Energy use per passenger	WTW energy use
	Heavy rail	Electric Intercity	Metropolitan area	Peak	62.89	2.2616	1000	86%	0.07	0.16
			Metropolitan area	Off-peak	62.89	2.2616	1000	46%	0.14	0.31
			Medium city	Peak	62.89	2.2616	1000	75%	0.08	0.19
			Medium city	Off-peak	62.89	2.2616	1000	40%	0.16	0.36
		Diesel intercity	Metropolitan area	Peak	115.29	0.2042	1000	86%	0.13	0.16
			Metropolitan area	Off-peak	115.29	0.2042	1000	46%	0.25	0.30
			Medium city	Peak	115.29	0.2042	1000	75%	0.15	0.19
			Medium city	Off-peak	115.29	0.2042	1000	40%	0.29	0.35

CO₂ emission resultsTable A3: Full results for CO₂ emissions. Source: Ricardo Energy & Environment calculations

Mode	Sub-mode	Fuel Type	Urban type	Time period	Energy use per vehicle	TTW CO ₂ factor	WTT CO ₂ Factor	Vehicle capacity	Occupancy factor	CO ₂ per passenger	WTW CO ₂
					MJ/ vkm	kg/ MJ	kg/ MJ	(Pass/ veh)	%	kg/pkm	kg/pkm
Car		Petrol	Metropolitan area	Peak	2.7770	0.0734	0.0138	5	34%	0.1199	0.1423
			Metropolitan area	Off-peak	2.2163	0.0734	0.0138	5	34%	0.0957	0.1136
			Medium city	Peak	2.5337	0.0734	0.0138	5	34%	0.1094	0.1299
			Medium city	Off-peak	2.1144	0.0734	0.0138	5	34%	0.0913	0.1084
		Diesel	Metropolitan area	Peak	2.3899	0.0732	0.0154	5	34%	0.1030	0.1246
			Metropolitan area	Off-peak	1.9892	0.0732	0.0154	5	34%	0.0857	0.1037
			Medium city	Peak	2.2109	0.0732	0.0154	5	34%	0.0953	0.1152
			Medium city	Off-peak	1.9220	0.0732	0.0154	5	34%	0.0828	0.1002
		LPG	Metropolitan area	Peak	2.6076	0.0657	0.0080	5	34%	0.1007	0.1131
			Metropolitan area	Off-peak	2.2884	0.0657	0.0080	5	34%	0.0884	0.0992
			Medium city	Peak	2.4844	0.0657	0.0080	5	34%	0.0960	0.1077
			Medium city	Off-peak	2.2155	0.0657	0.0080	5	34%	0.0856	0.0961
		CNG	Metropolitan area	Peak	2.8396	0.0562	0.0130	5	34%	0.0939	0.1157
			Metropolitan area	Off-peak	2.2661	0.0562	0.0130	5	34%	0.0750	0.0923
			Medium city	Peak	2.5901	0.0562	0.0130	5	34%	0.0857	0.1055
			Medium city	Off-peak	2.1636	0.0562	0.0130	5	34%	0.0716	0.0882
		Petrol Hybrid	Metropolitan area	Peak	1.0083	0.0734	0.0138	5	34%	0.0435	0.0517

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			Metropolitan area	Off-peak	1.0197	0.0734	0.0138	5	34%	0.0440	0.0523
			Medium city	Peak	1.0018	0.0734	0.0138	5	34%	0.0432	0.0513
			Medium city	Off-peak	1.0380	0.0734	0.0138	5	34%	0.0448	0.0532
		Electric	Metropolitan area	Peak	0.6445	0.0000	0.1501	5	34%	0.0000	0.0569
			Metropolitan area	Off-peak	0.6154	0.0000	0.1501	5	34%	0.0000	0.0543
			Medium city	Peak	0.6205	0.0000	0.1501	5	34%	0.0000	0.0548
			Medium city	Off-peak	0.6299	0.0000	0.1501	5	34%	0.0000	0.0556
Motorcycle	Moped	Petrol	Metropolitan area	Peak	0.9642	0.0734	0.0138	1	100%	0.0707	0.0840
			Metropolitan area	Off-peak	0.9642	0.0734	0.0138	1	100%	0.0707	0.0840
			Medium city	Peak	0.9642	0.0734	0.0138	1	100%	0.0707	0.0840
			Medium city	Off-peak	0.9642	0.0734	0.0138	1	100%	0.0707	0.0840
	Motorcycle	Petrol	Metropolitan area	Peak	1.7839	0.0734	0.0138	2	55%	0.1190	0.1413
			Metropolitan area	Off-peak	1.4368	0.0734	0.0138	2	55%	0.0958	0.1138
			Medium city	Peak	1.6214	0.0734	0.0138	2	55%	0.1082	0.1284
			Medium city	Off-peak	1.3928	0.0734	0.0138	2	55%	0.0929	0.1103
Bus	Midi	Diesel	Metropolitan area	Peak	14.1379	0.0732	0.0154	60	86%	0.0200	0.0242
			Metropolitan area	Off-peak	12.6723	0.0732	0.0154	60	12%	0.1345	0.1627
			Medium city	Peak	13.1096	0.0732	0.0154	60	75%	0.0213	0.0258
			Medium city	Off-peak	11.9159	0.0732	0.0154	60	10%	0.1455	0.1760
		Diesel Hybrid	Metropolitan area	Peak	8.5703	0.0732	0.0154	60	86%	0.0121	0.0147
			Metropolitan area	Off-peak	7.6819	0.0732	0.0154	60	12%	0.0815	0.0986
			Medium city	Peak	7.9469	0.0732	0.0154	60	75%	0.0129	0.0156

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			Medium city	Off-peak	7.2233	0.0732	0.0154	60	10%	0.0882	0.1067
		CNG	Metropolitan area	Peak	17.6723	0.0562	0.0130	60	86%	0.0192	0.0237
			Metropolitan area	Off-peak	15.8404	0.0562	0.0130	60	12%	0.1291	0.1590
			Medium city	Peak	16.3870	0.0562	0.0130	60	75%	0.0205	0.0252
			Medium city	Off-peak	14.8949	0.0562	0.0130	60	10%	0.1396	0.1720
		Electric	Metropolitan area	Peak	4.3408	0.0000	0.1501	60	86%	0.0000	0.0126
			Metropolitan area	Off-peak	3.8908	0.0000	0.1501	60	12%	0.0000	0.0846
			Medium city	Peak	4.0250	0.0000	0.1501	60	75%	0.0000	0.0134
			Medium city	Off-peak	3.6585	0.0000	0.1501	60	10%	0.0000	0.0915
	Large	Diesel	Metropolitan area	Peak	18.5625	0.0732	0.0154	100	86%	0.0158	0.0191
			Metropolitan area	Off-peak	16.7396	0.0732	0.0154	100	46%	0.0267	0.0322
			Medium city	Peak	17.2869	0.0732	0.0154	100	75%	0.0169	0.0204
			Medium city	Off-peak	15.7848	0.0732	0.0154	100	40%	0.0289	0.0350
		Diesel Hybrid	Metropolitan area	Peak	11.2524	0.0732	0.0154	100	86%	0.0096	0.0116
			Metropolitan area	Off-peak	10.1474	0.0732	0.0154	100	46%	0.0162	0.0195
			Medium city	Peak	10.4792	0.0732	0.0154	100	75%	0.0102	0.0124
			Medium city	Off-peak	9.5686	0.0732	0.0154	100	40%	0.0175	0.0212
		CNG	Metropolitan area	Peak	23.2031	0.0562	0.0130	100	86%	0.0151	0.0186
			Metropolitan area	Off-peak	20.9244	0.0562	0.0130	100	46%	0.0256	0.0315
			Medium city	Peak	21.6086	0.0562	0.0130	100	75%	0.0162	0.0200
			Medium city	Off-peak	19.7310	0.0562	0.0130	100	40%	0.0277	0.0342

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		Electric	Metropolitan area	Peak	5.6993	0.0000	0.1501	100	86%	0.0000	0.0099
			Metropolitan area	Off-peak	5.1396	0.0000	0.1501	100	46%	0.0000	0.0168
			Medium city	Peak	5.3076	0.0000	0.1501	100	75%	0.0000	0.0106
			Medium city	Off-peak	4.8464	0.0000	0.1501	100	40%	0.0000	0.0182
	BRT	Diesel	Metropolitan area	Peak	22.8109	0.0732	0.0154	140	86%	0.0138	0.0167
			Metropolitan area	Off-peak	20.8804	0.0732	0.0154	140	46%	0.0237	0.0287
			Medium city	Peak	21.4708	0.0732	0.0154	140	75%	0.0150	0.0181
			Medium city	Off-peak	19.8273	0.0732	0.0154	140	40%	0.0259	0.0314
		Diesel Hybrid	Metropolitan area	Peak	13.8278	0.0732	0.0154	140	86%	0.0084	0.0101
			Metropolitan area	Off-peak	12.6576	0.0732	0.0154	140	46%	0.0144	0.0174
			Medium city	Peak	13.0154	0.0732	0.0154	140	75%	0.0091	0.0110
			Medium city	Off-peak	12.0191	0.0732	0.0154	140	40%	0.0157	0.0190
		CNG	Metropolitan area	Peak	28.5137	0.0562	0.0130	140	86%	0.0133	0.0164
			Metropolitan area	Off-peak	26.1005	0.0562	0.0130	140	46%	0.0228	0.0281
			Medium city	Peak	26.8385	0.0562	0.0130	140	75%	0.0144	0.0177
			Medium city	Off-peak	24.7841	0.0562	0.0130	140	40%	0.0249	0.0307
		Electric	Metropolitan area	Peak	7.0037	0.0000	0.1501	140	86%	0.0000	0.0087
			Metropolitan area	Off-peak	6.4109	0.0000	0.1501	140	46%	0.0000	0.0149
			Medium city	Peak	6.5922	0.0000	0.1501	140	75%	0.0000	0.0094
			Medium city	Off-peak	6.0876	0.0000	0.1501	140	40%	0.0000	0.0163
Rail	Tram/Light rail	Electric	Metropolitan area	Peak	84.68	0.0000	0.1501	285	86%	0.0000	0.0517
			Metropolitan area	Off-peak	84.68	0.0000	0.1501	285	46%	0.0000	0.0970

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			Medium city	Peak	43.92	0.0000	0.1501	170	75%	0.0000	0.0517
			Medium city	Off-peak	43.92	0.0000	0.1501	170	40%	0.0000	0.0970
	Metro	Electric	Metropolitan area	Peak	355.78	0.0000	0.1501	1200	99%	0.0000	0.0449
			Metropolitan area	Off-peak	355.78	0.0000	0.1501	1200	46%	0.0000	0.0967
			Medium city	Peak	141.80	0.0000	0.1501	550	86%	0.0000	0.0449
			Medium city	Off-peak	141.80	0.0000	0.1501	550	40%	0.0000	0.0967
	Heavy rail	Electric Intercity	Metropolitan area	Peak	62.89	0.0000	0.1501	1000	86%	0.0000	0.0109
			Metropolitan area	Off-peak	62.89	0.0000	0.1501	1000	46%	0.0000	0.0205
			Medium city	Peak	62.89	0.0000	0.1501	1000	75%	0.0000	0.0109
			Medium city	Off-peak	62.89	0.0000	0.1501	1000	40%	0.0000	0.0205
		Diesel Intercity	Metropolitan area	Peak	115.29	0.0732	0.0154	1000	86%	0.0098	0.0118
			Metropolitan area	Off-peak	115.29	0.0732	0.0154	1000	46%	0.0184	0.0222
			Medium city	Peak	115.29	0.0732	0.0154	1000	75%	0.0098	0.0118
			Medium city	Off-peak	115.29	0.0732	0.0154	1000	40%	0.0184	0.0222

Annex 3: Cost results tables

Table A4: Full results for cost assessment. Source: TRT calculations

Mode	Sub-mode	Fuel Type	Urban type	Time period	Energy cost	Other private modes variables costs	PT vehicle cost	Other Service production costs	Service production costs	Vehicle occupancy	Actual Cost	Vehicle capacity	Theoretical cost
					<i>Euro/vkm</i>	<i>Euro/vkm</i>	<i>Euro/vkm</i>	<i>Euro/vkm</i>	<i>Euro/vkm</i>	<i>Pass/veh</i>	<i>Euro/pkm</i>	<i>Pass/veh</i>	<i>Euro/pkm</i>
Car		Petrol	Metropolitan area	Peak	0.122	0.29				1.70	0.244	5	0.083
			Metropolitan area	Off-peak	0.097					1.70	0.230	5	0.078
			Medium city	Peak	0.111					1.70	0.238	5	0.081
			Medium city	Off-peak	0.093					1.70	0.227	5	0.077
		Diesel	Metropolitan area	Peak	0.083	0.22				1.70	0.179	5	0.061
			Metropolitan area	Off-peak	0.069					1.70	0.171	5	0.058
			Medium city	Peak	0.077					1.70	0.175	5	0.060
			Medium city	Off-peak	0.067					1.70	0.170	5	0.058
		LPG	Metropolitan area	Peak	0.071	0.24				1.70	0.183	5	0.062
			Metropolitan area	Off-peak	0.062					1.70	0.178	5	0.060
			Medium city	Peak	0.067					1.70	0.181	5	0.061
			Medium city	Off-peak	0.060					1.70	0.177	5	0.060
		CNG	Metropolitan area	Peak	0.064	0.21				1.70	0.158	5	0.054
			Metropolitan area	Off-peak	0.051					1.70	0.150	5	0.051
			Medium city	Peak	0.058					1.70	0.155	5	0.053

			Medium city	Off-peak	0.048					1.70	0.149	5	0.051	
		Hybrid	Metropolitan area	Peak	0.044	0.24				1.70	0.165	5	0.056	
			Metropolitan area	Off-peak	0.045					1.70	0.165	5	0.056	
			Medium city	Peak	0.044					1.70	0.165	5	0.056	
			Medium city	Off-peak	0.045					1.70	0.166	5	0.056	
		Electric	Metropolitan area	Peak	0.037	0.39				1.70	0.250	5	0.085	
			Metropolitan area	Off-peak	0.036					1.70	0.249	5	0.085	
			Medium city	Peak	0.036					1.70	0.249	5	0.085	
			Medium city	Off-peak	0.036					1.70	0.249	5	0.085	
Moped		Petrol		Peak	0.042	0.16				1.00	0.202	1	0.202	
				Off-peak	0.042						0.202		0.202	
Motorcy cle		Petrol	Metropolitan area	Peak	0.078	0.21				1.10	0.265	2	0.146	
			Metropolitan area	Off-peak	0.063								0.251	0.138
			Medium city	Peak	0.071								0.258	0.142
			Medium city	Off-peak	0.061								0.249	0.137
Bus	Midi	Diesel	Metropolitan area	Peak	0.491	0.30	2.8	3.55	52	0.069	60.0	0.059		
			Metropolitan area	Off-peak	0.440			3.50	7	0.507	60.0	0.058		
			Medium city	Peak	0.455		2.8	3.51	45	0.078	60.0	0.059		
			Medium city	Off-peak	0.414			3.47	6	0.578	60.0	0.058		
		Diesel Hybrid	Metropolitan area	Peak	0.298		0.38	2.8	3.43	52	0.066	60	0.057	

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			Metropolitan area	Off-peak	0.267			2.8	3.40	7	0.493	60	0.057
			Medium city	Peak	0.276				3.41	45	0.076	60	0.057
			Medium city	Off-peak	0.251				3.38	6	0.564	60	0.056
		CNG	Metropolitan area	Peak	0.396		0.39	2.8	3.54	52	0.068	60	0.059
			Metropolitan area	Off-peak	0.355				3.50	7	0.507	60	0.058
			Medium city	Peak	0.367			2.8	3.51	45	0.078	60	0.059
			Medium city	Off-peak	0.334				3.48	6	0.580	60	0.058
		Electric	Metropolitan area	Peak	0.145		0.56	2.8	3.46	52	0.067	60	0.058
			Metropolitan area	Off-peak	0.130				3.44	7	0.499	60	0.057
			Medium city	Peak	0.134			2.8	3.45	45	0.077	60	0.057
			Medium city	Off-peak	0.122				3.43	6	0.572	60	0.057
	Large	Diesel	Metropolitan area	Peak	0.644		0.40	2.8	3.80	86	0.044	100.0	0.038
			Metropolitan area	Off-peak	0.581				3.74	46	0.081	100.0	0.037
			Medium city	Peak	0.600			2.8	3.76	75	0.050	100.0	0.038
			Medium city	Off-peak	0.548				3.70	40	0.093	100.0	0.037
		Diesel Hybrid	Metropolitan area	Peak	0.391		0.50	2.8	3.65	86	0.042	100	0.037
			Metropolitan area	Off-peak	0.352				3.61	46	0.079	100	0.036
			Medium city	Peak	0.364			2.8	3.62	75	0.048	100	0.036
			Medium city	Off-peak	0.332				3.59	40	0.090	100	0.036
		CNG	Metropolitan area	Peak	0.520		0.52	2.8	3.79	86	0.044	100	0.038
			Metropolitan area	Off-peak	0.469				3.74	46	0.081	100	0.037

			Medium city	Peak	0.484			2.8	3.76	75	0.050	100	0.038
			Medium city	Off-peak	0.442				3.72	40	0.093	100	0.037
	Electric						0.74	2.8					
		Metropolitan area	Peak	0.190					3.69	86	0.043	100	0.037
		Metropolitan area	Off-peak	0.171				2.8	3.67	46	0.080	100	0.037
		Medium city	Peak	0.177					3.67	75	0.049	100	0.037
		Medium city	Off-peak	0.162					3.66	40	0.091	100	0.037
	BRT	Diesel	Metropolitan area	Peak	0.792		0.40	3.4	4.58	121	0.038	140.0	0.033
			Metropolitan area	Off-peak	0.725				4.51	64	0.070	140.0	0.032
			Medium city	Peak	0.745			3.4	4.53	105	0.043	140.0	0.032
			Medium city	Off-peak	0.688				4.48	56	0.080	140.0	0.032
		Diesel Hybrid	Metropolitan area	Peak	0.480		0.50	3.4	4.37	121	0.036	140	0.031
			Metropolitan area	Off-peak	0.439				4.33	64	0.067	140	0.031
			Medium city	Peak	0.452			3.4	4.34	105	0.041	140	0.031
			Medium city	Off-peak	0.417				4.31	56	0.077	140	0.031
		CNG	Metropolitan area	Peak	0.639		0.52	3.4	4.55	121	0.038	140	0.032
			Metropolitan area	Off-peak	0.585				4.49	64	0.070	140	0.032
			Medium city	Peak	0.601			3.4	4.51	105	0.043	140	0.032
			Medium city	Off-peak	0.555				4.46	56	0.080	140	0.032
		Electric	Metropolitan area	Peak	0.233		0.74	3.4	4.36	121	0.036	140	0.031
			Metropolitan area	Off-peak	0.214				4.34	64	0.067	140	0.031
			Medium city	Peak	0.220			3.4	4.35	105	0.041	140	0.031

			Medium city	Off-peak	0.203				4.33	56	0.077	140	0.031
Rail	Tram/LRT	Electric	Metropolitan area	Peak					5.7	246	0.023	285	0.020
			Metropolitan area	Off-peak						131	0.044	285	0.020
			Medium city	Peak					5.7	128	0.045	170	0.034
			Medium city	Off-peak						68	0.084	170	0.034
	Metro	Electric	Metropolitan area	Peak					14.1	1190	0.012	1200	0.012
			Metropolitan area	Off-peak						552	0.026	1200	0.012
			Medium city	Peak					14.1	474	0.030	550	0.026
			Medium city	Off-peak						220	0.064	550	0.026
	Heavy rail	Electric Intercity	Metropolitan area	Peak	2.096				16.00	863	0.019	1000	0.016
			Metropolitan area	Off-peak	2.096				16.00	460	0.035	1000	0.016
			Medium city	Peak	2.096				16.00	750	0.021	1000	0.016
			Medium city	Off-peak	2.096				16.00	400	0.040	1000	0.016
		Diesel intercity	Metropolitan area	Peak	2.802				16.00	863	0.019	1000	0.016
			Metropolitan area	Off-peak	2.802				16.00	460	0.035	1000	0.016
			Medium city	Peak	2.802				16.00	750	0.021	1000	0.016
			Medium city	Off-peak	2.802				16.00	400	0.040	1000	0.016

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