TRAFIKVERKET

RESEARCH REPORT

HBEFA FoI

Development work 2019-2021
for improving Swedish HBEFA

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Abbreviations

ADT	Average Daily Traffic
ARR	Annual Reduction Rate
BEV	Battery Electric Vehicle
CNG	Compressed Natural Gas
ERMES	European Research for Mobile Emission Sources
FBC	Fuel Base Correction Factor
FFV	Flexi-fuel Vehicle
HBEFA	Handbook of Emission Factors
HCT	High-Capacity Transport
HDV	Heavy Duty Vehicle
HGV	Heavy Goods Vehicle
IPA	A simplified network geometry suited to the analysis tool in question.
LCV	Light Commercial Vehicle
LoS	Level of Service
MPLW	Maximum Permissible Laden Weight
NEDC	New European Driving Cycle
NVDB	Swedish national road database
PC	Passenger car
SERMES	Swedish ERMES working group
TRAFA	Transport Analysis, a Swedish government agency for transport policy analysis
VKT	Vehicle Kilometres Travelled
WLTP	Worldwide Harmonised Light Vehicle Test Procedure

1 Introduction

1.1. Background

The European emission model HBEFA (Handbook of Emission Factors – www.hbefa.net) is the main model used to calculate air emissions, fuel consumption and energy use connected to Swedish road traffic on the national, regional, and local level. HBEFA was developed in the mid 1990:s and is managed jointly by Germany, Austria, Switzerland, Sweden, France and Norway, with some support from the EU Joint Research Centre through their coordination of the European collaboration ERMES (www.ermes-group.eu). In Sweden, HBEFA is managed by the Swedish Transport Administration.

The data needed for reliable calculations of the emissions and fuel consumption of the Swedish road vehicle fleet is in part provided by the general EU data compiled in the model (e.g. emission and fuel consumption factors for different vehicle types and traffic situations) and in part based on annual statistics, e.g., on vehicle stock and vehicle mileage travelled (VKT) provided by various Swedish authorities. However, some important calculation parameters are not updated on a yearly basis. This means that the adaptation of HBEFA to Swedish conditions would gradually deteriorate, resulting in declining quality over time in the Swedish emissions and fuel consumption statistics, as well as in corresponding forecasts and scenarios.

The Swedish Transport Administration oversees the so called SERMES working group, through which statistics describing the Swedish vehicle fleet and the VKT on Swedish roads are produced. The group also works continuously with improving and developing the methods used to estimate changes in for instance vehicle stock, driving habits, driving patterns and other activity data. However, due to the rapid changes in various circumstances, this work is lagging.

1.2. The current project

In order to focus on several issues in need of attention, the Swedish Transport Administration assigned IVL Swedish Environmental Research Institute and WSP to conduct the research project *Development work for quality improvement of official statistics and forecasts/scenarios for emissions to the air, fuel consumption and energy use from Swedish road traffic using HBEFA.*

The project comprises several activities which aim to improve knowledge concerning the Swedish vehicle stock, VKT on Swedish roads, the distribution of VKT over road types and vehicle types, how the vehicle fleet changes over time, energy use in road vehicles and emissions of greenhouse gases and air pollutants from road traffic. A large part of the results can be (and have been) directly implemented in the Swedish HBEFA model, when estimating emissions from road traffic in Sweden. Other parts have resulted in method development that will be useful in future work on collecting data for implementation in HBEFA and can serve as a guide when prioritising future development needs.

1.3. This report

The research project was set up in the form of seven work packages (WP1-7), listed below:

- WP1 Enhanced methods for estimating activity data for light and heavy vehicles
    - WP1.1 Average annual mileage for light duty vehicles
    - WP1.2 Reviewing data sources for HGV > 60 t
    - WP1.3 Distribution of bus VKT over traffic situations
- WP2 Fuel consumption for light duty vehicles
- WP3 Turnover tool for road vehicle fleet vehicle fleet scenarios
- WP4 Data sources for analyses of driving patterns
    - WP4.1-2 Feasibility study on driving pattern data, including new vehicle technologies (electric cars, hybrids etc.)
    - WP4.3 Main study on driving patterns (*postponed*)
    - WP4.4 Adapting classification of traffic situations to Swedish conditions
- WP5 Development of current method for classification of traffic situations
    - WP5.1 Setting guidelines for input data requirements
    - WP5.2 Allocating traffic to the local road network
    - WP5.3 Differentiated method for categorising level of service (LoS)
    - WP5.4 Adaption of Swedish HBEFA after introducing a fifth level of service
    - WP5.5 Distribution of VKT over different gradients
- WP6 Study on differences in diesel consumption for road traffic between different national models
    - WP6.1 Sources for national VKT
    - WP6.2 Energy use in auxiliary equipment

WP1-6 have been documented in separate reports in Swedish (see Appendix), available on the Swedish Transport Administration website[1]. This final report (WP7) is a summary of the findings from the Swedish reports (chapter 2), followed by effect analyses of how changing selected factors affect HBEFA results (chapter 3). The final chapter presents a discussion on various data and methodology issues as well as suggestions for future work.

[1] Sök forskningsprojekt - Bransch (trafikverket.se)

2 Results by work package and tasks

2.1. Average annual mileage for light duty vehicles (WP1.1)

Background

In HBEFA, the average vehicle mileage is used to calculate the total national VKT. The average annual mileage is specified for each vehicle category, e.g., passenger cars, and by multiplying with the number of vehicles the national VKT is calculated. For estimating VKT on segment level also relative mileage between the segments must be estimated and implemented in HBEFA.

The vehicle mileage generally varies with age, where newer vehicles have a higher mileage and older vehicles a lower mileage. Furthermore, company cars (which have a high annual mileage) are often 1–3 years old and may after that be sold to private users often leading to a lower annual mileage. For describing this age dependency HBEFA uses data on segment level.

The estimate of the relative mileage between the segments is based on statistics provided by Trafikanalys[2], that in turn is based on odometer readings from periodical technical inspections. Since no technical inspection is carried out within the first three years for new vehicles the annual mileage for each of the first three years must be estimated in some other way. The method used for this by Trafikanalys was last updated in 2011 and is described in "Revised model for calculating driving distances - new data for road traffic 1999–2009", Trafikanalys (2011). In the method missing values for annual mileage are estimated outgoing from different groups of vehicles (e.g., diesel fueled leasing cars etc.).

The objective of this study was to estimate the average annual mileage for passenger cars using other fuels than petrol and diesel and for all light commercial vehicle segments. Annual mileages for diesel and petrol cars had already been estimated as part of the annual quality improvement work within the SERMES project. The estimates were needed either because there were no previous estimates or because there was a need to update current figures. At the same time the relative mileage distribution between the segments was updated as was also the vehicle mileage age dependency functions for all segments.

[2] A Swedish government agency for transport policy analysis, also referred to as TRAFA

Method

To estimate annual mileage per vehicle segment and as a function of age, two data sources have been used:

• Trafikanalys: Vehicle mileage from odometer readings at the periodical technical inspection.

• Autouncle: Vehicle mileage from odometer readings in combination with vehicle age when sold. At the time of writing, Autouncle's database contains information on approximately 770,000 passenger cars that have been advertised for sale in Sweden. Of these, approximately 400,000 were cars without odometer reading information and hence, they were not used in this investigation.

To estimate mileage per segment for passenger cars (PC), both sources have been used. Only data from actual odometer readings was included and hence estimations made by Trafikanalys when odometer readings were missing, were excluded from the analysis.

The age dependency per segment for PC was based only on the odometer readings obtained from Trafikanalys. The vehicle mileage during the three first years (when no odometer reading from the periodical technical inspection is available) was distributed per year using an exponentially decreasing function. Since the usage behavior changes over time, three different age distributions were developed and adapted for the years 1990–2007, 2008-2015 and from 2016 onwards.

Regarding average mileage per segment for light commercial vehicles (LCV) only odometer readings obtained from Trafikanalys was used as source. Average mileage for the first three years was estimated using the same method as for PC and the age dependency of the average annual mileage was estimated as for PC.

Results

The new data from this study was implemented in HBEFA in January 2020.

Average annual mileage for PC is presented in Figure 1 and for LCV in Figure 2. The figures compare updated mileage with those previously used. The low annual mileage for battery-electric (BEV) LCVs is likely due to a low technological maturity. As the electric driving range increases with technological development, annual mileage will likely also increase.

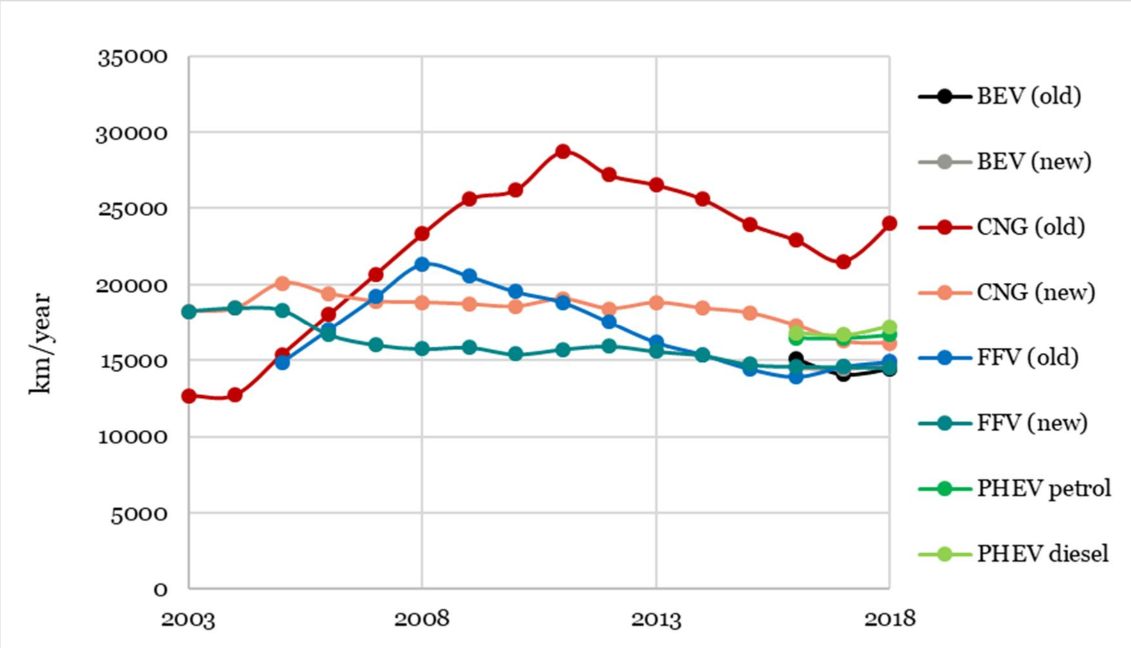

Figure 1. Previously used data and newly estimated data of average annual mileage for passenger cars per HBEFA-segment. The annual mileage is the average for all cars within a HBEFA-segment, but the annual mileage within a segment differs between vintages where newer cars drive more than older cars.

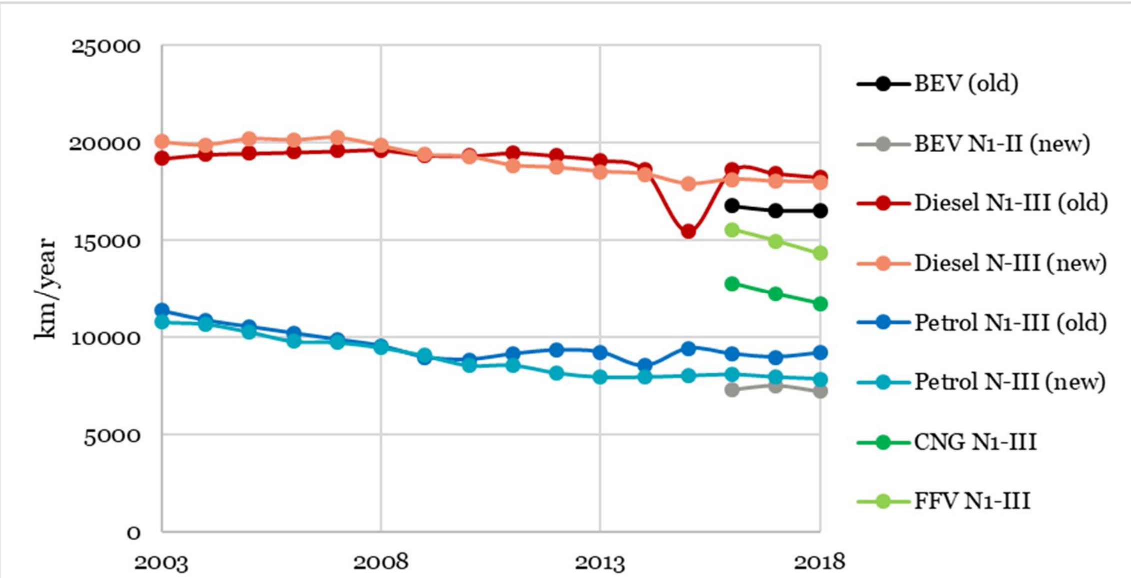

Figure 2. Previously used data and newly estimated data of average annual mileage for light commercial vehicles per HBEFA-segment. Mileage estimates for CNG and FFV were not available before this study. For increased readability only the heaviest vehicle weight segment (N1-III) is presented.

Differences in relative annual mileage before and after the update are exemplified by functions for PC petrol and PC diesel in Figure 3 and Figure 4 respectively.

A petrol car registered in the last year (index = 100) has roughly half the annual mileage compared to a 1-year-old petrol car (index = 192). This is because the brand-new petrol car was, on average, only in use during six months of the last year. The oldest petrol cars are assumed to have an annual mileage that equals about 10 per cent of a 1-year-old petrol car (index = 19).

For diesel cars, the relative annual mileage looks roughly the same as for petrol cars with the new function.

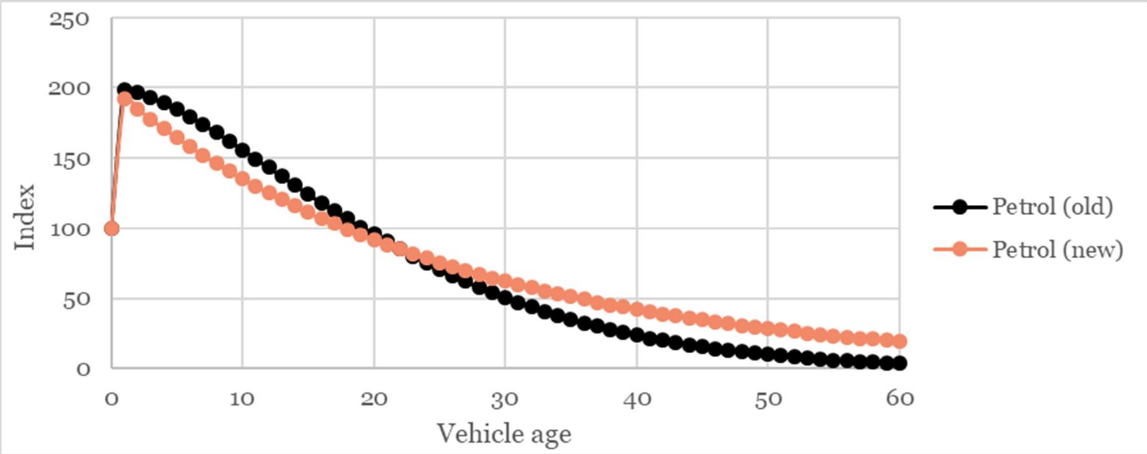

Figure 3. Relative average annual vehicle kilometers as a function of age for petrol powered passenger cars. The function is used from 2016 and onwards.

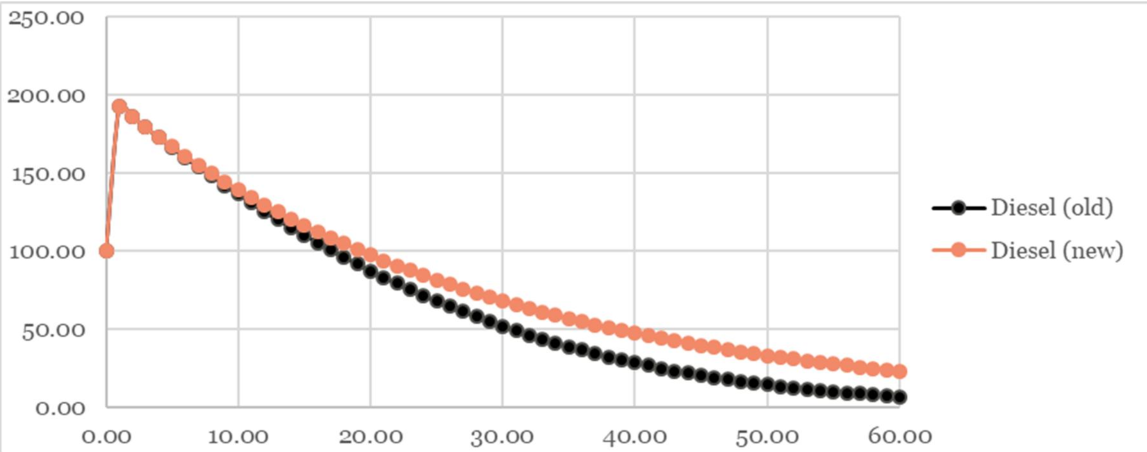

Figure 4. Relative average annual vehicle kilometers (y-axis) as a function of age (x-axis) for diesel powered passenger cars. The function is used from 2016 and onwards.

Conclusions

By combining data from odometer readings at the periodic technical inspection with odometer reading of sold cars of age 0-3 years, we have to some extent solved the issue associated with that new cars are inspected first after three years of use. The results are implemented in HBEFA from HBEFA 4.1 (2020).

The newly estimated average vehicle mileage per HBEFA-segment is more consistent with the trend seen for the main vehicle categories (PC and LCV) compared to the previously used figures.

For LCV, the differences between the old and the new method are smaller compared to what is seen for passenger cars, which is probably due to that diesel-powered LCV dominate both now and at the time for the latest method change made by Trafikanalys, but also because the average annual mileage for alternative fueled LCV´s was not estimated with the old method.

There are some differences in age dependency between new and old data. The oldest petrol and diesel cars drive slightly longer distances in the estimate that applies for 2016 and onwards. Such a shift in driving patterns should lead to increased emissions compared to if "new cars" drive more. However, the change cannot be considered separately for each segment, but must be seen together with the distribution of total vehicle mileage across all segments.

Discussion

It is possible that there are systematic errors as a result of using mileage data from advertisements of cars for sale. This is because it could not be ruled out that certain types of vehicles and also specific driving patterns associated with these vehicles are underrepresented or overrepresented among vehicles sold on the open market (Autouncle collects data on advertisements from several different websites that advertise cars for sale). For example, new cars that are primarily sold to private persons could be thought to be sold to a lesser extent than company cars.

For new vehicle technologies, such as BEV cars, there is both an issue with limited data availability and limited representativity for future annual mileages. Most BEV cars are less than three years old and therefore lack inspection data. Autouncle did not contain a large enough sample of BEV cars for an estimate to be made. For both passenger cars and LCVs, it is also likely that BEV technology will mature and that the average annual mileage will increase as the driving range increases with future BEV models. In the documentation of the method used by Trafikanalys (2011) it is explained how suspected incorrect driving distances are handled. This can occur e.g., if the odometer has "started over" without any deliberate tampering, or if there has been an error while reading or documenting the mileage (e.g., entering the mileage in Swedish "mil" (one Swedish "mil" corresponds to 10 km) instead of kilometers). Also, during the time of data collection, it has not been illegal to roll back the odometer reading. This would probably result in an underestimation of the mileage rather than an overestimation, as the incentives to reduce the odometer reading are higher than the incentives to increase it. We have not quantified the extent to which this could affect the estimated mileage.

The distribution of mileage over the first three years has been assumed to follow the same exponential pattern as for later years. An alternative approach used for example in Ricardo-AEA (2015) is to assume a uniform distribution over the first three years. The consequences of such an assumption are that 3-year-old vehicles would drive slightly longer and 1-year-old vehicles slightly shorter than in our assumption, which would mean slightly higher emissions (given that cars are becoming more energy efficient for each model year). The difference in emissions between the methods has not been quantified.

2.2. Reviewing data sources for HGV > 60 t (WP1.2)

Background

Starting in 2009, pilot projects have been carried out where so called HCT (high-capacity transports, i.e. trucks with a gross weight >64 tonnes) have been used on certain roads in Sweden. The trial period ended in 2018 and at the same time it became allowed to use these vehicles on special parts of the so called BK4 (bearing capacity class 4[3]) road network

[3] https://www.transportstyrelsen.se/globalassets/global/publikationer/vag/yrkestrafik/lasta-lagligt/tran045-lasta-lagligt-eng-low.pdf

without special permits. In the HBEFA model, these vehicles are currently (end of 2021) not treated as a separate vehicle segment but are instead included in the HGV 50-60t segment. This means, among other things, that the fuel consumption and emissions for HCT vehicles are likely currently underestimated by the model. Another consequence of the vehicles not being treated as a separate segment is that it is not possible to use the model for making forecasts of how the introduction of HCT vehicles affects total emissions and fuel consumption for trucks annually on a national level.

To be able to make separate calculations for HCT vehicles in the future, a method is needed to produce statistics on the number of vehicles and other parameters that are needed as input to HBEFA. The main purpose of this study was to investigate which sources that are available and whether they can be used to produce the information needed as input to HBEFA. A second task was to find a way to validate the fuel consumption factors used for HGV > 60t in HBEFA with the purpose to find out if it is representative for HCT vehicles used in Sweden.

A final objective was to decide how to handle trucks with a gross weight between 60 and 64 tonnes, i.e., if they should be included in the HBEFA segment HGV 50-60t or in the segment HGV >60t. As early as 2015, the maximum permitted gross weight on Swedish roads was increased from 60 to 64 tonnes. This is something that has not been considered in HBEFA so far and just like HCT, these vehicles are allocated to the HGV 50-60t segment.

Method and data sources

Data was collected from available sources with the purpose to investigate what kind of information on HCT vehicles that could be obtained. In addition, discussions were held with an expert on HCT vehicles from the Swedish Transport Administration. The three used data sources are described below.

- **The Swedish Road Traffic Registry:** The register contains useful information, such as curb weight and maximum permissible laden weight (MPLW) (the total weight of the vehicle and of the load declared permissible by the Swedish Transport Agency), for trucks and tractors registered in Sweden.
- **The Truck survey:** A survey which is sent to owners of trucks with a maximum load weight of more than 3.5 tonnes. Only trucks registered in Sweden are included and there are also a couple of other selection requirements which means that a small proportion of the Swedish-registered heavy trucks are not included in the survey (e.g., trucks with a maximum load weight of less than 3.5 tonnes, vehicles older than 30 years, etc.). The survey is conducted quarterly and is also compiled on an annual basis. The results are published by Trafikanalys in their publication Swedish road goods transport[4].
- **Operating data obtained from vehicle manufacturers:** Data from HCT pilot projects which includes information on towing vehicle (truck or tractor), curb weight for the combination of towing vehicle and trailer, maximum permissible gross weight, gross vehicle weight rating, towing vehicle total weight, average or median gross weight for the transport, annual mileage and fuel consumption data. Data extend over the period 2009-2019, although not all vehicles have been in service during the entire time.

[4] https://www.trafa.se/en/road-traffic/swedish-road-goods-transport/

Conclusions

HBEFA segments for trucks >60 ton

It should be considered to continue to allocate transports with a total weight of 60-64 tonnes to the TT/AT segment >50-60 tonnes. This is because it may be valuable being able to differentiate heavier HCT trucks from, for example, general cargo transports by truck, dolly and semi-trailer that may weigh 64 tonnes and hence can be operated freely on the BK1 network. Doing so will likely result in a slightly too low fuel consumption for transports with a gross weight between 60-64 tonnes. On the other hand, the load factor would probably increase if all transports with a gross weight of 60–64 tonnes were classified as "100 percent". In the current HBEFA load patterns for the TT/AT segment 50–60 tonnes, the share of vehicles with 100 percent load varies between 2-10 percent depending on the age of the vehicle. Presently used data in HBEFA probably also includes transports that are substantially heavier. In the case of the introduction of a separate vehicle segment for trucks > 60 tonnes, where 60–64 tonnes are included in the TT/AT 50-60t, the load pattern for the TT/AT 50-60t should be updated.

Tractor for AT >60 ton

Based on this study, it is not possible to distinguish towing vehicles used for transports over 60 or 64 tonnes from other transports by using only register data. It cannot be ruled out that it is possible to make such a classification based on other parameters, but in that case, it should be done in dialogue with the vehicle manufacturers. More likely, mileage should be assigned to the segment TT/AT> 60t in HBEFA based solely on transformation patterns.

Transformation patterns for TT/AT >60t

Results from this study show that towing vehicles used for transports with MPLW > 64 tonnes is mainly trucks with a total weight between 26–32 tonnes. To some extent heavier trucks are used and also tractors with a total weight over 20 tonnes. However, these are results that need to be investigated further. The biggest challenge is to correctly identify the truck/tractor trailer combinations with a certain permissible gross weight, instead of only using information on the MPLW. This study has shown that the MPLW is often higher than the maximum permitted gross weight. When this problem has been previously described (Hammarström & Yahya, 2003), data on " maximum permitted gross weight semi-trailer" were used instead of MPLW. Further research is needed to determine whether the variables available in the Road Traffic Registry today can be used in a similar way.

Load patterns

The publication Swedish road goods transport[5] includes data on the vehicle's age, curb weight and goods weight, which makes it possible to produce tables with average load for use in HBEFA.

[5] https://www.trafa.se/en/road-traffic/swedish-road-goods-transport/

Foreign trucks

It should be noted that all vehicles considered in the publication Swedish road goods transport[5] and also the vehicles included in data provided by vehicle manufacturers are registered in Sweden. Just over 15 percent of the vehicle kilometers travelled with heavy trucks on Swedish roads is carried out with foreign-registered trucks. Even though Finland (and to some extent Norway) also permits >64t transports the proportion of foreign vehicles on Swedish roads that have a weight of over 64 tonnes is likely small. Observational studies (Yahya & Henriksson, 2016) have shown that foreign-registered trucks to about 2/3 consist of vehicles in the TT/AT segment 34-40 tonnes and to about 1/3 in the TT/AT segment 40-50 tonnes.

Other possible data sources

Larger-scale statistics on HCT transports are not collected after that the HCT-pilot projects were completed. Vehicle manufacturers may have data that can be usable, but data on e.g., freight weights are probably missing. An expert assessment is that at in 2021 there are approximately 200-300 HCT transports on Swedish roads (Trafikverket, 2021a).

An additional source of data could be the measuring stations used to weigh the axle loads and gross weights of heavy vehicles (Trafikverket, 2020). The measuring stations are part of several programs, including one that covers the BK1 (bearing capacity class 1) network, one that covers the BK4 (bearing capacity class 4) network and one that includes points where the BK1 network connects to BK4 roads. A challenge with such data is to translate the measurement points into national vehicle kilometers travelled, which is the central variable for HBEFA. However, the measuring stations may be used as a complement to study estimates of overload based on the survey results in the truck survey.

Fuel consumption for HGV >60t segment

If the HBEFA segment TT/AT> 60t is to be used for emission calculations, it is important to assess how representative fuel consumption for this segment is for Swedish trucks >60 t. Fuel consumption and emissions in HBEFA are based on modeling of vehicles with a total weight of 90t, which is why it can be suspected that fuel consumption will be higher than for the majority of the HCT vehicles presently operating in Sweden, where most have a gross weight of 74 tonnes or less.

To assess whether the fuel consumption per kilometer in HBEFA is representative, a comparison was made with consumption data from the HCT pilot projects. Data from HBEFA is presented in Table 1 and data from the pilot projects are presented in Table 2.

When comparing data from HBEFA with data from the pilot projects, it can be seen that HBEFA's consumption for empty vehicles is slightly lower, while consumption for fully loaded trucks is slightly higher. The average figures from the pilots are close to HBEFA's consumption for half-full trucks. The fact that HBEFA's consumption is modeled based on a total weight of 90t probably explains the model's relatively high consumption for full trucks. As long as the average load factor in HBEFA is close to 50 percent, the modeled fuel consumption should be representative for HCT in Sweden if assuming that data from the pilot project is representative for future transports.

Table 1 Fuel consumption for the segment HGV> 60h in HBEFA 4.1 when driving with an empty, half full and full truck on motorways, rural roads and urban roads.

Source	HBEFA segment	Road type	l/100km empty	l/100km half loaded	l/100km fully loaded
HBEFA	HGV >60t	Motorway	41	57	75
HBEFA	HGV >60t	Rural Non Motorway	39	62	84
HBEFA	HGV >60t	Urban Non Motorway	41	72	105

Table 2 Fuel consumption for HCT vehicles with a maximum permissible gross weight of 74 tonnes. Based on data from HCT pilot projects.

Source	Vehicle weight	Road type	l/100km empty	l/100km half loaded	l/100km fully loaded
Dataset 1	65-74 t when fully loaded	Average for the included vehicles	48	59	70
Dataset 2				60	

Recommendations and further work

One recommendation is that the TT / AT 50-60t segment should include vehicles with a gross weight of up to 64 tonnes. For transports with a permissible gross weight> 64 tonnes, the segment TT / AT >60t should be used. It may also be worth considering discussing within ERMES to change the name of the subsegment TT/AT 50-60t to TT/AT 50-64t.

Further dialogue should take place with truck manufacturers, hauliers and Skogforsk[6] to determine whether any characteristic criterion for identifying HCT vehicles (gross weight> 64 tonnes) has been missed in this study.

There are great benefits to using the publication Swedish road goods transport[7] to generate transformation patterns. It is a comprehensive survey that is carried out regularly, and which probably covers the majority of transports with a permissible gross weight of more than 64 tonnes, as foreign lorries probably to a lesser extent has such high gross weight. Further work is needed to correctly identify vehicles used for transports with a total weight over 64 tonnes. Using the MPLW is likely to overestimate the total vehicle kilometers travelled for the HGV >60 segment.

A major update of HBEFA, version 5.1, is planned to be ready in 2025. With the new version comes the opportunity to further discuss improvements of data on fuel consumption and emissions for HGV >60t. Also, a division of the segment into e.g., 60-74t and 74-90t can be made if deemed necessary. It is recommended that discussions and decisions on this is done during the development of HBEFA 5.1.

[6] https://www.skogforsk.se/english/
[7] https://www.trafa.se/en/road-traffic/swedish-road-goods-transport/

2.3. Distribution of bus VKT over traffic situations (WP1.3)

When it comes to bus traffic, the information regarding national vehicle kilometers travelled (VKT) in different traffic situations in Sweden has so far been inadequate in the Swedish application of HBEFA. The aim of this work package was to produce more correct data for distributing bus VKT over the Swedish road network, instead of the current method which assumes the same distribution for busses as for trucks without trailers.

A method based on data on the *General Transit Feed Specification (GTFS)* format was developed to calculate VKT for buses and the distribution over HBEFA traffic situations in the Swedish road network. GTFS is a standardized format developed by Google. The project used *GTFS Regional Static data (beta)*, a database where the regional public transport authorities (RKM) have reported information and timetables for planned public transport.

The GTFS data was downloaded in January 2021 and processed in order to create a description of the bus lines geographically as well as the services offered (number of scheduled departures). The assumption made is that the HBEFA categories Urban bus and Coach correspond to city bus service and regional bus service, respectively. However, only a few RKM (including Skåne and Uppsala) have registered information about bus type (Route_desc) that can be used directly to classify different bus lines as a city or regional bus service. As an alternative, it is suggested that average speed is used to make this classification. The average speed is calculated based on travel time according to the timetable, divided by total distance of the bus route. To define limits, GTFS data for Skåne was used (Figure 5), resulting in the following:

- Average speed below 27 km/h = city bus
- Average speed above 27 km/h = regional bus

These limits were then applied to GTFS data from Uppsala as a control, resulting in an 80-92 percent correspondence with the registered information about bus type.

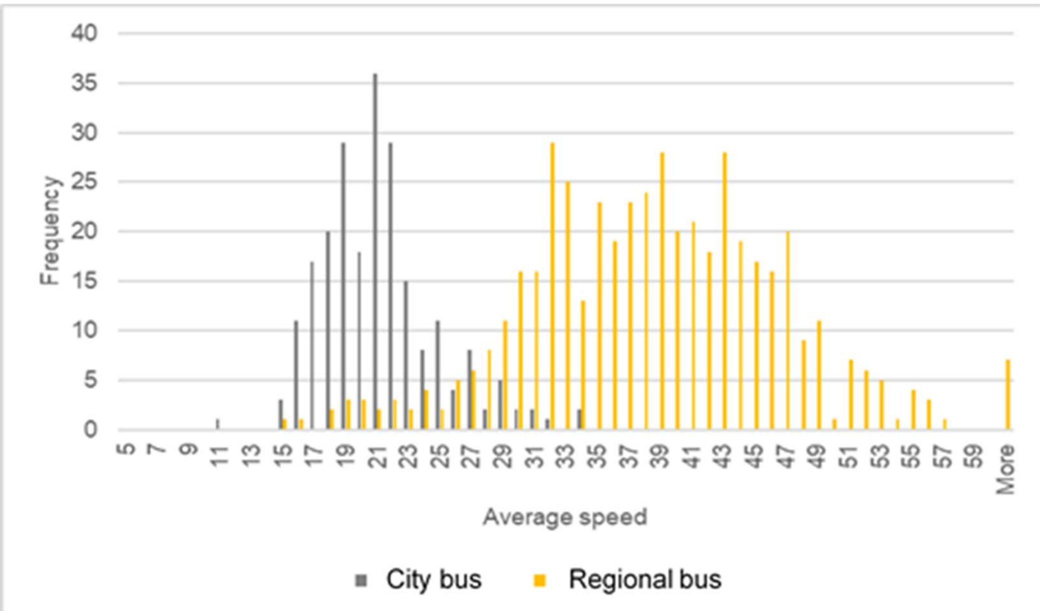

Figure 5. Average bus service speeds (km/h) in Skåne, divided into city bus and regional bus according to registered GTFS-data (Route_desc).

The calculated VKT per RKM was compared to Trafikanalys (TRAFA) statistics regarding regional scheduled traffic on roads from 2019 (Figure 6). The VKT is generally overestimated but follows the same pattern as the statistics from Trafikanalys. The calculated VKT is on average 14 percent higher when compared to Trafikanalys data. This is likely explained by the fact that several bus services cross a regional boarder. Since overlapping services in different counties have not been removed from the dataset, such lines are counted twice. However, this will not be a problem in the future when a coordinated dataset for all the regions in Sweden is established. Yet another reason for the observed differences could be that public transport supply increased between 2019 and 2021.

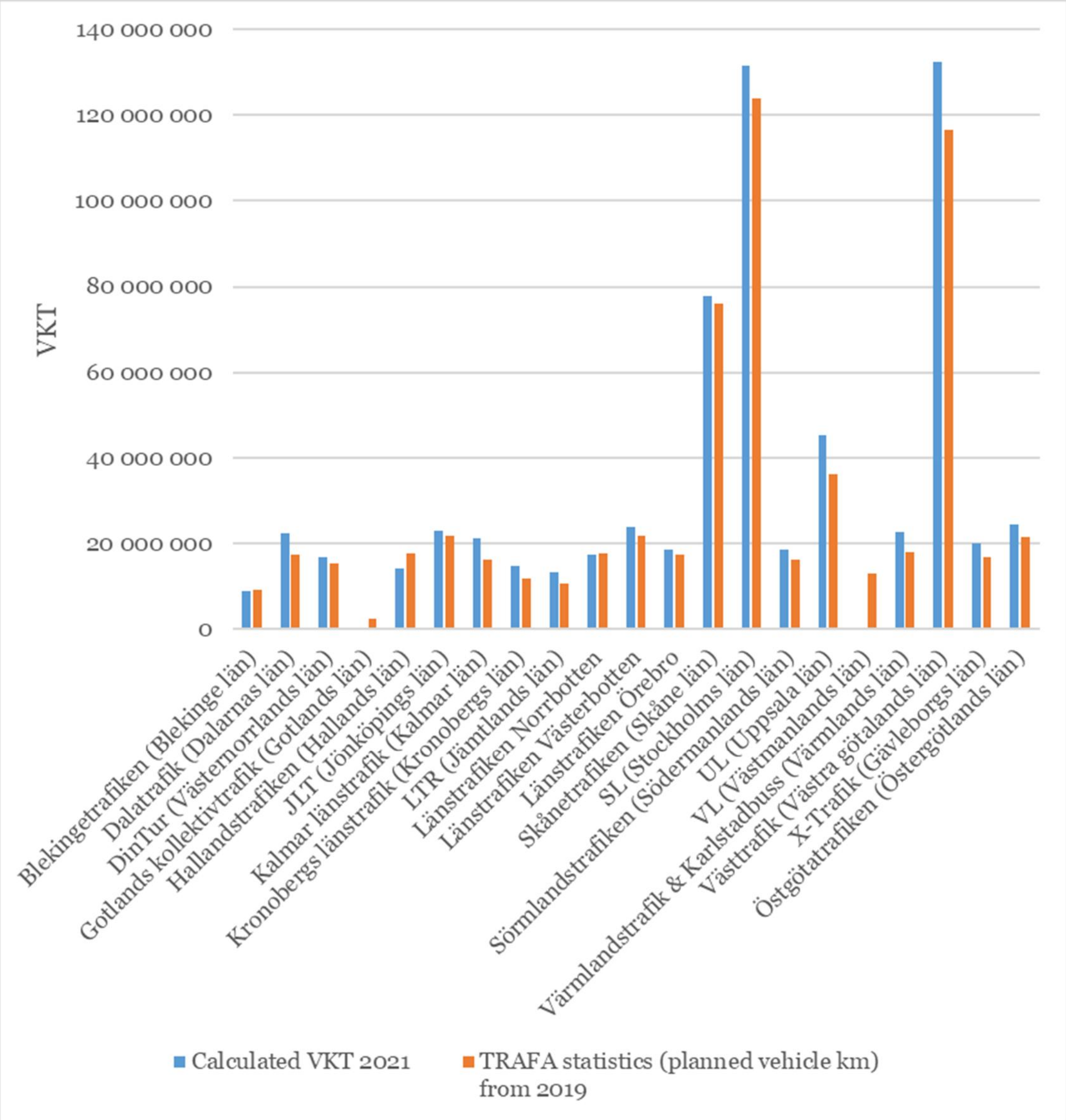

Figure 6. Calculated vehicle kilometers travelled based on GTFS-data for 2021 compared to Trafikanalys statistics (planned service km) from 2019 (different regional public transport authorities on the x-axis).

When allocating the resulting VKT for city busses and regional busses to the HBEFA traffic situations, it was concluded that city busses are responsible for a far higher share of the bus VKT in urban areas compared to regional busses, as expected. Furthermore, city bus VKT is mostly produced on streets with speed limits between 30 and 60 km/h, whilst regional busses to a greater extent are using roads with speed limits between 70 and 110 km/h. The previously applied method, assuming the same distribution for busses as for trucks without trailers, results in a higher share of bus VKT on countryside roads with a speed limit of 110-120 km/h. With the new method, based on GTFS data, VKT by bus is to a greater extent allocated to roads in urban areas with lower speed limits, which is considered more reasonable. Thus, the presented method based on GTFS data distributes VKT by bus over HBEFA traffic situations in a way that matches the expected routes of busses better.

A brief account of how the HBEFA emission calculations were affected by using GTFS-data to produce specific VKT distribution input data is presented in section 3.1.

2.4. Fuel consumption for light duty vehicles (WP2)

Background

Fuel consumption, unlike regulated pollutants, is not regulated for individual vehicles. The existing legislation for light-duty vehicles (Regulation (EU) 2019/631) target each manufacturer's average CO_2 emissions for all vehicles sold in Europe. This means that the fuel consumption between vehicle models can vary greatly. And since the popularity of models differs between countries this also means that the average fuel consumption for new passenger cars varies between the countries, which is illustrated in Figure 7.

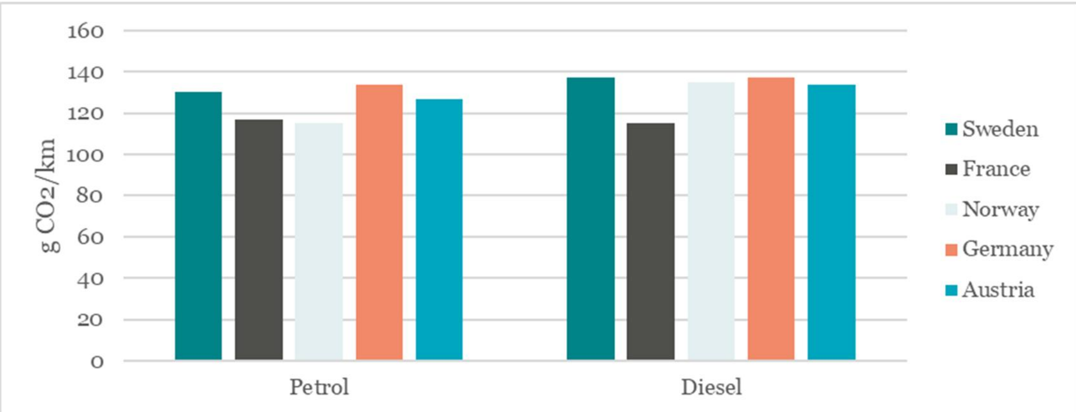

Figure 7. CO_2/km (NEDC) for registered cars in 2019 by fuel type for the "HBEFA countries" that report to the EU. Data retrieved from EEA website (EEA, 2021).

National differences in fuel consumption can be partly estimated from the statistics on average CO_2 values for newly registered passenger cars and light-duty trucks. EU countries report national statistics to the EEA in accordance with Regulation (EU) 2019/631. Differences in registered CO_2 values describe the vehicle's consumption in a standardized driving cycle, which captures differences in consumption that depend on, for example, weight, body shape or engine power.

Not all factors that affect fuel consumption are captured by the driving cycles. A growing difference has been observed between the NEDC[8] driving cycle and real-world consumption (Tietge et al., 2017; Fontaras et al., 2017). The gap, "real-world excess", is partly due to the fact that manufacturers have become better at designing vehicles with low consumption in test environment. In addition, there are factors that are not measured in a driving cycle.

[8] New European Driving Cycle, designed to assess the emission levels of car engines and fuel economy in passenger cars.

Examples of such factors are the use of heating and air conditioning systems, driving with a trailer and driving in wet or snowy road conditions.

To calculate how much more efficient the Swedish car fleet has become over time an analysis is needed of i) how the consumption measured in the driving cycle has developed, and ii) how the real-world excess has developed.

HBEFA's national fuel consumption is determined by two parameters for each segment, the Fuel Base Correction Factor (FBC) and the Annual Reduction Rate (ARR). ARR represents the annual improvement in fuel consumption for new vehicles. FBC is a calibration factor that adjusts for differences between the average new Swedish car registered in 2002, compared to the average European car registered in 2002 (as 2002 is the reference year in HBEFA).

In the release of HBEFA 4.1, FBCs were implemented for petrol, diesel, battery electric and plug-in hybrid passenger cars. The ARR was derived from the national CO2 values reported to EEA, together with a common estimate for the real-world excess used for all countries. The FBC for electric powered passenger cars is calibrated so that energy consumption is 0.2 kWh per km (excluding charging losses) under German driving conditions.

To date, no European countries using HBEFA have FBCs for light commercial vehicles (LCVs), motorcycles and mopeds or heavy-duty vehicles (HDVs). On the other hand, LCVs and HDVs are also divided into weight-based segments, which also captures differences in fuel consumption between national fleets, as heavier vehicles have higher fuel consumption.

Scope and delimitations

The aim of this study was to answer the following questions, under the delimitation that the share of fuel consumption due to cold start (4 percent) is assumed to be unchanged:

1. Are further adjustments of the Swedish FBC and ARR for petrol and diesel passenger cars needed compared with the HBEFA 4.1 default values?

2. Could FBCs be calculated for the passenger car segments where these are now missing (i.e. for flexi-fuel cars and bi-fuel cars)?

3. Is an adjustment of the ARR needed for flexi-fuel cars and bi-fuel cars in connection with a possible new FBC?

4. Could FBC and ARR be calculated for LCVs (which today lack FBC)?

Fuel consumption for Swedish light-duty vehicles

A new set of FBCs and a time series of the efficiency (ARR) were calculated for passenger cars and LCVs based on new time series with CO_2 registration values and estimates of real-world excess. CO_2 values per fuel type for passenger cars were obtained from the Swedish Transport Administration by e-mail, but the corresponding fuel consumption can also be accessed online (Trafikverket, 2022). This time series dates back to 1978 while EU CO_2 figures only starts in 2001.

CO_2 values for LCVs for 2000-2020 are based on data from the national Road Traffic Registry (RTR), as the registry also provide data on vehicle weight. In HBEFA, LCVs are divided into three weight segments per fuel (since the emission legislation differs depending on the vehicle's reference weight). This means that RTR-data for CO2-values per model year are aggregated into six time series (three for petrol LCVs and three for diesel LCV). The result is presented in Appendix 1 together with fuel consumption data for passenger cars.

The real-world excess figures for passenger cars are based on data from ICCT (Tietge, et al., 2019). Data in the report has been adapted to represent the average Swedish car as well as possible. Real-world excess has been weighted with regards to the share of hybrid/non-hybrid cars in Sweden, as well as adjusted for the share of VKT driven by Swedish company cars. It is assumed that all cars are used as company cars in proportion to the national average of company car VKT, which is 28 percent (Transport Analysis, 2020).

The real-world excess for non-hybrid petrol cars is used for other spark-ignition engines, i.e., CNG/petrol bi-fuel cars and FFV E85 / petrol cars.

The results can be found in Table 3. Some of ICCT's previous reports contain data for cars older than 2001, but they are not included in this study's weighted compilation.

Table 3 Real-world CO_2 excess factors based on Tietge, et al., (2019).

Model year	Real-world excess (all cars)	Real-world excess (diesel)	Real-world excess (petrol)	Real-world excess (hybrids)
2001	7%	8%	7%	
2002	9%	10%	9%	
2003	10%	11%	10%	
2004	11%	11%	11%	
2005	13%	13%	13%	23%
2006	13%	12%	13%	24%
2007	15%	14%	14%	23%
2008	17%	16%	16%	23%
2009	19%	17%	18%	29%
2010	21%	20%	20%	33%
2011	24%	24%	23%	38%
2012	26%	27%	26%	41%
2013	30%	34%	30%	42%
2014	33%	38%	33%	44%
2015	35%	41%	35%	46%
2016	36%	43%	35%	50%
2017	37%	42%	35%	49%

There is significantly less data on actual fuel consumption for LCVs compared to passenger cars (Tietge, et al., 2019). In this study, two reports have been used; a compilation of German LCV fuel consumption that formed the preliminary basis for default data in HBEFA 4.1 (Tietge, et al., 2020) and a previous study that is partly based on the same data (Zacharof, Tietge, Franco, & Mock, 2016). The conclusion is that there is a growing gap between fuel consumption according to the driving cycle and real-world consumption for LCVs, just as for passenger cars. On the other hand, the difference between driving cycle and actual consumption is lower than for passenger cars. The data sources contain no information on fuel type (petrol, diesel or other) and there are no data records for Swedish vehicles. This means that it is difficult to determine whether the figures are also representative for Sweden, in terms of the composition and use of the vehicles.

Fuel Base Correction and Annual Reduction Rate – petrol and diesel cars

The FBC was obtained by HBEFA's calibration module together with the adapted national data described in previous section.

$$FBC = \frac{CO2_{NEDC}(1+excess)-CO2(cold)}{CO2(HBEFA)} \quad (1)$$

CO_2 emissions according to NEDC combined with a real-world excess of 9 percent for petrol cars and 10 percent for diesel cars means that the CO_2 emission factor in 2002 should be 215 g per km for petrol cars and 202 g per km for diesel cars. HBEFA's estimated CO_2 emission factor for each driveline with traffic situations in 2002 was 166 and 151 g CO_2 / km, respectively. After deducting the increased consumption due to cold start, an FBC of 1.25 was obtained for petrol cars and 1.29 for diesel cars.

The ARR is calculated as the difference between two calibration factors, which corresponds closely to the quotient between the numerator in equation (1) between one year and the previous year. The accumulated efficiency for petrol cars calculated with the HBEFA CO_2 module between 1968 and 2017 was 21.4 percent, compared to 22.5 percent if calculated using only NEDC + excess emissions.

Accumulated efficiency gains in real traffic for new cars sold between 1990–2017 based on this survey are presented in Figure 8 (petrol) and Figure 9 (diesel).

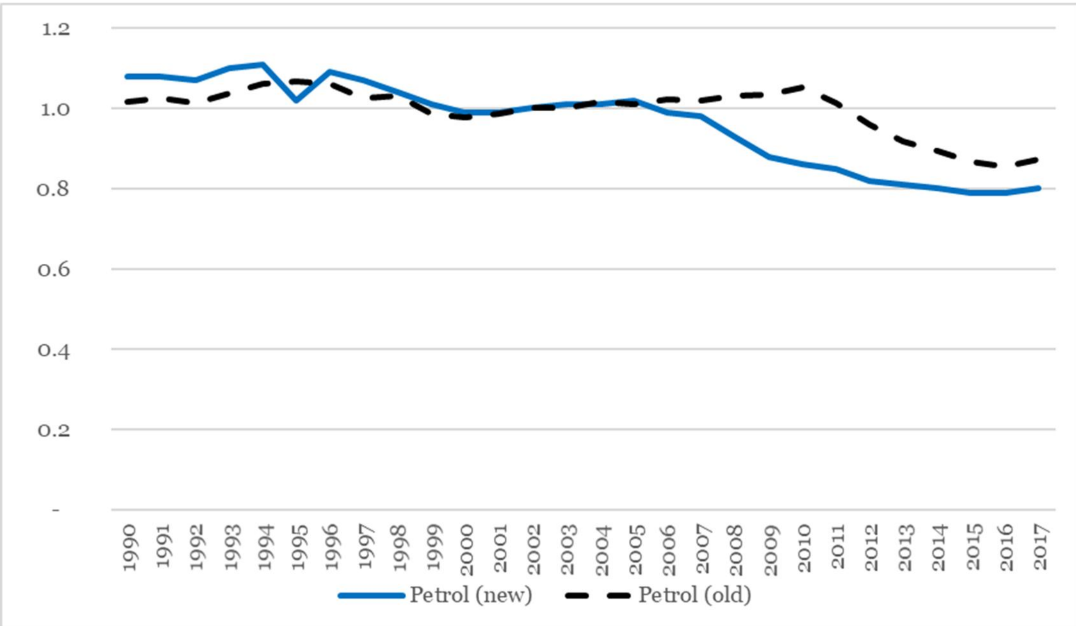

Figure 8. Accumulated efficiency gains in real traffic for petrol cars sold between 1990–2017 based on this survey. Electric hybrids are included in both petrol cars. 2002 is indexed to 1.

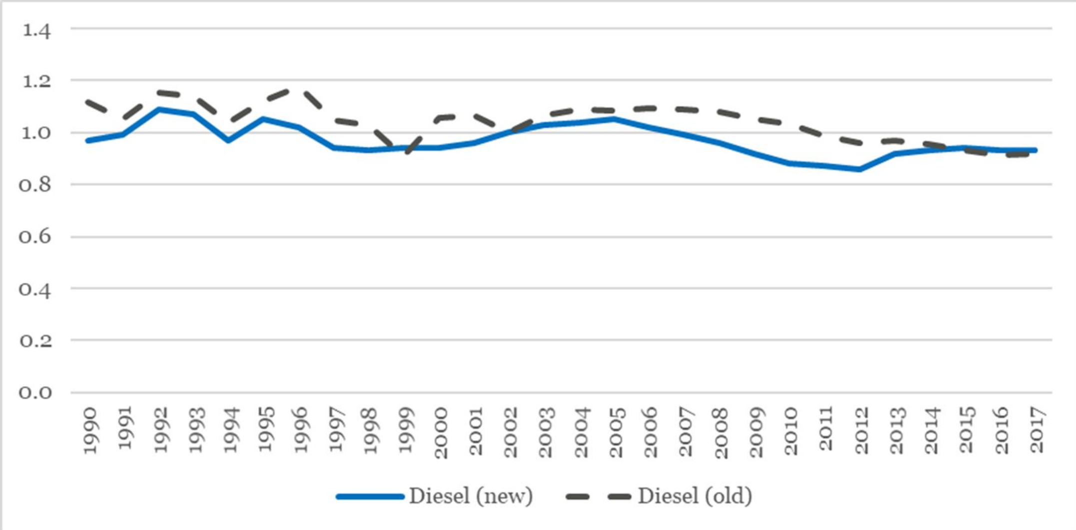

Figure 9. Accumulated efficiency gains in real traffic for diesel cars sold between 1990–2017 based on this survey. Electrical hybrids are included in the substrate. 2002 is indexed to 1.

Fuel Base Correction and Annual Reduction Rate – bi-fuel and flexi-fuel cars

HBEFA's CO_2 module cannot be used for FFV (flexi-fuel vehicle, E85/petrol) and CNG bi-fuel cars (methane/petrol). The fuel consumption for these vehicle types is not calculated from measured data but are so-called "derived" segments for which the fuel consumption is derived from petrol cars. For the base year 2002, it is thus assumed that the fuel consumption for Euro 3 FFV and CNG bi-fuel cars will be 1: 1 to petrol cars. FBC and ARR are instead calculated manually.

The CO_2 value for FFV cars (when powered by petrol) in 2002 is 180 g CO_2 per km, based on a driving NEDC value of 165 g CO_2 per km and an excess factor of 9 percent. For CNG bi-fuel cars in 2002 (when powered by petrol) the corresponding value is 214 g CO_2 per km, based on a NEDC value of 197 g CO_2 per km and an excess of 9 percent. Since petrol cars had a consumption of 215 g CO_2 per km in 2002, nu further adjustment is needed for CNG cars. FFV cars, on the other hand, had a lower consumption than petrol cars in 2002, and the FBC should be set to 0.86 after a comparison with its petrol correspondence (180/215).

Since fuel consumption factors for bi-fuel CNG and FFV cars are "derived", an FBC cannot be defined in HBEFA. Therefore, in practice, the annual fuel efficiency is adjusted between 2001 and 2002, and between 2002 and 2003 so that the fuel consumption is correct for all model years before and after 2002. Fuel consumption for model year 2002 will be underestimated, but these cars are few compared to later model years.

Fuel Base Correction and Annual Reduction Rate – LCV

As default in HBEFA 4.1 LCVs have the same efficiency for all segments using the same fuel. Based on CO_2 data from the vehicle register together with an estimate of real-world excess from Spritmonitor (one of the data sources in the reports), the efficiency per vehicle segment was calculated. A possible source of error is that Spritmonitor contains a small number of models per model year for LCVs, and that the excess according to Spritmonitor was lower than for other data sources. This could imply an underestimation of fuel consumption and an overestimation of efficiency. Even with a real-world excess that is suspected to be too low, the rate of fuel efficiency is lower for almost all segments with the new calculations compared to current assumptions. Based on the new figures, there has been little to no efficiency gain at all from 2002 for three of the segments (petrol N-II and N-

III, and diesel N-III). Other segments have become 7–15 percent more efficient compared to 2002.

After calculating the fuel consumption with the new efficiency rate, it was also considered if an FBC is needed. The same method as for FFV and CNG vehicles was used. Overall, the results suggest that an FBC for LCV segment would adjust fuel consumption slightly compared to today's estimated consumption. The heaviest diesel LCV segment would get a lower consumption, but the fuel consumption for all other segments would increase by 9-43 percent.

Plug-in hybrids

For plug-in hybrids, the difference between average fuel consumption according to the driving cycle and real driving is mainly due to what extent the vehicle is using its electric motor (the “use-factor”, UF). According to an ICCT special report on plug-in hybrids (Plötz, Moll, Bieker, Mock, & Li, 2020) NEDC fuel consumption corresponds to an average UF of 69 percent. The report shows that real-world UF varies greatly between car models, user groups and countries, with an average around 37 percent. The difference in UF is the main explanation for the fact that the real-world excess for plug-in hybrids is significantly higher than for other vehicles with a range spanning from 58–533 percent (Tietge, et al., 2019) and an average around 200 percent. This means that ICCT's report from 2019 (which was used for other drivelines in this study) cannot easily be used to estimate real-world fuel-consumption for plug-in hybrids, since part of the difference is taken into account due to the lower share of the mileage using electricity in HBEFA (approx. 53 percent) compared to NEDC (69 percent).

An alternative for measuring the efficiency of plug-in hybrids may be to measure annual differences in consumption in charge-sustaining (CS) mode. CS mode is when there is no depletion of battery state-of-charge and the plug-in hybrid can be considered to the same as a non-chargeable hybrid vehicle. A conservative assumption is that the difference between consumption in CS mode between the test cycle and real traffic is constant over time. If the difference is constant, the annual efficiency of internal combustion engine operation will be the same as the difference in consumption according to the WLTP between two years.

Discussion and conclusions

The method of using crowd-sourced data seems to work well. However, a couple of things should be considered.

The relationship between fuel consumption according to the driving cycle and real-world driving could change for a specific model year over time. A trend that can be seen in the ICCT reports used within this study is that the gap is larger for company cars, compared to privately owned vehicles. The reasons are believed to be a combination of a different driving styles (company cars are used to a greater extent on motorways at high speeds (Tietge et al, 2020) and lower incentives for an economical driving style.

Since company-cars are usually less than three years old, this suggests that the gap is larger in the first three years for a specific model year and lower in the following period. In HBEFA, however, it is assumed that the gap for a model year is constant over time. The weighted estimate of the gap according to ICCT assumes 50 percent privately owned cars and 50 percent company-cars. This is likely representative for new vehicles in Sweden where 1/3 of sales are to private customers, 1/3 to companies (excluding car retail) and 1/3 to car retail.

If a real-world excess value has to be constant regardless of vehicle age, it is probably more appropriate to use a mileage-weighted function where the gap for company-owned vehicles and privately-owned vehicles is weighted according to the proportion of vehicle mileage. We therefore assumed a company car share of VKT of 28 percent, based on statistics of the total vehicle mileage carried out by passenger cars owned by legal entities (Transport Analysis, 2020). The assumption means that the gap is underestimated for newer vehicles and overestimated for older vehicles.

Finally, the calibration of fuel consumption for LCVs presented in this study should be considered very uncertain. No validation against data from Sweden has been made since such data was not available during the time of the study, and the amount of available international data is both less than for passenger cars and shows a significant scatter.

The following general conclusions can be drawn from the study:

•Fuel consumption data for passenger cars derived in this study can be used without adjustments and has been implemented to the Swedish HBEFA since May 2021.

•LCV fuel consumption calibration presented in this study has not been verified to be more representative than HBEFA's built-in emission factors and has not yet been implemented in HBEFA. However, there are indications that real-world fuel consumption for LCVs could be higher than in HBEFA.

•The transition from NEDC to WLTP means that real-world excess will be lower in the future. An initial approach is to assume a WLTP excess for 2020 and 2021 so that real-world fuel consumption remains unchanged.

•To keep the fuel calibration in HBEFA up to date it is necessary to consider future studies on divergence driving cycle and real-world consumption. It is conceivable that a similar development will take place for WLTP as for NEDC, where the gap increases over time.

•In order to obtain better data on actual fuel consumption for the Swedish vehicle fleet, more studies are needed, especially for light commercial vehicles and plug-in hybrids.

2.5. Turnover tool for road vehicle fleet (WP3)

Background

In this work package an Excel based tool, the Turnover tool for Road Vehicle Fleet, was developed. The tool is using the same parameters and calculation principles as HBEFA with some simplifications and is used to create future scenarios for road traffic. The tool uses input data on the Swedish vehicle fleet and associated activity data down to segment level which is already available through the Swedish Transport Administration´s annual work on updating national data in HBEFA. The main purpose of the tool is that it should be easier to use than HBEFA when it comes to elaborating with different parameters used for making future scenarios, such as new sales shares for cars using different fuels and technologies and the size of the fleet.

Just like HBEFA, the Turnover tool classifies vehicles into several vehicle categories, technologies and size classes. In total, the tool divides the vehicle fleet into six categories and 33 subgroups. In addition, average annual mileage, annual national vehicle kilometers travelled, energy efficiency, turnover rate and the share of electric driving for plug-in hybrids are all included in the model. All parameters are managed year by year, from the current year until 2050.

The tool has so far only been used for Sweden`s road fleet but could be used for other countries as well.

Building scenarios

The user builds a scenario by entering desired data for total VKT for the vehicle category, technology shares for new sales, annual percentage change in fuel consumption for new vehicles and share of electric driving for plug-in hybrids. It is also possible to choose a constant annual (percentage) change of the turnover rate between any two years.

If not desired the user does not need to enter all the required data when creating a scenario, since an available option is to use same data as in the national Reference Scenario, which is pre-filled in as "default".

Presentation of results

The result is presented with respect to five different parameters which are explained below:

1. **The number of vehicles**. The absolute number of vehicles in the fleet for the current category.

2. **Total vehicle kilometers travelled**. Total kilometers traveled by the fleet (as millions of vehicle kilometers) per vehicle group.

3. **Energy use**. Energy use per kilometer (kWh per km) per vehicle group.

4. **Carbon dioxide emissions, newly registered vehicles**. Average CO_2 emissions per vehicle kilometers (g per km) corresponding to the NEDC for newly registered vehicles.

5. **Carbon dioxide emissions, the fleet**. Average CO_2 emissions corresponding to the NEDC for all vehicles in the fleet.

The user can easily compare results from his/hers own created scenarios with the Reference Scenario, by exporting the result data with copy- paste into an external excel file.

Keeping the tool updated

To keep the tool up to date the latest available fleet and activity statistics should be implemented when available, i.e., after data has been implemented in HBEFA in conjunction with the annual national update. The National Reference Scenario should also be updated if a new scenario has been developed by the Swedish Transport Administration.

Average fuel consumption for different vehicle groups should be updated using data from the HBEFA model. For all vehicle groups, except for HGVs, the consumption can be obtained directly from HBEFA. Since HGVs is split into distribution trucks and long-distance trucks, a mutual weighting of HBEFAs segments is needed.

If a certain vehicle type greatly increases or decreases its average annual mileage, the survival probability (SP) function probably also needs to be adjusted, as the SP value depends on age and mileage.

The tool also handles several fixed inputs (not possible to change by the user). These are the age dependence of the mileage and the age dependence of share of electric driving for plug-in hybrids. This data can also be updated annually after the annual national HBEFA update.

2.6. Feasibility study on new driving pattern data (WP4.1-2)

The aim of this feasibility study was to investigate new data sources for driving pattern data in order to facilitate enhancement of the HBEFA model and its application. Four underlying purposes were identified:

- Clarifying model prerequisites and how they affect the need for different types of driving pattern data.
- Describing different types of data and data collection methods, giving examples of potential data sources.
- Prioritising the needs regarding driving pattern data.
- Investigating new data sources and their applicability.

The study presents requirements regarding driving pattern, as well as the need to supplement driving pattern data today and in the future. An initial analysis made clear that driving pattern data is needed in a national as well as an international context and that the data requirements are somewhat different depending on the context.

Data on an overall international level is needed to validate and improve the driving cycles connected to each vehicle type in the HBEFA traffic situations. This purpose was denominated:

- A. Development and improvement of HBEFA driving cycles, divided into:
  - present day vehicle types
  - future vehicle types and concepts

Different vehicle types have different driving patterns. In HBEFA this is represented by giving each vehicle category a separate driving cycle for each traffic situation. The driving cycles will need to be validated and modified in order to better represent how vehicles are driven, both now and in the future.

Purpose A requires representative samples of driving pattern data for different traffic situations and vehicle types. Ideally data collections from several countries would be included and it is important that Sweden contributes with driving patterns from Swedish roads. To our knowledge there are currently no official plans to review traffic situation driving cycles within the ERMES collaboration. It could, however, come about if individual countries can provide driving patterns that demonstrate a need for reviewing the driving cycles for different vehicle categories. It should be noted that such a review demands data from different levels of service, as there is usually a predominance in data for free flow conditions. It is also important to collect data from other vehicle types than passenger cars. Developing new/enhanced driving cycles for the model demands measurements of vehicle speed profiles, with registrations at fixed intervals, preferably a frequency of 1 Hz. The driving patterns also need to be connected to the road environment in question. Furthermore, the corresponding road network needs to have relevant attributes in terms of road type (including road design, functional rank, number of lanes etc.), speed limit and traffic flow (in terms of ADT and time of day, simultaneously measured or estimated). The latter needs to be registered in a way that allows for categorisation into the HBEFA road types and levels of service.

From a national perspective it is concluded that driving pattern data is of great importance to enhance compatibility between the current traffic situations (and driving cycles) in HBEFA and the way traffic actually “behaves” in the Swedish road network. This purpose was denominated:

- B. Data to serve as a base for better adaptation of HBEFA traffic situation classification to Swedish conditions

Purpose B requires representative samples of driving pattern data for passenger cars in different traffic situations, since the classification of the national road network is primarily validated against driving patterns of cars. Data collection should primarily focus on common traffic situations for which current driving pattern data for Sweden is inadequate or missing altogether.

The study shows that Swedish driving pattern data is missing for many of the most common traffic situations of today. In built-up areas, independent driving pattern data is missing in general for streets with speed limits 40 and 60 kilometres per hour. Data collection on the most common road types with these speed limits should therefore be prioritised. It is also important to collect data from adjacent traffic situations, to distinguish between driving pattern characteristics on similar roads with different speed limits.

For rural roads, no measured data has so far been available for validation. An initial approach is to prioritise measurements for the most common traffic situations and the associated Swedish road types. The road types carrying the most vehicle mileage are denominated National motorways 110 and Greater non-motorway arterials >=2 lanes per direction, low disturbance (sometimes grade-separated) junctions 70. HBEFA is often used to demonstrate effects on emissions and energy consumption due to modified road design and/or speed limits in rural areas. Therefore, it can also be of importance to focus on road types/designs that are frequently remodelled today as well as on the resulting road types/designs after remodelling.

The literature review regarding new data sources resulted in an in-depth examination of different forms of probe-data in Swedish applications. The increasing number of vehicles that are “on-line” should present new opportunities for data collection. Interviews conducted with people who have experience from working with INRIX revealed that probe-data exists to an increasing extent, as many vehicles are connected today via e.g., internal GPS systems. The vehicles send out e.g., speed and position while driving and at a first glance this seems promising for new data collection.

Driving pattern analyses demands specific data requirements and the feasibility study established that data currently collected from connected vehicles does not meet these requirements well enough. Among other things, the registration of e.g., speed and position is most often done at varying intervals. This prevents adequate analyses of the driving pattern, including also levels of acceleration, etc. Therefore, recommendations are put forward to enhance data quality for further driving pattern research purposes. The utility of data from the vast databases of connected vehicles would gain from a possibility to select data based on necessary attributes and measurement frequency. The applicability would increase further with greater transparency regarding measurement precision and filtering methods.

Examples of desirable improvements include:

- Measuring coordinates and/or speeds at set intervals of one (or maximum two) second(s).
- More distinct division into vehicle categories: private cars, light commercial vehicles, trucks, buses, motorcycles.
- Division into propulsion/fuel system: petrol, diesel, gas, hybrid (e.g., electric/petrol etc.).
- Smooth coupling to NVDB (the Swedish national road database), e.g., through developing a method for transferral from Open Street Map.
- Possibility to buy specific data selections based on e.g.:
    - road type, speed limit
    - vehicle type, propulsion system
    - measurement method and/or interval

Based on the outcome of the feasibility study, the initially proposed main study regarding driving patterns was postponed until availability of better-quality input data is ascertained.

2.7. Adaption of traffic situation classification (WP4.4)

During the development of HBEFA version 4.1., the HBEFA traffic situations were reviewed within ERMES WP2 (Ericsson et al., 2019). This resulted in for instance the addition of new traffic situations for the speed limits 30 and 40 km/h, as well as a new level of service called "heavy stop and go". The review also included validation of different traffic situation driving cycles against recorded driving patterns. A large part of the driving patterns that were compiled originated from studies in Sweden. In this research project, the Swedish data was used to review the classification key between Swedish roads and HBEFA traffic situations, a process which is described chronologically as follows:

- Collection of data in the form of recorded European driving patterns connected to HBEFA traffic situations within the project ERMES WP2.
- Extraction of Swedish data from four different studies and removal of single outliers where average speed exceeded 150 km/h or where RPA exceeded 3,8.
- HBEFA classification of driving patterns based on two methods for classification of level of service.
    - Current method using cumulative distribution curves of hourly traffic flows.
    - New method based on the amount of stop time in the driving pattern (s/km).
- Compilation of average speed and RPA per traffic situation for the Swedish data, according to both methods for classification of level of service, using observed confidence intervals.
- Comparison of parameter values according to HBEFA traffic situations with parameter confidence intervals in the Swedish data.
- Evaluation of the previous HBEFA classification to decide on re-classification. Given that the recordings for the road type in question could be assumed to be

representative enough, a new traffic situation with a proximate road type was chosen based firstly on similar average speed, and secondly on similar RPA.

- When deciding on re-classification of some urban roads based on Swedish data, additional controls concerning proximate road types were made also for those road types for which data was missing. This was done in order to ensure consistency after re-classification so that:
    - roads of a certain road type in the municipal road network do not have higher average speed than the corresponding road type in the road network owned by the state.
    - roads of higher functional rank do not have lower average speed than roads of lower functional rank.
    - roads of higher standard do not have lower average speed than roads of lower standard.
    - roads with higher speed limits do not have lower average speed than roads with lower speed limits.

In general, the Swedish data often showed average speed in urban areas to be lower than the corresponding HBEFA values. Therefore, new translation keys between the Swedish road network and the HBEFA traffic situations were developed, to obtain better conformity with Swedish conditions.

2.8. Guidelines for input data requirements (WP5.1)

This work package involved developing several guiding principles regarding which demands should be put on traffic model data that is to be used as input for the classification of the VKT (Vehicle Kilometers Travelled) distribution over the Swedish road network[9]. Stipulating guiding principles would increase both consistency and quality when creating the necessary input data. Another purpose is to improve the coupling to NVDB (the Swedish national road database) and other road network databases, which could also open possibilities for more efficient data handling through for instance automatization.

The underlying traffic model data has varied in for instance coverage and quality between different years. This has clarified the need to formulate minimum requirements for dataset design to enable an efficient process for producing the data necessary for HBEFA. The development of these requirements is to a large extent based on experiences from previous deliveries of modelled traffic data, resulting in a list of absolute requirements as well as several desirable properties for the design of the dataset. Areas in which requirements have been developed are modelling, information (IPA[10] and NVDB networks) and VKT for busses. A desirable property for e.g., the modelling is to eventually include functional road rank 7 when running the model and in the traffic assignment, whilst an absolute requirement is that the coverage rate for the traffic assignment is checked and presented for each road operator and functional road rank. Furthermore, a number of attributes that need to be included in the dataset have been identified, including definitions and units.

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[9] Previously called *traffic simulations for SIMAIR*, the web-based system for evaluating levels of air pollution, run by the Swedish Meteorological and Hydrological Institute in collaboration with the Swedish Transport Administration.
[10] Application for processing data from NVDB using simplified network geometry suited to different analysis tools.

2.9. Allocating traffic to the local road network (WP5.2)

Road traffic emissions in Sweden are calculated annually using the emission model HBEFA. The emissions are calculated based on the total VKT (Vehicle Kilometers Travelled) and its distribution on the Swedish road network, also taking road network characteristics into account. Input data on how the VKT is distributed on links and zones is produced in the traffic forecast models Sampers/EMME every few years, so far with an interval of 2-5 years.

The traffic model calculation process is in short:

- The number of trips between and within traffic zones is calculated in Sampers.
- EMME is used to distribute the trips on the road network between the zones. Primarily, however, only the principal road network is included (functional road rank <7).
- The number of trips within the zones is also calculated but the trips are not distributed on links.

Sampers and EMME are first and foremost tools for modelling trips and the subsequent traffic flows in a principal road network. In addition, the models and their results also make it possible to estimate VKT inside the areas included. This section describes the method for how the trips within and between zones are estimated in terms of VKT to begin with and then how this VKT is distributed on local road links.

Road network for allocation of local traffic

When simulated traffic flows are produced for SIMAIR, the number of trips between different zones is calculated with Sampers and exported as traversal matrices. These trips are then distributed on the IPA road network for SIMAIR[11] using EMME.

The IPA network is sparser than the NVDB (the Swedish national road database) network and a big part of the physical road network, especially in urban areas, is not represented in IPA. Furthermore, some of the links in the IPA network have no traffic allocated to them. In order to obtain a road network with greater coverage, the simulated traffic flows from the IPA road network are matched to the NVDB network. Despite a higher coverage in the NVDB network, a majority of municipal and private roads lack estimated traffic flows. A large part of the traffic flows in the local road network can be assumed to originate from the trip fractions that occur within the zones, before they reach the principal network. Some of the trips also occur completely within zones. Therefore, connector trips and trips within zones are used to estimate traffic flows on the local road network (Figure 10).

[11] IPA is a simplified network geometry suited to the analysis tool in question.

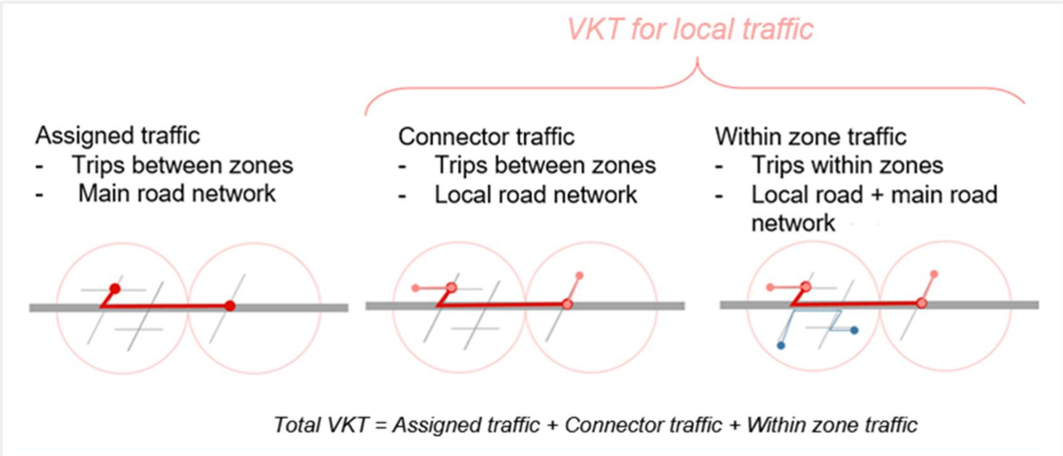

Figure 10. Illustration of model assigned traffic (dark red), connector traffic (light red) and traffic within zones (blue)

Connector trips and trips within zones

Connector trips are trips that start or finish outside zones and they are included in the traffic assignment. However, since the IPA network consists of larger road links only, the trip fractions that occur in the beginning or at the end – often on the local road network – are not captured. The number of trips on the connectors can be used to estimate the size of the VKT (Vehicle Kilometers Travelled) that would have occurred on the local road network

Trips within zones are trips that both start and end within a zone. The number of trips within zones is calculated in the forecasts, but they are not distributed over the road network.

Method for calculating VKT per traffic zone

VKT per zone was estimated in conjunction with the EMME traffic simulations conducted for all Swedish counties in 2018 to serve the air quality model system SIMAIR. Apart from traffic flows on links in the principal road network, VKT on connectors and within zones was also included.

Method for distributing VKT from areas on the NVDB road network

The VKT distribution on road links is assumed to vary according to the priority of the road (functional road rank). This means that the higher the priority, the more traffic is allocated to the road in question.

The VKT from trips within zones is distributed over the local road network (links with functional road rank 7 to 9) and on the links in the principal road network (functional road rank 0 to 6) that have no traffic allocated to them. Connector traffic is only distributed over the local road network (functional road rank 7 to 9).

Thereafter, traffic from connectors and from within zones is translated into flows per link.

In the data, the VKT on connectors and within zones was calculated as the total number of vehicle kilometers per area. The described method for distributing this traffic flow on the links in the network is suitable for links that are situated completely within one and the same area. However, a link stretching over two or more areas is assigned traffic flows from *all* the areas in question and over its *entire* length, not just on the sections situated in the respective areas. Using the same method straight off on such “cross-surface” links would yield an overestimation of the total VKT. Instead, these links were assigned a flow corresponding to the mean value of the assigned traffic flows from the affected areas.

However, this led to a slight underestimation of the total VKT after distribution on the local road network since 11,7 percent of the areas' total VKT (corresponding to ca 5 percent of the total VKT overall) were not distributed at all. This was adjusted through a general increase of 11,7 percent in the VKT on all links that had been assigned vehicle kilometers from areas.

Results

It can be concluded that the forecasting tools (simulated traffic) first and foremost are distributing traffic along links in the principal road network. The traffic flow coverage is high on state roads of lower functional road rank and only a few percent consist of so-called area traffic. On municipal roads, the coverage is considerably lower and on private roads (often functional road rank 7-9) the coverage is generally very low. Also distributing connector trips and trips within zones gives a more correct picture of the VKT distribution, with traffic being assigned also to smaller roads (higher numerals for functional road rank), where the area traffic constitutes basically 100 percent.

2.10. Differentiated method for categorising LoS (WP5.3)

Driving patterns and emissions are not only affected by the current road environment and the speed limit, but also by the level of traffic load along the road. The distribution of VKT (Vehicle Kilometres Travelled) over traffic situations is one of the keystones in the HBEFA model. The traffic situations are made up of road categories (road types and speed limits in rural and urban areas respectively) and five different levels of service (LoS), from free flow to heavy congestion with many stops.

Traffic flow, and consequently the level of congestion, on the road varies depending on month, weekday and hour of the day. This leads to different driving pattern characteristics depending on at which point in time a specific road link is observed. Different shares of the VKT on a road link therefore occur during different levels of congestion, i.e., different shares of the VKT belong to different levels of service. This is taken into consideration when emissions are calculated in HBEFA.

Today, classification of free flow, heavy traffic and saturated traffic (levels of service 1-3) is done by estimating how the average daily traffic (ADT) is distributed across flow levels using cumulative distribution curves of hourly traffic flows. The estimated flow levels are then translated into HBEFA level of service categories based on limits extracted from fundamental speed-flow curves for different road categories and speed limits. In the cases of more or less congested roads and queues with an increasing share of stops (levels of service 4-5), the classification cannot be made unambiguously based on flow data alone. Instead, fixed shares are assumed and used to estimate the VKT in level of service categories 4 and 5, on those roads that reach their capacity limit.

Level of service categories featuring congestion lead to considerably higher emission factors in comparison to free flow traffic. However, the VKT in these "high" categories is very low. In Sweden, 98 percent of the total VKT is conducted in free flow conditions. In the national calculations, the cumulative distribution curves of hourly traffic flows are currently distinguished based only on whether the road is situated in a rural or an urban area. A more detailed differentiation, yielding specific cumulative distribution curves for every road type, would be resource-intensive and would probably not affect the results on a national level to any considerable degree. For local emission calculations, however, it can be important to determine the congestion level in a way that is better suited to the specific road or street, especially if high traffic flows and congestion are frequent.

An alternative approach which would demand less resources could be to create a few additional subdivisions beyond rural/urban, based on how common congestion is in different contexts. One solution would be to single out motorways into a separate group when categorising level of service. However, new cumulative distribution curves for motorways would need to be produced and additional resources would be required every time a new distribution of VKT over traffic situations is made.

The research project MEDY (Ekström et al., 2021; see also section 2.11) studied possibilities for alternative and more precise methods to determine level of service for local applications of HBEFA. One hypothesis was that traffic density would be a better classification measure, based on data concerning variations in both traffic flow and speed from either continuous field measurements or results from dynamic modelling. This makes it possible to estimate how the traffic density varies over time. The share of VKT for each level of service could then be decided unambiguously, by setting density limits for when traffic shifts from one level of service to another on different road types. The density limits should be adjusted to ensure results consistent with the flow-based methodology used in national calculations.

MEDY presents preliminary density limits for several traffic situations based on Swedish data on driving patterns. Further method development is needed to determine consistent density limits for all traffic situations. In summary, MEDY concludes that the two methodologies could complement each other in HBEFA: the flow-based methodology for large (national and regional) networks, and the density-based methodology for detailed calculations on congested roads in a local setting.

2.11. Adaption to “Heavy stop-and-go” (WP5.4)

As was described above, driving patterns and emissions are not only affected by the road type and the speed limit, but also by the level of traffic load on the road. In HBEFA, the VKT (Vehicle Kilometres Travelled) on each road type is classified into one of five different level of service categories:

- Free flow
- Heavy traffic
- Saturated
- Stop and go
- Heavy stop and go

The fifth level of service (heavy stop and go) was introduced in HBEFA version 4.1, since level of service 4 (stop and go) was deemed to not reflect the driving patterns under heavy congestion well enough. This change necessitated an adaption of the input data for HBEFA so that the fifth level of service would also be included in the distribution of VKT.

The distribution of Swedish VKT over the HBEFA traffic situations is produced using data from traffic models, assigning traffic flows (annual average daily traffic, ADT) from a certain year to the links in the Swedish road network. To estimate how the ADT on a certain link is distributed between hours of different traffic load, a conventional methodology based on cumulative distribution curves of hourly traffic flows is used to classify levels of service 1-3 (see section 2.10). For the fourth and the fifth category, it is not possible to deduce when the conditions in question are at hand by flow data only. Levels of service 4-5 are therefore classified based on assumptions of set (standard) shares.

It has been discussed how to determine the share of traffic in "heavy stop and go". Since the share of "stop and go" is already decided by assumption, there was no method for using available data to determine a differentiated share for "heavy stop and go". It was therefore decided that Sweden would use the same assumed division as the other countries in the ERMES collaboration, i.e., the initially calculated share of "stop and go" should be divided so that 70/30 percent of the VKT falls into the "stop and go" and "heavy stop and go" category respectively. In general, the share of VKT in free flow is predominant in Sweden. In the data from 2019 only 0,02 percent is categorised as "stop and go" and 0,01 percent falls into the "heavy stop and go" category.

A brief account of how the HBEFA emission calculations were affected by the introduction of a fifth level of service in the VKT distribution input data is presented in section 3.1.

The research project MEDY (Ekström et al, 2021; see also section 2.10) studied possibilities for alternative and more precise methods to determine level of service for local applications of HBEFA, based on either continuous field measurements or results from dynamic traffic modelling. Three methods to define level of service in the HBEFA traffic situations were studied and compared, based on flow (current method), speed and density respectively. The results show that using traffic density might be a more precise and unambiguous method to define the degree of congestion, compared to the other methods studied. The method was tested with preliminary density boundaries for the level of service categories for some HBEFA traffic situations and the results were found to be well in line with established traffic theory. For total emission levels, using the current flow-based level of service definitions or the proposed density-based definitions shows only a small difference in estimated emissions. However, the density-based version is better at capturing how the emissions vary in time and space and would be a complement for more detailed estimations of emissions on roads/streets where congestion occurs.

MEDY found that the two methodologies (flow-based for national and density-based for local calculations) could complement each other and still give congruent results in relation to one another. However, the density-based method needs to be developed further, e.g., by determining level of service categories for all traffic situations and adapt them so there is consistency with the results for service levels 1-3 when using the flow-based method.

These results are interesting for upcoming discussions in the ERMES group regarding which methods to use in the future to determine traffic flow conditions as input data to the HBEFA model.

2.12. Distribution of VKT over gradients (WP5.5)

It is widely known that emissions from road traffic differ depending on if the vehicles are driving uphill or downhill. However, HBEFA calculations of Swedish emissions have until the year 2020 been based on VKT (Vehicle Kilometers Travelled) distributions over traffic situations without taking road gradients into account. The assumption was previously that Sweden is relatively flat, compared to many other European countries. This inadequacy is likely to cause an underestimation of total emissions from Swedish road traffic on a national level. The current development project therefore included dividing the Swedish road network into so called gradient classes and distribute the Swedish VKT accordingly, to allow for an implementation in HBEFA.

To implement a distribution over gradient classes in the Swedish adaption of HBEFA, altitude information (z) from NVDB (the Swedish national road database) was used. The absolute average slope (difference in altitude along the length of the road link) was calculated as a percentage for each road link as follows:

$$Slope = \frac{abs(z_{start} - z_{end})}{Shape\_Length} \cdot 100$$

The slopes were then categorised into the following gradient classes:

0%	-1% < slope < 1%
+/- 2%	-3% < slope < -1% or 1% < slope < 3%
+/- 4%	-5% < slope < -3% or 3% < slope < 5%
+/- 6%	slope < -5% or slope > 5%

The road network used is non-directional, i.e., it isn't possible to account for traffic going uphill or downhill, the results show only the size of the incline. It is also worth noting that peaks or valleys in the middle of a link do not affect the slope calculation, since it is done using the difference in altitude between the end points only.

The gradient calculation showed that 78 percent of the Swedish road network has an incline of 3 percent or lower and only 5 percent of the network links have an incline greater than 5 percent (Figure 11). For 8 percent of the road network altitude data was missing or obviously incongruous, which made it impossible to calculate the slope along these road links. The majority (78 percent) of the links in question were found to be private roads, i.e., roads with a comparatively small traffic load.

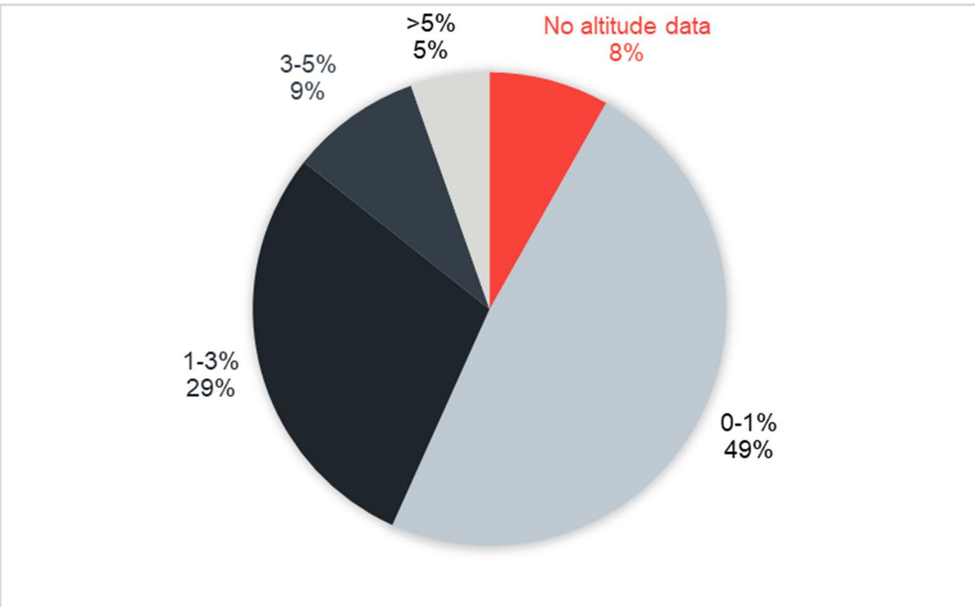

Figure 11. Share of the total Swedish road network length in different gradient categories.

When distributing total VKT over the different gradient classes, 60 percent is allocated to “flat” roads with a maximum incline of 1 percent while only 2 percent is allocated to roads steeper than 5 percent (Figure 12).

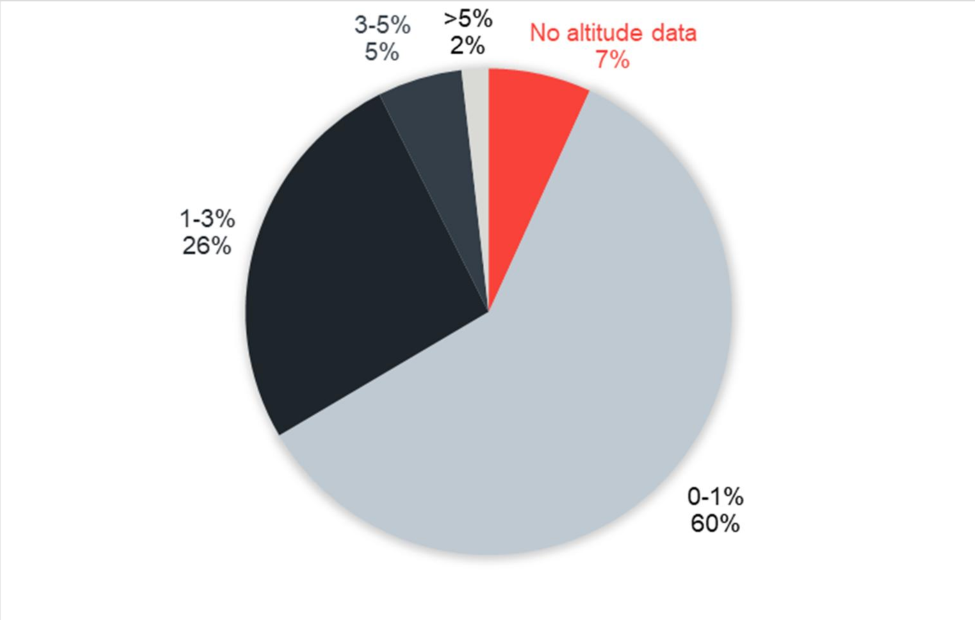

Figure 12. Share of the total Swedish VKT in different gradient categories.

Regarding emissions of carbon dioxide, heavy vehicles are especially affected by the slope. When differentiating between vehicle type the results show that a slightly higher proportion of the heavy duty VKT (61-64 percent) in Sweden is allocated to roads with an incline of less than 1 percent, compared to passenger car VKT (59 percent).

It can be interesting to know whether the distribution over gradient class differs between road operators. In Sweden, 76 percent of the total road length belongs to the private road network, in which we also find a large proportion of the roads with the steepest slopes. The VKT on the private road network, however, is estimated to be only ca 4 percent of the total Swedish VKT. The VKT on state roads is 75,5 percent of the total and 90 percent of this traffic is driving on roads with an incline below 3 percent. The VKT on the municipal road network amounts to 20,5 percent of the total and 74 percent of it is found on roads with an incline below 3 percent. Therefore, the tendency is that larger traffic shares are allocated to roads of higher gradient classes in the municipal and private networks, compared to the state road network.

The VKT distribution over speed limits and gradient classes was also studied. The largest part of the total VKT occurs on roads with a speed limit of 70 km/h, followed by roads with a speed limit of 110 km/h. The most traffic on inclines greater than 3 percent occur on roads with speed limits 70 km/h and 50 km/h.

Even if a relatively small share of the VKT occurs on links with greater inclines, it is more accurate to relinquish the earlier assumption that the Swedish road network can be regarded as comparatively flat. It was therefore decided to henceforth use input data that includes gradient classes, as well as to adjust input data from previous years retroactively, otherwise there is a risk of false representation of historical emission development, with increasing emissions in 2019 because of introducing gradients this year. The VKT distribution was retroactively produced from the start of the HBEFA calculations in 1990 using the 2019 network slope calculations, since it would be very time consuming to obtain older network data and calculate "historical" slope conditions and also considering that network topography does not change that often. Going forward, gradient classifications should be updated regularly, but how often is more a question of budget and resource allocation.

A brief account of how the HBEFA emission calculations were affected by the introduction of gradients in the VKT distribution input data is presented in section 3.1.

2.13. Sources for national VKT (WP6.1)

Background

Energy use in the road traffic sector in Sweden is estimated by the Swedish Energy Agency (SEA) and published as a part of the official national energy balance. In addition to this, the energy use is also calculated by the Swedish Transport Administration (STA) and the Swedish Environmental Protection Agency (SEPA) for use in the national greenhouse gas inventory. The SEA and STA/SEPA approaches for estimating the energy use are different. In the SEA method energy for road traffic is estimated as the difference between energy in delivered fuel and the use in other applications than road traffic (which is mainly non-road machinery). The energy used in non-road machinery is estimated from surveys aimed at different sectors, e.g., the industrial and agriculture. In the method used by the STA and the SEPA the HBEFA model is used as the basis for the calculations for the road traffic sector. The calculated fuel consumption for road traffic in combination with modelled results for non-road machinery, trains, leisure boats, etc., are compared with statistics on national fuel deliveries. The difference between models and delivery statistics is then allocated to road traffic and non-road machinery in proportion to the modeled consumption for each sector.

When comparing energy reported in the national energy balances versus energy reported in the national greenhouse gas reporting, the estimated amounts of energy differ. The difference is greatest for diesel (15–20 percent). One possible reason for this discrepancy that has been discussed between the involved authorities is an underestimation of the national total VKT (Vehicle Kilometers Travelled) for trucks as a result of an underestimation of the VKT for foreign trucks in Sweden. This hypothesis was tested in this study by comparing different available sources of VKT.

Impact of recent improvements in HBEFA

Every year, the STA updates and improves input data to HBEFA to reduce uncertainties. In 2020, a number of improvements was implemented which resulted in an increase of the modeled diesel consumption. There were mainly two improvements that had a major impact. The first was the updated distribution of national VKT on different road gradients (see further section 2.12 and section 3.1). The effect of this improvement was significant since previous calculations were based on the assumption that the national road network in average is flat (+/- 0% gradient). This improvement mainly affects the average consumption for heavy trucks.

The second improvement was a new national calibration of HBEFA's base factors for passenger car fuel consumption (see further section 2.4 and section 0). An additional factor that lately has affected estimated fuel use is the version change from HBEFA 3.3 to 4.1, which means a higher energy use for light trucks of 5 percent and for heavy trucks of 8 percent.

A comparison between estimated diesel quantities before and after the updates is illustrated in Figure 13.

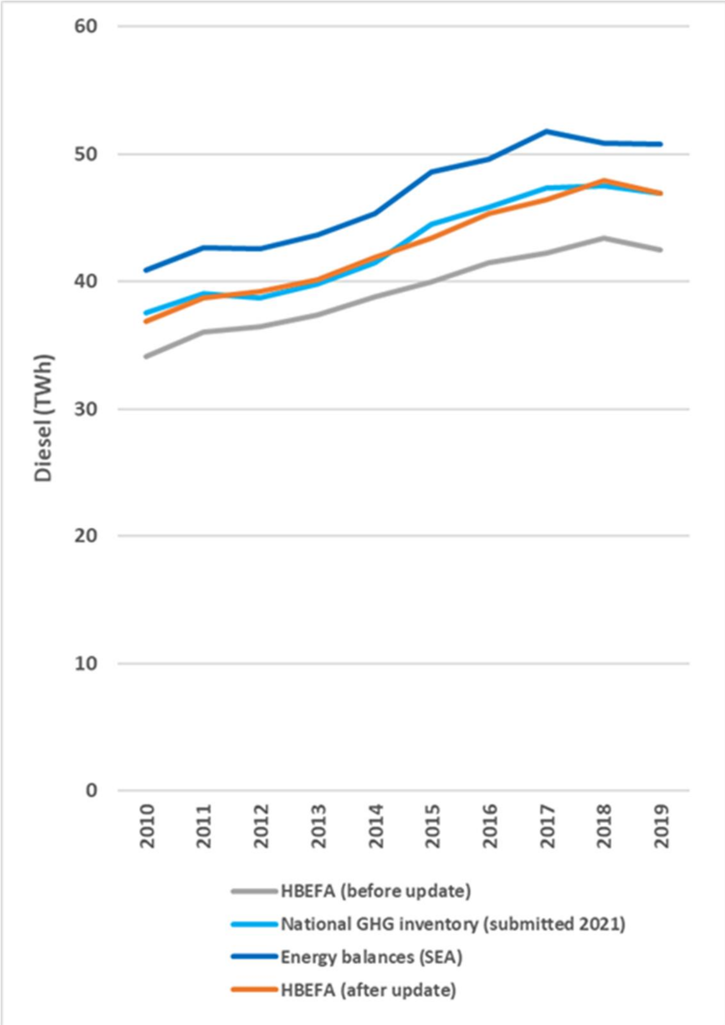

Figure 13. Estimated diesel (in MWh) used in road vehicles according to four different methods.

Scope

The described improvements have meant that the difference between reported energy in the national official energy balance and the official greenhouse gas reporting has decreased significantly, although some differences still remain. The original question is thus less relevant than it was when this study was initiated, but it was still considered useful to continue to investigate whether the annual national VKT in HBEFA is underestimated. Hence, in this study, different estimates of the national VKT and the change of the VKT over time have been analyzed, with the main purpose of investigating whether the VKT used in HBEFA is underestimated.

Data sources

Two data sources of national traffic activity and its changes over time have been compared in this study 1) traffic counting and classification using inductive loop detectors and road tubings 2) odometer readings collected during PTI (periodical technical inspections).

Traffic counting with inductive loop detectors and road tubings is conducted by the STA to measure vehicle passages at many locations on state roads. Inductive loop detector measurements are conducted using two plates that are embedded in the road surface. When classifying passing vehicles, heavy-duty trucks and buses are merged into one category and are then divided into "light" and "heavy" vehicles (both of which have a total weight > 3.5 tonnes). Light vehicles are divided into passenger cars with and without trailers, these categories also include light commercial vehicles. The method is in theory better than using the wheelbase for vehicle classification as done for measurements with road tubes (see below), but a weakness is that the classification is very uncertain. Results from measurements with inductive loop detectors can only be expressed as a relative development and not in absolute values for the whole of Sweden. The method has been used since the 1970s and the technology is today considered obsolete and uncertain and therefore at present is under review and will probably be improved (Trafikverket, 2021b).

When conducting measurements with road tubings two tubings are put on the surface of the road separated from each other with a known distance. These kinds of measurements are carried out at approximately 1500–2000 sites/locations per year. The sections of the road network that are not covered by measurements are estimated using general adjustments based on 83 permanent measuring sites with inductive detector loops (see above). The vehicles passing the tubings are classified by interpreting and categorizing combinations of number of axles and wheelbase. The results are simplified in that sense that the traffic is classified in only two categories; all vehicles and heavy vehicles. The measurements and its associated classification method are planned to be developed and improved. One important planned improvement is that vehicles with two-axles and a wheelbase of 3.3–4.4 meters will be interpreted as light-duty vehicles instead of heavy-duty vehicles as is the case at present. This change means that the number of vehicles interpreted as light-duty vehicles will increase and hence, the number of heavy vehicles will decrease. Historical measurement data is not planned to be reinterpreted using the new method, which means that the changes will be seen gradually from when the new method is started to be implemented and then increase. Hence, it is assessed that the effects on estimated VKT because of the methods change cannot be evaluated in the near future in a credible way.

The VKT estimated from odometer readings was obtained from Trafikanalys. Compared with the official figures[12], the data used in this study were adjusted to include VKT for foreign trucks in Sweden and at the same time exclude VKT abroad for trucks registered in Sweden.

Analysis

Data from the described data sources were analyzed and compared. The traffic counting with inductive detector loops and tubings are not directly comparable to the method based on odometer readings for several reasons, which is why the analysis should take both into account, in order to have two independent and different sources. One difference is for instance that the traffic counting only includes state roads whereas odometer readings cover all driving.

When compared, the odometer-based method showed a higher yearly VKT for light-duty vehicles compared to the traffic counting methods, which is logical since the later lacks an estimate for municipal roads. For heavy-duty vehicles on the other hand, the estimates based on traffic counting are far above the estimates from odometer readings, which is plausible. In addition, a sharp increase is seen during the analyzed ten-year period 2010–2019. The data for heavy-duty vehicles measured with tubings refer to the estimated VKT before the planned update of classification method. In order to analyze the causes of differences between methods and sources, their relative development over time was compared, Figure 14. When comparing the methods, observed differences in the relative

[12] https://www.trafa.se/en/road-traffic/swedish-road-goods-transport/

development for light-duty vehicles are logical. The traffic counting method, which includes all light duty vehicles, are in between the odometer-based curves for light commercial vehicles and passenger cars plus motorcycles, but closer to the latter. This makes sense since passenger cars are significantly higher in numbers than light commercial vehicles. For heavy-duty vehicles, it is clear that the difference between the methods increases during the period. Also, the estimates from the inductive loop detectors and tubings differ relatively much from each other. From these results it is not possible to draw any specific conclusions.

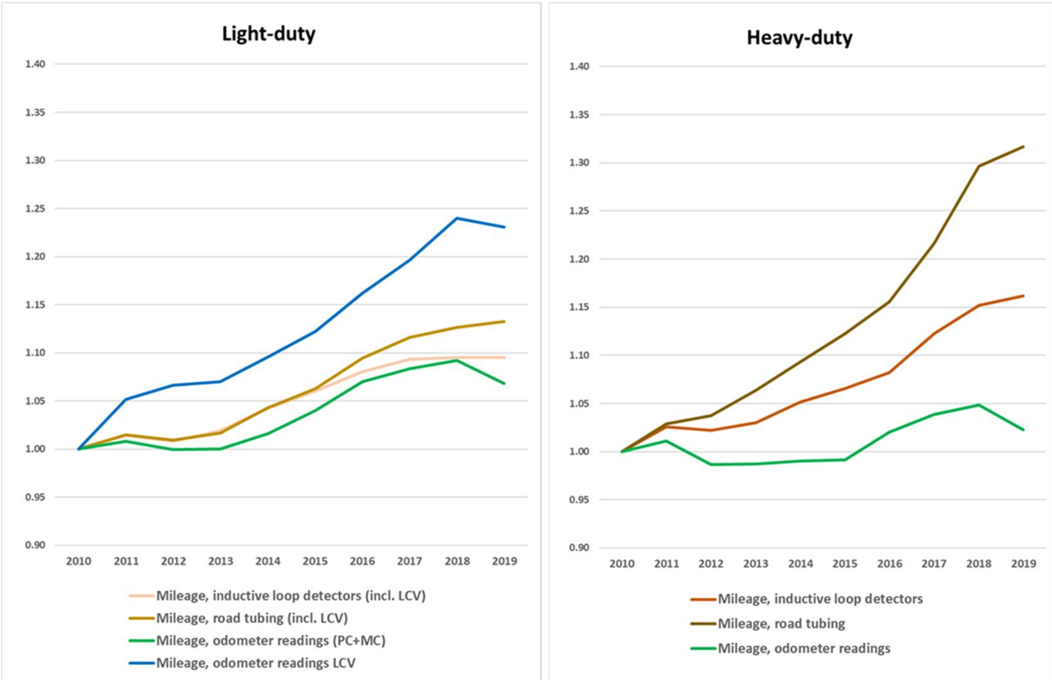

Figure 14. Relative change over years (2010=1) using the different methods.

Regarding the possible implementation of a new classification method for road tubing measurements, there are yet no definitive results on the impact of classification on VKT for light-duty and heavy-duty vehicles, respectively. However, a survey conducted by the STA in 2020 (Trafikverket, 2021c) at 83 measurement sites with road tubings (close to sites using inductive detector loops) showed a decrease of the proportion of heavy vehicles from about 13.6 percent to about 8.7 percent, expressed as the proportion of total traffic activity.

The change is relatively large, and a possible explanation may be that the share of a specific vehicle segment (light commercial vehicles with wheelbase> 3.3 meters) of all light commercial vehicles has increased significantly in later years.

If the percentage change resulting from the new classification method is applied to historical measurement data, it is possible to "simulate" the annual VKT for heavy-duty and light-duty vehicles when using the updated method. Figure 15 shows the results from such a simulation (for the years 2018–2019).

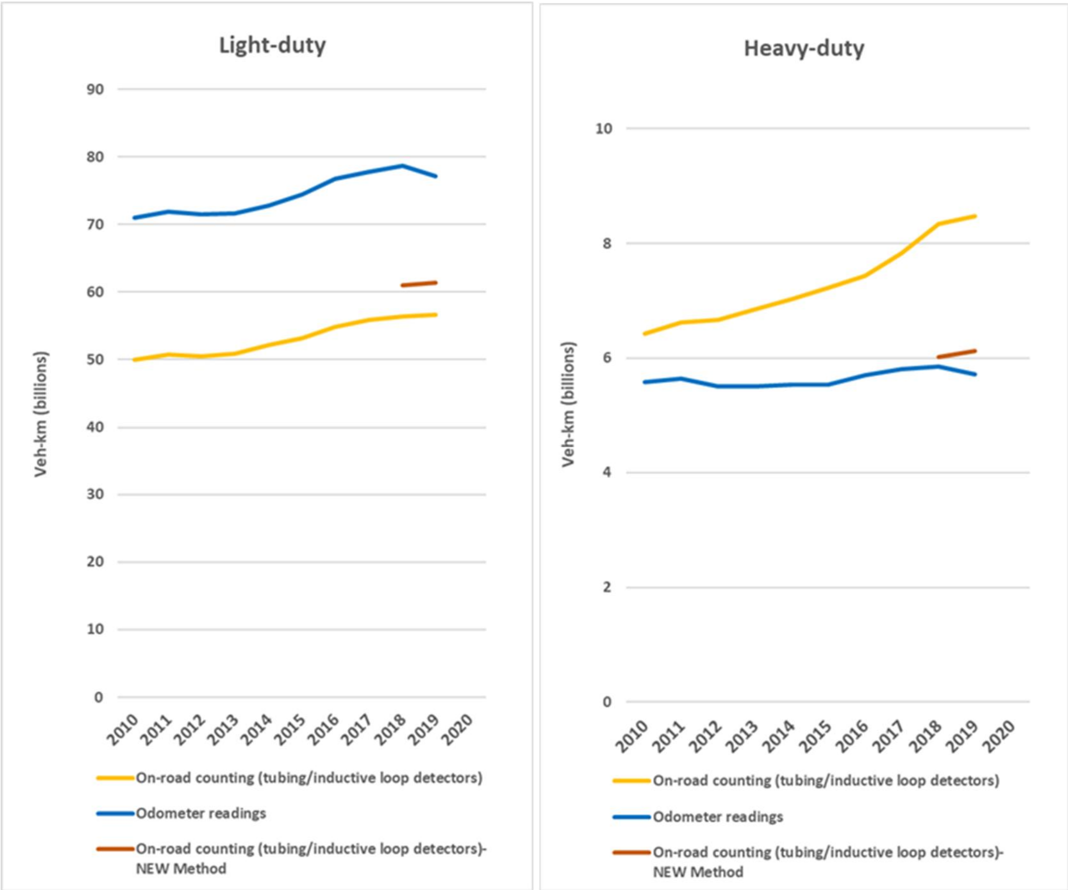

Figure 15 Vehicle kilometers travelled for light-duty and heavy-duty vehicles as estimated from odometer readings and measurements with road tubings (odometer readings for heavy-duty trucks are adjusted to include VKT for foreign trucks in Sweden) Estimated VKT after adjustment for the new classification method are included for the years 2018–2019. Note that the estimates based on traffic counting only represents traffic on the state road network, while the VKT from odometer readings represent all traffic.

The total VKT for light-duty vehicles according to the traffic counting method is increased slightly and comes closer to the level of the odometer method when the new classification is used but remains significantly lower. This is logical as the difference reflects the light-duty traffic on municipal and private roads that is significant for light-duty vehicles.

For heavy-duty vehicles, estimated VKT using the new classification drops drastically down to a level very close to the level of the odometer method. However, the new level is still slightly higher. The remaining difference is assessed to be relatively small, although not insignificant.

Conclusions

The following conclusions can be drawn from this study:

- The issue with large difference in estimated national fuel consumption by HBEFA and the fuel delivery statistics has decreased since HBEFA was updated with new VKT distribution over road gradients and fuel consumption for passenger cars has been calibrated to better match real-world consumption data. Also, the gap between the HBEFA calculation and the national energy balances has decreased (see further Figure 13).

- A difference can be seen between the two methods for estimating national VKT that have been compared within this study. The difference in yearly relative development of VKT between the methods has been tentatively and partly explained by the obsolete method used for classifying vehicles into light- or heavy-duty vehicles when using road tubings for traffic counting.
- The upcoming improved method for classifying vehicles passing a road tubing measurement station will possibly lead to a more consistent estimate of total national VKT for heavy-duty vehicles compared to estimates derived from odometer readings. However, it is yet not possible to fully evaluate how the improved method will affect the estimates and it cannot be ruled out that significant differences will remain.
- This investigation does not indicate that the total VKT of foreign trucks in Sweden are underestimated in HBEFA to the extent that it would give rise to a significant underestimation of the total heavy-duty VKT on Swedish roads.
- The cooperation between Swedish authorities could be improved further to solve the remaining issues and to investigate other possible reasons for differences between methods and data sources concerning the total national VKT.

It should also be mentioned that measurements with road tubings also capture vehicles for which mileage are not estimated in the odometer-based method, for example A-tractors and other vehicle types. To better understand what differences in vehicle mileage are due to, the methods should continue to be developed. One approach may be to analyze the mechanical measurements in more detail with respect to more vehicle types.

2.14. Energy use in auxiliary equipment (WP6.2)

HBEFA estimates energy use and emissions from road vehicles operating in normal traffic. Energy used for other purposes, e.g., when idling during loading and unloading of trucks or for powering auxiliary equipment in e.g., refuse trucks, cement mixers and refrigeration systems, is not included in the model. Consequently, emissions from these activities are not estimated either. However, emissions during idle due to stops at traffic lights or traffic jams are included in the underlying driving cycles in HBEFA and hence accounted for in the model.

From an emissions inventory point of view, all emission sources need to be included in the inventory in order to make it as complete as possible, but when it comes to auxiliary equipment for trucks, there is no method presented in the EMEP / EEA Guidebook 2019 (Winther & Dore, 2019). The Guidebook briefly deals with the subject in a text section where the following can be read:

"In some cases, there is a risk of misallocation, overlap or double counting, because it is not always clear whether e.g. specialized utility vehicles such as fire trucks, refuse collectors, sewage trucks, road tankers, etc. are included in the on-road vehicle reporting categories. In addition, some of the vehicles may have a second combustion engine in order to operate specialist equipment or machinery. Where possible, the machinery should be reported under the appropriate NRMM reporting category and not road transport. If it is not possible to resolve the fuel used by the main vehicle and the on-board mobile machinery, then emissions from the mobile machinery can be reported under the same source category as the main vehicle."

In the Swedish Non-Road emission model, road transport refrigeration units powered by auxiliary diesel engines are included. In Sweden's emissions inventory for road traffic, trucks with auxiliary equipment are not distinguished from other trucks when the National vehicle register is used to produce statistics on the number of vehicles etc. to the HBEFA model. This is because HBEFA do not group trucks with regard to type chassis or auxiliary equipment but by vehicle weight. On the other hand, the register includes information that makes it possible to group vehicles into different categories of used auxiliary equipment.

In summary, this means that fuel consumption for powering truck auxiliary equipment not is included in HBEFA's driving cycles and only to some extent included in the non-road emission model. This is likely one contributing reason why the statistics on delivered diesel volume to the mobile sector for many years have been higher than the modelled volumes.

Goals and objectives

The purpose of this feasibility study has been to:

- Examine what types of diesel-powered auxiliary equipment that are used for heavy-duty trucks and how many vehicles with each type of equipment that are registered in Sweden.
- Assess the magnitude of the volume of diesel used in trucks for powering auxiliary equipment.
- Review the present fuel consumption calculations for refrigeration and freezing units, used in the Swedish national non-road model.
- Make suggestions on how the national emission inventory can be improved and discuss different possibilities regarding how emissions can be calculated and to which sector they should be allocated.

Method and delimitations

A literature study was first conducted. The findings were supplemented through contact with experts and by using information from the national vehicle register. Subsequently, an estimation of fuel consumption for special equipment was done based on the information from the above-mentioned sources.

The study was limited to consumption of diesel fuel. One exception is that information found in the literature on emissions of NO_X and particles from auxiliary diesel engines for operation of refrigeration and freezing units has been compiled.

Estimation of fuel used for auxiliary equipment on diesel trucks

Based on available information it was not possible to make any detailed calculations of volumes of diesel used for auxiliary equipment on a national level. However, it was possible to make an estimate of the order of magnitude. This was done outgoing from the following information:

- The number of vehicles by type of auxiliary equipment
- Average annual operating hours for different types of equipment
- Hourly fuel consumption for different types of equipment

The number of vehicles with certain types of auxiliary equipment was obtained from the national vehicle register. Operating hours and consumption per hour have in most cases been estimated by using information from Volvo (2016). The intervals specified by Volvo have been used to make a low and a high estimate of the fuel consumption. Hourly consumption and annual operating time for refrigeration and freezing equipment was based on estimates from Thermo king (2021).

Calculated annual diesel volumes per type of equipment in 2020 is presented in Table 4. The used method and the results have been discussed with one person at Volvo Trucks (Volvo, 2021). Since the source of the data presented in Volvo (2016) could not be traced, it was not possible to fully assess the suitability of using them as a basis for the calculations. For compressor vehicles, however, it could be confirmed that the used hours and the size of power outtake looks reasonable. For other vehicles, there was no possibility to make a reasonableness assessment at present. Something that could be confirmed was that almost all special equipment listed in Table 4 is operated through PTO, with the exception of equipment used for refrigerated transports, where a diesel-powered auxiliary engine is the most common solution. It was also mentioned that it could be suspected that the specified power range indicates values that are helpful when the PTO is dimensioned rather than representing an average actual power outtake when the equipment is used. That is, the used method tends to overestimate the energy demand.

For vehicles that according to the vehicle register is equipped with a lift, it has not been possible to specify the type of lift used, but it is assumed that many are tail lifts powered by electric batteries, however this has not been confirmed. Anyway, it was decided not to make any estimate of the diesel consumption for this type of auxiliary equipment.

Table 4 only includes diesel-powered vehicles, which constitutes most of the vehicles in each category. For refuse transports, however, methane (i.e., natural gas or biogas) is a commonly used fuel, accounting for about 20 percent of all refuse transports in 2020.

Table 4 Number of heavy-duty trucks with different types of auxiliary equipment in 2020 and estimated annual national consumed volumes of diesel. Also light commercial vehicles used for refrigerated transports are included.

Auxiliary equipment	Number of vehicles	Diesel volume (m^3/year)		
		Low estimate	High estimate	Average
Lifts	14 107	-	-	-
Refrigerated transport (Heavy trucks and trailers, with aux engine)	10 664	92 625	92 625	92 625
Tanker trucks/compressor trucks	2 492	5 098	9 594	7 346
Refuse truck	1 949	5 426	7 234	6 330
Concrete pump	232	5 268	7 244	6 256
Tipper trucks	7 855	2 358	5 896	4 127
Skip trucks	4 484	3 366	4 173	3 769
Cement mixer	799	2 181	4 907	3 544
Vehicle mounted cranes	4 371	2 297	4 593	3 445
Combinations of winch, crane, tips and lifts	3 419	1 796	3 593	2 694
Acces vehicles with ladder	2 358	2 195	2 372	2 283
Timber truck cranes	457	1 297	2 108	1 703
Refrigerated transports (Light commercial vehicles)	2 963	1 390	1 390	1 390
Refrigerated transports (Heavy trucks and trailers, without aux engine)	285	800	800	800
Container lifts	722	325	650	488
Car transporters	603	309	411	360
Lift dumpers	236	162	201	182
Winches	359	39	66	53
Total	**58 355**	**126 932**	**147 857**	**137 394**

The category that according to the estimation accounts for the single largest share of energy use is refrigerated transports (35 percent) followed by refuse transports (10 percent) and concrete pumps (10 percent). The number of heavy trucks with special equipment was estimated to approximately 50,000 in the end of 2020, which corresponds to about 60 percent of all heavy trucks in traffic. If vehicles with a lifting device are excluded (because they are assumed to be powered by a battery) and all vehicles for refrigerated transport that uses an auxiliary diesel engine, it results in a little more than 30,000 vehicles, which corresponds to about 37 percent of all heavy trucks in traffic. This number agrees reasonably well with the rule of thumb given by Volvo Trucks, saying that about half of the heavy vehicles sold within the entire Volvo Group have equipment that requires PTO.

The estimate yields that the operation of special equipment included in Table 1 accounts for a consumption of between approximately 125,000 m^3 and 150,000 m^3 of diesel per year. According to Sweden's official greenhouse gas reporting (submission 2021), approximately 1,700,000 m^3 of diesel was consumed in heavy-duty trucks in 2019 and approximately 4,900,000 m^3 was reported to be used for road traffic in total. These figures are based on HBEFA's calculations but are adjusted to take into account that the delivered volumes of diesel are larger than those modelled for road traffic, off-road machinery and other sectors using diesel. The adjustment thus corrects for the unmodeled volumes consumed in auxiliary equipment for trucks. From this follows that auxiliary equipment on trucks roughly accounts for 1 -1.5 percent of the total diesel volume used for road traffic and 3-5 percent of the diesel volume used by heavy-duty trucks.

Estimates of fuel consumption and emissions from refrigerated transports using an auxiliary engine is already included in Sweden's emission reporting in the non-road sector. The annual diesel volume is then estimated at about 40,000 m^3 per year, which is about half of the calculated average value in Table 1. The main reason for the difference in the two calculations is the large difference in the number of non-road vehicles, which has not been updated in the national non-road model for many years. This means that a volume of approximately 100 000 m^3, is not accounted for in either of the national bottom-up emission models.

Refrigeration units

Refrigeration and freezing units are according to the calculation the single category of auxiliary equipment that accounts for the largest consumption, therefore the focus was on finding more detailed information for this type of equipment.

The number of units in 2020 together with estimates of operating hours and hourly fuel consumption that have been used within this study is presented in Table 5. Operating hours and fuel consumption are estimates from a manufacturer of refrigeration units. That data should be seen as rough estimates that has to be updated once better information becomes available. Which source of power that is used for the different categories in Table 5 was estimated in discussion with the same manufacturer that provided operation and fuel consumption estimates.

Table 5 Number of powered refrigeration units used in light commercial vehicles and heavy goods vehicles in Sweden 2020 together with estimates of annual operationg hours and fuel consumption per operating hour.

Category	Power source	Power source	Annual operating hours	Fuel consumption (l/h)
Light commercial vehicles	2 963	Vehicle driveline	625	0.75
Heavy goods vehicles 3.5 t - 6 t	90	Vehicle driveline	1 000	0.75
Heavy goods vehicles 6 t - 12 t	195	Vehicle driveline	1 500	2.5
Heavy goods vehicles 6 t - 12 t	195	Auxiliary engine	1 500	3.5
Heavy goods vehicles > 12 t	6 669	Auxiliary engine	2 500	3.5
Trailers	3 800	Auxiliary engine	2 500	3.5
Total	13 912			

Other information found about mobile refrigeration systems in the literature study is compiled below.

Tassou et. al, (2009a) states that at full capacity utilization and at a cooling temperature of -20 ° C, the fuel consumption of the auxiliary engine can be between 1 and 5 liters per hour depending on the size of the unit. BEIS (2019) states approximately 19 percent and approximately 16 percent extra consumption for trucks and trailers with refrigeration, respectively. The figures are based on Ricardo (2011) which in turn is based on Defra (2009) and Tassou et al (2009b). The increase in consumption is regardless of whether the transport concerns a refrigerator or freezer as the difference in temperature is compensated by more insulation.

In Ricardo (2011) it is estimated that about 7 percent of the energy use in heavy trucks in the EU is used for trucks equipped for refrigerated transport (the figure includes both the vehicle's propulsion and operation of the refrigeration system). It is also noted that there is little available information on fuel consumption for these kinds of transports. Since consumption also depends on so many different parameters such as the efficiency of the refrigeration unit, the insulation effect, the number of stops for loading / unloading and the software for refrigeration control, it is difficult to produce general figures.

Vermeulen et al (2021) have measured fuel consumption and NO_X emissions from a heavy refrigerated trailer with a stage II D engine of 2 liters and an output of 25 kW. Engines certified for the Stage II emission standard are still common as the next tightening of requirements comes first with Stage V, which is required in the end of 2021, and according to the report, the tested model is a common type of cooling system on semi-trailers. The test was performed for 206 days, of which the trailer was used actively for 164 days. During this period, the trailer was used for 1 787 hours, corresponding to about 11 hours per day. The diesel consumption was measured at 2.2 liters per hour. Information about ambient temperature or temperature in the cooling room is not presented. NO_X emissions were measured to 52 grams per hour and 9.5 grams per kWh which should be compared to the emission standard's limit value of 8 grams per kWh. It is also stated that NO_X emissions per hour are approximately 1.5 times higher than from a Euro VI truck engine with an output of 300 kW.

According to Cenex (2021a), about 3 000 liters of diesel per year are used in an average refrigerated trailer in the UK and emissions from refrigeration units account for up to 40 percent of the NOx emissions from the vehicle and up to 95 percent of the particulate emissions if the vehicle's engine meets Euro VI requirements. Specified consumption is based on calculations with Cenex's own model for cooling units. Cenex was contacted (Cenex, 2021b) in this study to check if the data IVL used in this study on consumption per hour and annual operating time for refrigerators and freezers are reasonable and to find out if it is possible to make an estimate of total diesel use in refrigeration units used in Sweden using the Cenex model. The reasonableness of the data used by IVL was considered OK if you are only looking for a rough estimate. A proposal on how a more detailed study, which includes calculations in the Cenex model, was also made by Cenex.

Discussion

In HBEFA trucks with auxiliary equipment are treated as "ordinary trucks". This potentially leads to incorrect calculations for several reasons, such as incorrect load factors, incorrect annual average mileage or incorrect average traffic situations. In addition, energy use and emissions are not taken into account when using the special equipment. However, if you look at individual auxiliary equipment categories, e.g., concrete pumps, without a more detailed analysis it is not possible to ascertain if HBEFA underestimates the energy use. This is because parameters such as load factor and average mileage could be overestimated for this vehicle category, which theoretically could compensate for the energy used for the auxiliary equipment not being estimated. Such effects are difficult to assess without conducting a more detailed study.

One of the most interesting ways to validate HBEFA's energy calculations is to analyze actual operating data from trucks of different categories. After discussing this with Volvo trucks, it cannot be ruled out that some development of Volvo's vehicle operation data logging system probably will be needed before a detailed analysis of consumption due to PTO separated from consumption due to other activities can be made.

Fuel consumption in auxiliary engines for refrigeration and freezing units measured by Vermeulen et al (2021) and also the consumption reported in Cenex (2021a) show a slightly lower consumption per hour than what was used in the calculations in this study, which were instead based on information from Thermo King. Other sources also show that the consumption varies due to many different parameters and without a more detailed study it is difficult to determine what are reasonable average values for Swedish conditions. This can be investigated further, e.g., by interviewing hauliers.

Conclusions

- According to the EMEP / EEA Guidebook 2019 (Winther and Dore, 2019), emissions from auxiliary engines used to power auxiliary equipment on trucks should, if possible, be reported under the appropriate NRMM reporting category and not under road transport. The main reason for this is that the exhaust emission performance of the auxiliary engine in many cases does not meet the same requirements as the vehicle's main engine. For the same reason, it is reasonable that emissions from the use of extra equipment when powered by the vehicle's main engine are allocated to the road sector. Unfortunately, no guidance is given on how to estimate emissions from the use of auxiliary equipment.
- It is difficult to estimate the share of a vehicle’s fuel consumption that is consumed at idle not connected to normal driving or to power auxiliary equipment. With today's vehicle technology, where operating parameters are logged and stored, however, it should be possible to study this in more detail.
- The very rough estimation made in this study shows that fuel consumption for operation of auxiliary equipment on heavy-duty trucks accounts for about 1-1.5 percent of the total national diesel volume used for road traffic and 3-5 percent of the diesel volume used in heavy trucks.

- Approximately 100 000m^3 of diesel is estimated to be left out in the bottom-up calculations for the mobile sector in Sweden's climate reporting due to the consumption by extra equipment.
- Based on this study, refrigeration and freezing units are assessed to be the single auxiliary equipment that accounts for the largest diesel consumption at national level. Emissions from these are included Sweden´s current emission inventory for non-road machinery. However, the now estimated number of units is too low and need to be updated in order to not underestimate the calculated diesel consumption.
- A rough assessment from Volvo Trucks is that on average about 3 percent of the fuel consumption of trucks occurs at idle or at power take-off. This includes idling when driving on the road, e.g., at traffic lights. 3 percent of diesel consumption for heavy trucks according to Sweden's emission inventory translates to approximately 50,000m^3 of diesel.
- Emissions of NO_X and particulates from diesel engines to power refrigeration plants can be a significant part of the vehicle's emissions if the vehicle's own engine meets Euro VI, whereas the auxiliary engine only meets Stage II.

3 Effect analysis

3.1. Updated TSGrad-Patterns

Within this project the TSGrad-patterns (Traffic Situation and Gradient-patterns) used for Sweden have been updated according to the list below:

- TSGrad-patterns based on traffic data for 2019 have been produced for all vehicle categories. As for previous years the patterns are split into four different road categories; rural motorway, urban motorway, rural non-motorway and urban non-motorway. At present these patterns are applied in HBEFA from year 2019 and onwards. These are the first patterns used in Sweden to include an allocation of VKT (Vehicle Kilometers Travelled) to "heavy stop and go" traffic situations and also, the first time the VKT was distributed over different road gradients, (for further details see sections 2.9, 2.11 and 2.12).
- All TSGrad-patterns used for year 1990-2018 have been updated to include a distribution over different gradient classes, (for further details see section 2.12).
- The TSGrad-patterns used for busses have been updated by applying a new method giving more representative relative distributions (for further details see section 2.3). These new patterns have not yet been implemented in the national HBEFA calculations but will be so during 2022.

Of the abovementioned updates the new distribution of VKT over different gradient classes is the update that affects the calculated total national energy use and emissions the most. Regarding energy use it is almost exclusively the calculations for heavy vehicles that is affected by the gradients since for passenger cars and light commercial vehicles energy use is calibrated based on CO_2 monitoring values and real-world excess factors. The increase in estimated energy use due to gradients is similar all years from 1990 to 2019 and approximately 9-10 percent for HGVs. For buses the increase is approximately 5-6 percent. Gradients also effects emissions of e.g., NOx and PM for both light- and heavy-duty vehicles and the estimated yearly total emissions of NOx increased by 5-6 percent with the new patterns. For exhaust particles the new gradient patterns imply an increase of emissions of around 5 percent in 1990 but from around year 2000 the difference decreases steadily and is close to 0 percent in 2020.

The split of the fourth level of service category into "stop and go" and "heavy stop and go" and the new distribution pattern for busses each affects the national energy use and emissions by less than 0,5 percent. If only looking at emissions from busses, the new bus pattern results in a decrease of the national energy use in busses of approximately 5 percent and an increase in NO_X of approximately 2 percent. For particles there is no significant difference.

3.2. Fuel consumption calibration

The effects on estimated national energy use due to the new fuel consumption calibration for passenger cars are presented in Figure 16.

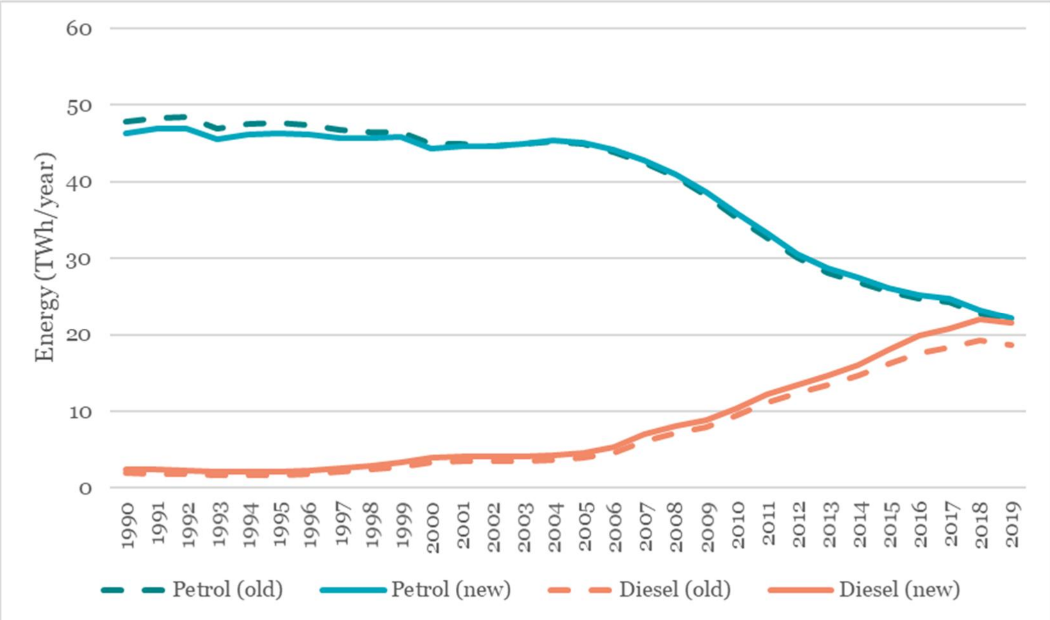

Figure 16 Estimated energy use in petrol cars and diesel cars before and after the new fuel calibration.

From 1990 and up to around year 2000 the total energy use in petrol cars is slightly lower with the new calibration in the past (3.0 percent lower in 1990) and slightly higher in recent years (2.0 percent higher in 2019). For diesel cars the energy use after the calibration is higher throughout the time series. The relative difference for diesel is greatest at the beginning of the time series (17–29 percent between 1990 and 2000), but since the number of diesel cars in Sweden was small by that time, the total difference in estimated consumption is small in terms of TWh. The relative difference increases later years and is around 15 percent in 2019.

3.3. Sweden´s official reporting for the mobile sector

Data produced within several of the work packages of this project was implemented in the Swedish HBEFA-database in 2021 and hence also used in the national greenhouse gas inventory for 1990-2020 (to be submitted in 2022). The new data has resulted in a higher modelled fuel consumption for road vehicles 1990-2020 which is due to the new TSGradPatterns (with a distribution over different gradients) together with the new fuel correction factors for passenger cars.

To assess the reasonableness of the new calculation, delivered fuel volumes were compared with bottom-up modelled consumption for the whole mobile sector. When it comes to diesel most of the volume is used in road vehicles (approximately 75 percent for later years) and in non-road mobile machinery. Also, a small part of the volume is used for trains, leisure boats and other domestic shipping. Volumes used for road and non-road applications are estimated with bottom-up models (HBEFA and the Swedish non-road model, respectively). Volumes used in locomotives, domestic shipping and leisure boats are based on different surveys and the Shipair model.

Within the greenhouse gas reporting the sum of bottom-up calculations for all applications is compared with the total national fuel deliveries. The residual, i.e., the difference between deliveries and modelled fuel consumption is then added (if positive) or subtracted (if negative) from road traffic and non-road machinery in proportion to the modelled volumes to each application. Figure 17 shows modelled diesel and delivered diesel 1990-2019 (energy, TJ). The first years of the time series show a relatively large negative residual. The residual then decreases to be negligible around 2005 and then becomes positive in the order of 1-5 percent from 2010 onwards. It is difficult to fully assess what this trend is due to, but factors that affect are:

- For road traffic, the statistical data for recent years is judged to be more reliable than in the 1990s.
- The estimate for the non-road sector (based on a Tier 3 method as defined in (Winther & Dore, 2019)) is assessed to be more uncertain than for road traffic due to a lack of data in terms of annual operating hours and the active machine stock. The average annual operating hours per machine vary between different types and age of the machinery but is constant between different years and are based on data from inspected machines in 2006 (Wetterberg et al., 2007). During the 90-ties the uncertainty in both vehicle stock and annual operating hours is assessed to be relatively high. For years after 2006 the stock data is assessed to be more reliable than for the 90´s but the uncertainty in annual operating remains.

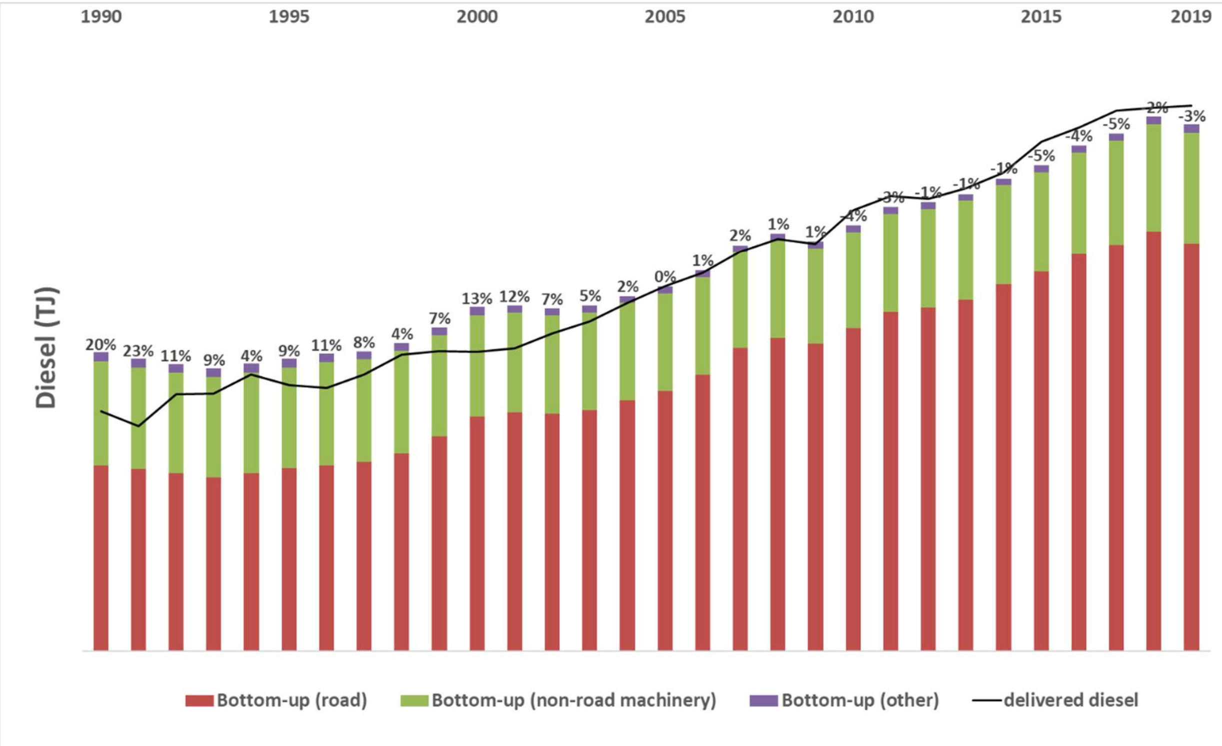

Figure 17 Bottom-up calculated diesel consumption for road, non-road and other (trains, leisure boats, domestic navigating) compared to official delivery statistics. Numbers above bars represent the residual size relative to the delivered fuel energy. Values on the y-axis have deliberately been left out since data was not official when this report was written.

For petrol the road sector is estimated to use around 93-96 percent of all delivered fuel. The residual for the whole timeseries is relatively low with a highest value of 4 percent, Figure 18.

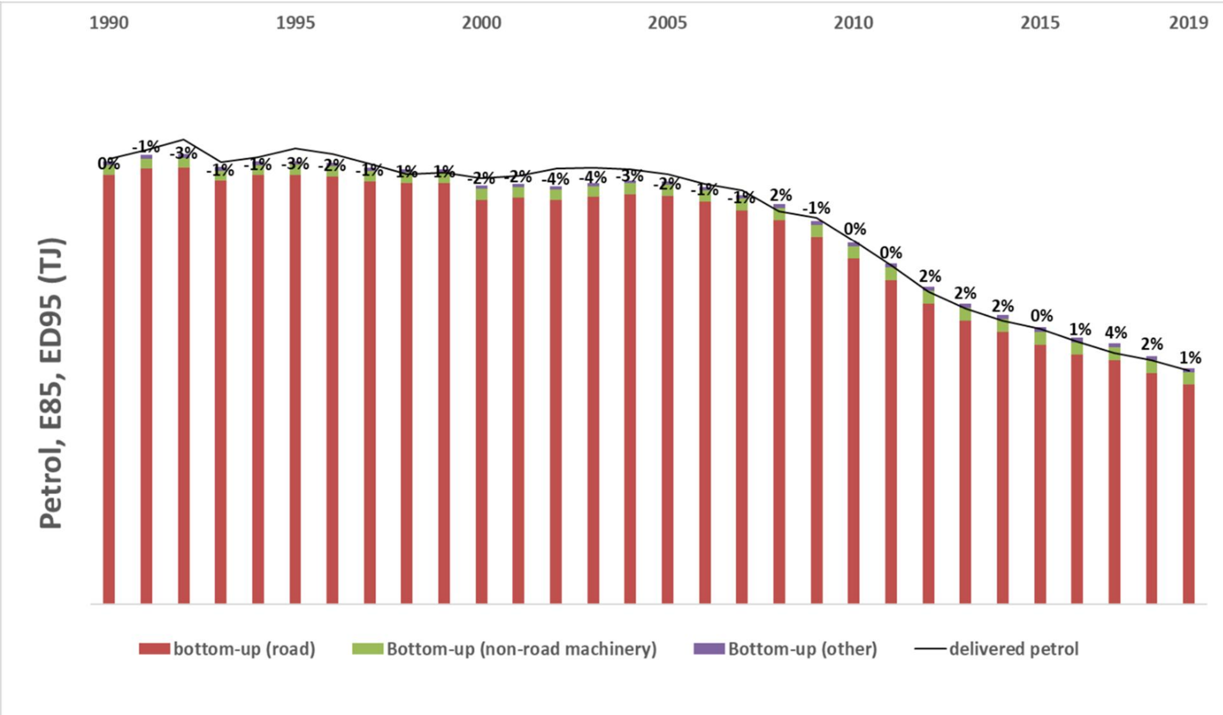

Figure 18 Bottom-up calculated petrol consumption for road, non-road and other (leisure boats) compared to official delivery statistics. Numbers above bars represents the residual size realtive the delivered fuel energy. . Values on the y-axis have deliberately been left out since data is not official at the time of release for this report.

4 Discussion and suggestions for future work

4.1. The need for new driving pattern data

The driving pattern studies that the driving cycles in HBEFA are derived from are several years old. Driving behaviour, road design standards etc., change over time and there is a risk that the driving cycles in the model do not mirror today´s traffic conditions and vehicle fleet correctly. The underlying driving pattern data contains several uncertainties and needs to be updated as well as extended. Today there is considerable variation in the amount of data pertaining to different vehicle types. In Sweden, questions raised include issues such as representativity of the driving cycles for heavy vehicles.

Driving pattern data needs to be sufficient in size as well as representativity regarding the traffic environment and the vehicles in question. As new vehicle types become more common, additional measurements will be needed. It must also be possible to link the data to outer attributes like rural/urban area, road type, speed limit etc., as well as traffic load in terms of annual daily traffic or other more precise traffic flows. More data connected to traffic flow conditions would make it possible to reach a common understanding regarding how to define the different traffic flow categories in HBEFA. In our experience, there is a lack of a generally accepted view among users and experts concerning what should be the basis/circumstances for classification into free flow, heavy traffic, saturated and stop and go/heavy stop and go.

In order to adjust the classification into traffic situations to Swedish conditions there is a need for more comprehensive driving pattern data for passenger cars on Swedish roads. The data requirements are the same as mentioned above, for validating HBEFA driving cycles. After acquiring new representative data on how Swedish cars are driven on different road types and at different speed limits, the translation key between HBEFA traffic situations and the Swedish road network should be updated. Today, only a relatively small proportion of the classification of the Swedish network is validated against Swedish driving pattern data.

Thus, collection of new driving pattern data is doubly motivated: to obtain a better classification of the Swedish network to HBEFA traffic situations and to contribute to updated driving cycles for all vehicle types in HBEFA. Today, there are great hopes for using so called “big data” from connected vehicles to gather more detailed information on vehicle movements. The feasibility study presented in previous section, however, shows that the quality of this data is currently relatively far from the prerequisites for e.g., application in HBEFA. A suggestion for future work is to investigate how to make driving pattern data from connected vehicles readily available and how it can be presented/processed to suit different purposes connection to e.g., HBEFA.

4.2. New method for estimating level of service

Taking advantage of the results from the research project MEDY would yield a more precise determination of level of service (LoS) on individual streets and roads that at times reach level of service ”stop and go” (4) and ”heavy stop and go” (5). The method is based on traffic density and makes it possible to unambiguously decide the level of service in different phases. The application needs to be adapted, however, to harmonize with the current method for level of service classification (mainly LoS 1-3) in an overall national perspective. To be able to adapt the MEDY-method, more data on driving patterns in different levels of service and for different road types/speed limits are needed.

4.3. Fuel consumption for light duty vehicles

In this study, the national fuel calibration in HBEFA was updated for passenger cars (petrol, diesel, E85 / petrol, CNG / petrol and plug-in hybrids) and the new data has already been implemented in the national HBEFA calculations. When more data on real world consumption for LCV´s becomes available in the future, it is suggested that it is used to do a new calibration for that vehicle category as well. The fuel calibration for passenger cars and LCV´s has a relatively large impact on the modelled total national energy use and hence it is important to keep the calibration updated. Thus, data from new relevant studies on the divergence between consumption reported by vehicle manufacturers and the actual consumption, should be used when available.

4.4. Heavy duty trucks: HGV >60t load & transformation patterns

For a more complete reporting for HGV´s the HBEFA segment TT / AT> 60t should be used for trucks with a total weight over 64 tonnes instead of including them in the TT/AT 50-60t segment as now is the case. Trucks with a total weight between 50 and 64 tonnes should continue to be reported in the TT / AT 50-60t segment. Some of the results from work package 1.2 can be used directly to derive the fleet data needed for the >60t segment, but it is also important that it is further investigated how the number of vehicles and vehicle kilometers travelled can be estimated in best possible way. The works should include discussions with vehicle manufacturers, hauliers and Skogforsk[13].

Some of the data that needs to be produced for HGV> 60t is load patterns and transformation patterns. The use of the HGV >60t segment may also lead to that load patterns and transformation patterns for other segments is affected since traffic activity is moved from these segments to HGV >60t. Therefore, a review of this data for all affected segments is needed.

[13] https://www.skogforsk.se/english/

4.5. Energy use in auxiliary equipment

It was estimated within this study that energy use in heavy trucks due to auxiliary equipment is in the order of 3-5 percent of the total energy use in heavy trucks, which not can be considered as negligible. The lack of estimates of energy use for some of this equipment in the present bottom-up models does not affect the official national CO_2 estimation since it is based on fuel deliveries statistics. However, it is possible to improve the method for allocating the emissions more correctly between road traffic and non-road machinery if the energy use in auxiliary equipment is investigated further. Such an investigation would also provide a better estimate of emissions of air pollutants, as it provides better information on the types of engines in which the fuel is used. Since refrigerating and freezing units are assessed to be the auxiliary equipment accounting for the largest diesel consumption, it is appropriate to start investigating this type of equipment in more detail. Real-world fuel consumption can be investigated e.g. by interviewing hauliers. Since most refrigerating and freezing units on heavy trucks uses second combustion engines the emission should be allocated to the non-road sector which already is the case in the current national emission inventory. Since the number of units is too low in the current estimates it is recommended to be updated.

4.6. Estimates of total energy use in the road sector

The reason for the relatively large difference in diesel usage in the road sector as estimated by the Swedish Energy Agency and as estimated by the Swedish Transport Administration together with the Swedish Environmental protection Agency could be further investigated. Results from this study indicates that a possible underestimation of truck vehicle kilometres travelled in HBEFA not likely is the main reason for the seen difference. Further studies on this topic could lead to a better national estimate of the energy use in the road and non-road sectors.

4.7. The Turnover tool

Since developed within this study the Turnover tool has been proven to be a good help when making forecasts for road traffic. In order to keep the tool updated and useful in the future, it is recommended that the latest available fleet and activity statistics should be implemented when available. The National Reference Scenario should also be updated when a new scenario has been developed by the Swedish Transport Administration. At present no need for further development of the tool is identified but if it should be needed in the future it could be handled within the annual national work with updating HBEFA.

4.8. Regarding frequencies for updating input parameters

Introduction

Some national data for Sweden is updated annually or every other year, other data are updated less frequently. What is updated annually with ex-post statistics is all data that has to do with the fleet (stock, new registrations, mileage, etc.) and fuel related data (fuel-mix, Sulphur-content etc.). Every other or third year, a distribution of vehicle mileage over traffic situations and road gradient is produced based on latest available ex-post statistics. Other updates are made if the data, or the methods used to produce data, are becoming obsolete and there is a need for an update. This can for example apply to load patterns, transformation patterns and survival probability functions. There is a national annual budget set aside for updates that are not made regularly and thus some updates of that kind are made every year. In general, input data which changes rapidly and/or impacts model results (calculated emissions and energy use) greatly should be updated more frequently than data of a more static nature. Below follow recommendations of frequencies for updating parameters that have been included in this study but also for parameters that not specifically has been investigated within the study.

Distribution of VKT over traffic situations

The distribution of VKT over traffic situations changes as the road network changes. New roads are built, existing roads are redesigned and/or speed limits are changed. Changes in society (population growth, employment rate, car ownership, fuel price, trade sector development etc.) including different measures and policy instruments also affect car traffic, both in magnitude and in what kind of trips are made by car. The trip length and purpose, destination choice and departure time affect the way traffic is distributed over rural/urban areas, road types and traffic conditions. This in turn affects which of the HBEFA traffic situations that are (more or less) commonly occurring.

Based on previous experience, the distribution of VKT over traffic situations should be updated every other or third year, due to new road constructions and changing speed limits, as well as changes in traffic flows in line with various trends, e.g., in travel patterns. So far, we have observed changes in the distribution even for the most common traffic situations over only a couple of years. The total share of VKT for the twenty most common traffic situations typically increases/decreases with +/- 20 percent, although changes over 30 percent have also occurred. Over longer time periods, for example 2012-2019, the changes have been substantial with more than 100 percent change in the relative total share of VKT for some individual traffic situations. The emission effects of those changes vary between vehicle types and different emission components. In the long run the effects of vehicle distribution over traffic situation need to be considered beside the effects of changes in vehicle stock.

Bus VKT distribution

The distribution of bus VKT over traffic situations is based on GTFS-data and produced using a newly developed method. Bus routes tend to remain relatively stable over time, but they can also change on short notice in connection to more extensive rerouting of bus traffic in different areas. This motivates frequent data updates. At the same time, the contribution to total emissions from bus VKT is relatively small. This speaks for frequent updating being of lower priority.

Today, attributes regarding vehicle characteristics and routes vary between different regional public transport authorities (RKM). This has limited the possibility to distinguish between “urban bus” and “coach” traffic. Data processing and classification would be facilitated by introducing standardised attributes for all RKM to use when entering data in the database. All in all, we recommend that a new distribution of bus VKT is produced in parallel with that of overall VKT, i.e., every other or third year.

Traffic distribution over gradients

Road network topography is relatively static, but it can still change in a few years' time, especially in rural areas. Also, general trends that affect VKT and its distribution can result in a larger proportion of the traffic being allocated to certain road types and/or speed limits, where the roads are undulating to a greater or lesser extent compared to the current distribution. Furthermore, altitude data was missing for eight percent of the network used for the gradient classification introduced 2019-20.

Even if the Swedish national road data base (NVDB) were to be updated continuously, so that the coverage of altitude coordinates would steadily improve, our assessment is updating the VKT distribution over gradient categories at an interval of five to ten years is sufficient. If a more extensive NVDB update focussing on altitude data is executed at some stage, an update of the VKT distribution over gradients would also be warranted.

Fuel calibration

Compared to other parameters the fuel calibration has a relatively large impact on the modeled energy use for passenger cars and light trucks and it is therefore recommended to annually look for new available data on actual fuel consumption and the gap between actual consumption and driving cycles. If the new data is relevant to use for Sweden it should be used to update the fuel calibration in HBEFA. This should be done for both cars and light trucks.

From 1 January 2020 all new passenger cars and light commercial vehicles must be fitted with an onboard fuel consumption meter. Car manufacturers must also from 1 January 2021 record the consumption data and report to the European commission. The detailed information must not be used for other purposes and will be deleted by the Commission. At the time of writing this report it is not decided yet which data will be published by the Commission. Depending on the level of aggregation of possible published data it will potentially be very useful information to use for calibrating the fuel consumption in HBEFA.

Transformation patterns

Transformation patterns have historically not been updated very often, less then every fifth year, as it has been considered that there have been relatively small changes over time. In the future, however, there may be changes that implies that the patterns may need to be reviewed at slightly more frequent intervals than before. One such example is the introduction of trucks with a permissible gross weight over 64 tonnes. The introduction of other new segments such as electric trucks and LNG-powered trucks also provides a reason to review transformation patterns with slightly shorter intervals the coming years. At least every two years, a review may be needed to further assess whether an update of some of the transformation patterns is needed.

Load patterns

Like transformation patterns, load patterns have not been updated very often historically, but there may be reason to review them a little more often in the future due to possible changes due to the introduction of new segments. At least every two years, a review every second year may be needed to further assess whether an update is needed or not.

4.9. Updates that may have greater effects locally

Some of the proposed or already implemented updates can significantly affect local emissions, even if the total effect is negligible on a national level.

- **Improved estimation of the proportion of traffic in different level of service categories** on individual roads, especially with respect to "stop and go", could in some cases have a great impact on results on the local level. In the national perspective, emissions would not be significantly affected since a very small share of the total VKT is conducted in non-free flow conditions[14].
- Previously data for implementing a specific distribution for bus VKT over traffic situations in Sweden was lacking. Instead, buses were assumed to follow the same distribution as trucks without trailers. As the bus share of the total VKT is negligible in a national perspective, changing this assumption cannot be considered to have a significant impact on total emissions. After producing the new, and **more correct distribution of bus VKT** it was established that bus traffic was previously greatly overestimated on some road types and underestimated on others. This probably causes a relatively big difference locally. However, the effect on total local emissions also depends on the composition of the local bus fleet, which varies a great deal between different public transport districts.
- It should be emphasised that there are **other sources of traffic data for local calculations**. These can consist of both actual traffic counts and data from traffic models or simulations. In these cases, more locally adapted distributions can be obtained. GTFS-data (which is of international standard) covers all of Sweden and should be introduced as a data source for local bus traffic.
- **A better validated classification key** between HBEFA traffic situations and Swedish road types could very well impact results on a local level, especially in before-after studies analysing effects of for instance redesign of a road section and/or changed speed limits.
- **Introduction of gradients** can be regarded as a "novelty" on a national level but has been used earlier on the local level, as slope can have a great impact on calculated emissions on individual road sections. Gradients have been found to have an impact also in the overall national perspective, but a greater relative effect can be expected locally.

[14] 1.5 percent in the 2020 calculations

4.10. Summary of suggestions for future work

In conclusion, the thoughts and suggestions regarding future work that have been presented above are listed as follows:

- Collection of driving pattern data to supplement, update and validate HBEFA driving cycles so that e.g., the driving conditions of new vehicle types are adequately included.
- Collection of Swedish driving pattern data to produce a better classification key between HBEFA traffic situations and the Swedish road network.
- Investigating how to make driving pattern data from connected vehicles readily available and how to present/process it to suit e.g., HBEFA requirements, preferably in collaboration with both Swedish and international vehicle manufacturers.
- Further development of a method using vehicle density to obtain an unambiguous classification of level of service, based on the results from the research project *Methodology for calculating emissions based on traffic data from dynamic traffic models and traffic measurements* (MEDY).
- An annual overview of new available data describing real world CO_2 excess emissions for passenger cars and light commercial vehicles. When new relevant data is available, it should be used to calibrate the fuel consumption in HBEFA. One interesting possible data source is data from on board fuel consumption meters. Useful such data may in future be published annually by the European Commission at an aggregate level.
- The segment HGV > 60t should be used for trucks with a total weight >64 tonnes. The needed data on number of trucks, vehicle kilometers travelled, load patterns, transformation patterns etc. should be produced and implemented in HBEFA. In connection with this work, load patterns and transformation patterns may need to be updated for other segments, especially for the HGV 50-60t, which today includes trucks> 60t.
- The number of refrigerating and freezing units used on heavy duty trucks should be updated in the national non-road machinery emission model.
- Further investigate the reason for the difference between different national estimates (i.e. the SEA estimate and the STA/SEPA estimate) of energy use in the road sector.
- To keep the Turnover tool up to date and usable it is recommended that the latest available fleet and activity statistics should be implemented when available. The National Reference Scenario should also be updated when a new scenario has been developed by the Swedish Transport Administration.

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Appendix

List of Swedish research reports

- PM – AP 1.1 Uppdatering av genomsnittliga årliga körsträckor för personbilar och lätta lastbilar som indata till HBEFA-modellen.
  Mohammad-Reza Yahya, Cecilia Hult & Martin Jerksjö (IVL) 2021-04-16
- PM – AP 1.2 Genomgång av möjliga datakällor till antal fordon och körda kilometrar för lastbilsekipage >60 ton.
  Cecilia Hult & Martin Jerksjö (IVL) 2021-06-21
- PM – AP 1.3 Fördelning av bussars trafikarbete över olika trafiksituationer.
  Anna Persson & Eva Ericsson (WSP) 2021-04-09
- PM – AP 2 Verklig bränsleförbrukning för lätta fordon.
  Cecilia Hult (IVL) 2021-05-31
- PM – AP 3 Verktyg för scenarier av framtidens vägtrafik: Omsättningsverktyget.
  Tomas Wisell & Cecilia Hult (IVL) 2021-11-05
- PM – AP4.1-2 Förstudie nya körmönsterdata.
  Eva Ericsson (WSP) 2021-09-15
- PM – AP4.4 Anpassa klassningen av trafiksituationer i HBEFA 4.1 till svenska förhållanden.
  Eva Ericsson (WSP) 2020-09-24
- PM – AP5.1 Kravställning indata till fördelning av trafikarbete på trafiksituationer.
  Anna Persson & Eva Ericsson (WSP) 2020-09-20
- PM – AP 5.2 Trafikutläggning på lokala vägnätet.
  Anna Persson & Eva Ericsson (WSP) 2020-09-30
- PM – AP 5.3 Differentierad metod för flödesklassning i svenska tillämpningen av HBEFA.
  Eva Ericsson (WSP) 2021-03-15
- PM – AP 5.4 Anpassning av svenska tillämpningen av HBEFA efter införandet av en femte flödesklass.
  Eva Ericsson (WSP) 2020-09-28
- PM – AP5.5 fördelning av trafikarbete på olika gradientklasser.
  Frida Persson, Anna Persson & Eva Ericsson (WSP) 2020-09-18
- PM – AP 6.1 Utredning om differenser mellan modellerad dieselförbrukning inom Sveriges klimatrapportering, Energimyndighetens årliga energibalanser och SCBs statistik över bränsleleveranser.
  Tomas Wisell & Cecilia Hult (IVL) 2021-09-27
- PM – AP 6.2 Förstudie om bränsleförbrukning i lastbilar med specialutrustning.
  Martin Jerksjö (IVL) 2021-10-29

Fuel consumption

Fuel consumption passenger cars

Årsmodell	Bensin	Andel bensinhybrider	Diesel	Andel dieselhybrider
2003	8,3	0,04%	7,0	
2004	8,2	0,3%	7,0	
2005	8,1	0,7%	7,0	
2006	7,9	1,2%	6,9	
2007	7,7	1,8%	6,6	
2008	7,2	3,6%	6,3	
2009	6,7	3,5%	6,0	
2010	6,5	3,6%	5,6	
2011	6,3	3,5%	5,4	
2012	6,0	3,1%	5,2	
2013	5,7	4,4%	5,2	0,21%
2014	5,6	5,5%	5,2	0,27%
2015	5,4	6,2%	5,0	0,14%
2016	5,3	8,1%	5,0	0,07%
2017	5,4	10,5%	5,0	0,01%
2018	5,6	10,8%	5,1	0,01%
2019	5,5	6,3%	5,2	0,01%

CO_2 (g/km) consumption light commercial vehicles

Års-modell	LCV bensin 1	LCV bensin 2	LCV bensin 3	LCV diesel 1	LCV diesel 2	LCV diesel 3
2000	186	198	290	140	165	254
2001	173	193	300	157	162	235
2002	174	212	290	150	171	229
2003	175	211	285	129	173	238
2004	163	204	290	131	172	238
2005	172	205	269	135	170	240
2006	186	203	279	143	159	239
2007	186	183	309	146	153	220
2008	181	189	358	132	159	233
2009	185	190	362	123	159	236
2010	181	186	376	124	155	226
2011	173	196	253	128	146	228
2012	144	162	326	113	142	216
2013	160	169	316	112	139	209
2014	162	169	321	111	134	205
2015	154	149	306	110	131	199
2016	137	142	306	107	122	186
2017	139	140	328	104	123	181
2018	150	136	321	133	126	184
2019	156	132	318		127	183
2020		133	282		129	182

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