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108/2025

HBEFA Traffic Situations

Application guidelines

by:

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Abstract: HBEFA Traffic Situations – application guidelines

The Handbook of Emission Factors for Road Transport (HBEFA) is a standard data source for emission calculations in the six European countries it covers (i. e. Germany, France, Switzerland, Austria, Sweden, and Norway). Emission factors can be distinguished by "Traffic Situations", i. e. combinations of area type, road type, speed limit, and level of service (LOS) that influence typical driving behaviour and thus emissions. Emission factors are further influenced by road gradients and, in aggregated calculations, by the fleet composition.

The present guidelines represent the first comprehensive documentation on practical approaches to classify input activity data for emission calculations by HBEFA Traffic Situations. Their objectives are:

- to promote consistent application of the "Traffic Situations" (TS) between users and use cases;
- to make methods and experiences developed over time available to all HBEFA users;
- to save HBEFA users time.

After explaining the underlying assumptions of the Traffic Situation approach and laying out basic principles for classification, the guidelines give practical recommendations on classification rules, data sources, and sensitivity of each individual Traffic Situation parameter, their combination, as well as gradients and fleet compositions. The Appendix contains additional materials such as example lookup tables and typical parameter distributions.

Kurzbeschreibung: HBEFA-Verkehrssituationen: Leitlinien für die Anwendung

Das Handbuch für Emissionsfaktoren des Straßenverkehrs (HBEFA) ist eine Standard-Datenquelle für Emissionsberechnungen in sechs europäischen Ländern Deutschland, Frankreich, Schweiz, Österreich, Schweden und Norwegen). Die Emissionsfaktoren des HBEFA können nach «Verkehrssituationen» differenziert werden – d.h. Kombinationen von Gebietstyp, Strassentyp, Höchstgeschwindigkeit und Verkehrsdichte, welche das typische Fahrverhalten und damit die Emissionen beeinflussen. Zusätzlich stellen Längsneigung und, im Falle aggregierter Berechnungen, die Flottenzusammensetzung, relevante Einflussfaktoren dar.

Die vorliegenden Leitlinien stellen die erste umfassende Dokumentation praktischer Herangehensweisen für die Klassifikation von Verkehrsdaten nach HBEFA-Verkehrssituationen dar. Ihre Ziele sind:

- die einheitliche Anwendung der „Verkehrssituationen" (VS) zwischen Anwendenden und Anwendungsfällen zu fördern;
- die im Laufe der Zeit entwickelten Methoden und Erfahrungen allen HBEFA- Anwendenden zur Verfügung zu stellen;
- den HBEFA-Anwendenden Zeit zu sparen.

Nach der Erläuterung der Annahmen hinter dem Verkehrssituationen-Ansatz und einiger grundlegender Prinzipien enthalten die Leitlinien praktische Empfehlungen zu Klassifikationsregeln, Datenquellen und der Sensitivität der einzelnen Verkehrssituationen-Parameter, deren Kombination, sowie zu Längsneigungen und Flottenzusammensetzungen. Der Anhang enthält zusätzliche Materialien wie Zuordnungstabellen und typischen Verteilungen von Parametern.

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Abbreviation	Explanation
ADT	Average daily traffic volume (in numbers of vehicles)
ARTEMIS	EU Horizon Research Project in the 5th Framework Research Programme
CLRTAP	Convention on long-range transboundary air pollution (convention in the United Nations Economic Commission for Europe UNECE)
CNG	Compressed natural gas
CO_2	Carbon dioxide (greenhouse gas)
CO_2(rep)	Carbon dioxide, “reported” emissions – i. e. emissions from fossil fuels (excluding those from renewable fuels)
COPERT	Emission modelling software implementing the methodology described in the EEA Emission Inventory Guidebooks
EMEP	European Monitoring and Evaluation Programme, i. e. co-operative monitoring and evaluation of long-range transmission of air pollutants under the Convention on Long-range Transboundary Air Pollution (CLRTAP)
EEA	European Environmental Agency
EF	Emission factor(s)
EMPA	Swiss Federal Laboratories for Material Science and Technology (formerly "Eidgenössische Materialprüfungsanstalt")
GHG	Greenhouse gases
HBEFA	Handbook of Emission Factors for road transport
HDV	Heavy duty vehicles (heavy goods vehicles + buses + coaches)
HGV	Heavy goods vehicles (lorries, trucks)
HSDAC	Heinz Steven Data Analysis and Consulting
LCV	Light commercial vehicle
LDV	Light duty vehicles (passenger cars + light commercial vehicles)
LOS	Level of Service (class of traffic conditions between freeflow and heavy stop+go)
MC	Motorcycles
N_2O	Nitrous oxide (laughing gas)

Abbreviation	Explanation
NH_3	Ammonia
NO_x	Nitrogen oxides relevant for air pollution: nitric oxide (NO) and nitrogen dioxide (NO_2)
Pb	Lead
PC	Passenger car
PHEM	Passenger car and Heavy duty Emission Model. Vehicle emission simulation model developed at TU (Technical University) Graz
PM10-ex	Partikelmasse mit maximaler Partikelgrösse 10 µm aus Abgas (exhaust)
PM10-nx	Partikelmasse mit maximaler Partikelgrösse 10 µm aus Nicht-Abgasquellen (non-exhaust, d.h. Reifen-, Brems-, Straßenabrieb und Wiederaufwirbelung)
SO_x	Sulfur oxides, compounds of sulfur and oxygen molecules (predominantly sulfur dioxide, SO_2)
Static TS	HBEFA Traffic situation only defined by static parameters, i. e. area, road type, and speed limit. Each static TS is subdivided into 5 TS by the 5 LOS (Levels of Service)
TS	Traffic situation
TTW	"Tank-to-wheel" - term for operational (or direct) emissions and energy consumption
UNFCCC	United Nations Framework Convention on Climate Change
V/C	Volume to capacity ratio (of traffic on a road link)
WTT	"Well-to-tank" - term for emissions and energy consumption from energy provision

Summary

Background and objectives

The classification of activity data (mostly vehicle mileages) by the categories that emission factors are differentiated by is a main challenge in emission calculation. In the case of the Handbook of Emission Factors for Road Transport (HBEFA), emission factors can be differentiated by "Traffic Situations" (TS).

Over time, users have developed different practices for classifying mileages by TS. These have not been centrally documented so far. Since standardization is one of the main objectives behind HBEFA, lacking guidance on how to apply the TS may lead to different emission results calculated based on the same input data, which could undermine the standardisation objective behind HBEFA.

Against this background, the present guidelines have been developed as part of the work program for HBEFA Version 5.1. Its objectives are:

- to promote consistent application of the "Traffic Situations" (TS) between users and use cases;
- to make methods and experiences developed over time available to all HBEFA users;
- to save HBEFA users time.

HBEFA and the Traffic Situation scheme

The Handbook Emission Factors for Road Transport (HBEFA) is an IT application that provides emission factors (EF) of greenhouse gases, air pollutants, and final energy consumption factors, for all relevant vehicle categories in road transport.

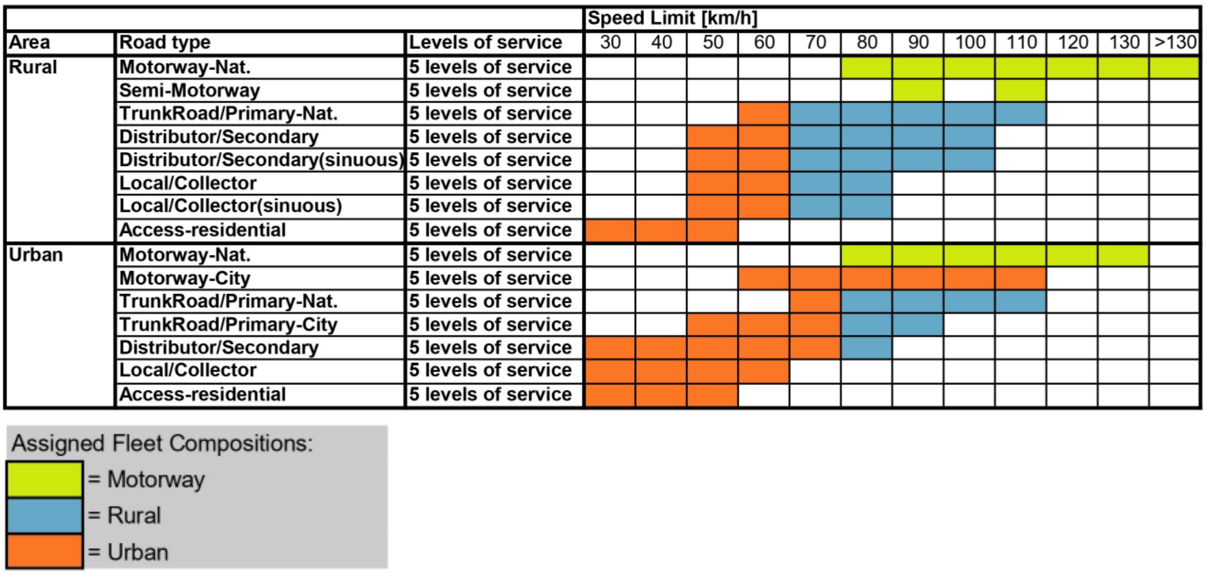
It is the product of a common effort by funding agencies and development partners in six European countries (Germany, Austria, Switzerland, France, Sweden, and Norway). The primary motivation is to enable consistent and comparable emission calculations, by providing a unified and regularly updated source of emission factors that reflect the current state of knowledge.

The categorization of emission factors by Traffic Situation in HBEFA considers the following **parameters**:

- **Area**: The environment of a given road section (larger urban agglomerations vs. "rural" areas)
- **Road type**: A hierarchical/functional categorization of road types.
- **Speed limit**: The signaled speed limit in km/h.
- **Level of Service (LOS)**: Five classes of traffic condition from free-flow to heavy stop+go.

Since not all possible combinations of these four parameters occur in the real world, the "HBEFA Traffic situation scheme" depicted in Figure 2 shows by colored backgrounds which combinations are "valid" in HBEFA and hence hot emission factors are available. Each color-shaded field represents a **"static TS"** (which may be assigned to a given road segment, considering only the first three parameters without the LOS); each "static TS" includes five LOS, which may vary in time. In total, **there are 365 valid Traffic Situations in HBEFA 4.x**.

Figure 1: The HBEFA Traffic Situation Scheme



The fields shaded in green, blue, and orange indicate valid HBEFA Traffic Situations with available emission factors. The shade colors indicate the fleet composition assigned to the respective traffic situation when emission factors are aggregated to a higher fleet aggregation level.
Source: HBEFA 4.2

The basic idea behind the Traffic Situation approach is that each combination of these parameters results in a particular driving behaviour that can be characterized by typical speed profiles. Therefore, **each Traffic Situation is assigned a typical speed profile (or driving cycle) for each vehicle category**. In some cases, identical driving profiles are assigned to different TS.

In addition to the driving behaviour captured in the TS, also **road gradients** influence energy consumption and emissions. HBEFA differentiates several gradient classes (0 % or flat road, +/-2 %, +/-4 % and +/-6 %, see Chap. 8.1). For aggregated emission factors, three **different fleet compositions** (motorway, rural, and urban) account for the fact that different vehicle types drive different shares of their total mileage on different road categories. These are indicated by the colors green, blue, and orange in Figure 2.

Basic principles of TS classification

In theory, for any real-world road section and time period, the Traffic Situation should be chosen of which the driving cycle best matches real-world driving behaviour.

In reality, a wide variety of driving behaviour may occur in a given time period on a given road section. Since it is not feasible to measure this actual driving behaviour in all its variability, we approach reality by classifying our activity data by the appropriate TS parameter in every dimension. How this can be done is explained in Chapters 3 to 7 of this document, and summarised in the following sections.

Furthermore, the following overarching principles should be observed:

- **Scale, available inputs, and required outputs of the application**: In a typical application case of the HBEFA TS methodology, traffic volumes on a road network (either traffic measurement data on a set of road sections, or outputs of a usually macroscopic traffic model) form the input for emission calculation. Accordingly, road links in a “loaded network” (i. e. a GIS road network with traffic volumes as attributes) are available as input building

blocks that traffic situations are typically assigned to. Since the driving cycles assigned to HBEFA TS include stops at intersections, as well as shorter periods of slower driving e. g. due to curves, intersections, or denser traffic, it is generally recommended not to subdivide road links based on local/temporary changes in vehicle speed, but only where static TS parameters such as area type or speed limit change.
For larger-scale applications, or if only aggregated emission totals are required as output, distributions instead of spatially explicit input data may be applied to the input traffic activities.

- **Consider emission sensitivity:** Since the TS methodology is an approximation of reality that can never be perfect, we need to minimize the largest potential errors by considering the emission impact of our classification:
    - By comparing the emission factors of the different TS in question for a particular case. Examples of such comparisons are shown throughout the present document.
    - By assessing the "weighted" sensitivity of a choice in the current application: A small difference in emission factors can have a large emission impact in total if it affects a lot of mileage, and vice versa.
- In cases of doubt, it can be helpful to **look at the driving cycles** (speed profiles) of the TS in question. E. g. the distances between deceleration/acceleration phases or stops can be compared with the roads in a given study area. From HBEFA Version 5.1 onwards, all driving cycles will be accessible in the published HBEFA application.

Area

The TS parameter "area" can take either the values "rural" (IDArea = 1) or "urban" (IDArea = 2). It describes the environment of a given road link, which influences driving behaviour via infrastructure or obstacles such as traffic lights, pedestrian crossings etc.

There are two interpretations of this parameter among HBEFA users:

- The original definition given in the HBEFA application implies that only larger settled areas are "urban". This interpretation is prevalent in central Europe. According to this definition, the total population in an "urban" area (possibly consisting of several contiguous municipalities) should exceed 10'000 inhabitants;
- Mainly in Scandinavian countries, the interpretation is prevalent that any built-up area is "urban" regardless of its total size.

When comparing driving cycles and emission factors of TS of the same road type, speed limit, and LOS, but different area, the urban variants are generally characterized by lower average speeds and more frequent stops/deceleration events. On motorways, energy consumption and pollutant emissions tend to be higher on the "rural" TS, while on distributor and collector roads, energy consumption and pollutant emissions tend to be higher in the "urban" TS. In stop+go conditions, there is no relevant difference.

The following recommendations are made regarding "area":

- For countries with explicit classification rules and data sources mentioned in Chapter 3.2, it is recommended to use these.
- For larger-scale applications, the emission impact of this parameter is low, since the situations where it makes a difference only account for a minor share of total mileage.

Therefore, it doesn't matter so much which classification rule is used – other TS parameters may be more worthwhile to invest classification effort in.

- For smaller-scale applications focusing on roads with speed limits up to 60 km/h, the emission impact of the choice of "area" is relevant. There it is recommended to select the appropriate "area" by comparing the cycles in question – mainly the distances between stops/decelerations – to the situation in the study area.

Road type

The TS parameter "road type" in HBEFA follows a functional/hierarchical definition shown in Table 4. Road types are usually classified from the input road network by using lookup tables that relate source road types to HBEFA road types. These can be

- simple, with 1:1 relationships;
- more complex, i. e. using additional criteria like speed limit or the number of lanes.

Examples of lookup tables are presented in Appendix A.1. For the "sinuous" (curvy) subtypes, please refer to Chapter 4.3.2.

Speed limit

The HBEFA TS parameter "speed limit" refers to the signaled speed limit per road link in kilometres per hour (not the actually driven average speed). Speed limits between 30 and 130 km/h in 10 km/h intervals are available, plus one category for all speed limits above 130 km/h (Table 5). Speed limits can be assigned to network links as follows:

- Ideally, the speed limit per road segment is directly available on the input road network;
- The speed limit may be transferred from another road network, e. g. OpenStreetMap;
- The freeflow speed from the traffic model ("v0") can be rounded up to the next available and plausible HBEFA speed limit.
- In data-scarce situations, simple classification rules based on road types and built-up area may be applied, such as 120 or 130 km/h for rural highways, 80 or 90 km/h for rural main roads, 50 or 60 km/h for urban main roads etc. (with thresholds depending on the country).
- Google Streetview can be used to look at the speed limit signs at sample locations to check classification rules.

Level of Service (LOS)

The HBEFA TS parameter "Level of Service" (LOS) describes traffic conditions at a given time based on traffic density or other temporally varying obstacles (such as pedestrians, construction sites, parked vehicles, etc.). Its definition is loosely based on the U.S. Highway Capacity Manual (US Transportation Research Board 2000).

Three fundamental approaches to estimate LOS can be applied:

- Capacity approach: Under this approach, the LOS is determined based on the ratio of traffic volume to link capacity, usually at hourly temporal resolution;
- Speed-based approach: Under this approach, the LOS is determined based on the actual average speed driven by vehicles on a given link, usually at hourly temporal resolution;

- Fixed shares based on empirical data or assumptions: Under this approach, LOS shares in traffic volume are directly input by the user.

There are also subtypes and combinations of these approaches – e. g. using the capacity approach to classify LOS 1-3 and using capacity-based rules and fixed shares to separate LOS 4 and 5 (as in the Swedish Index approach), or using capacity-restraint functions to estimate speed based on volume and capacity and then applying speed thresholds instead of capacity thresholds.

Recommendations regarding LOS include:

- Unless emission calculations are carried out at fine (e. g. hourly) temporal resolution anyway, distinguishing multiple LOS shares per time unit is preferable over using a static "average" LOS;
- If measured speed data by link and time slice are available, the speed-based approach is preferable over the other approaches. In practice, however, this is rarely the case;
- The capacity approach is preferable if measured speed data are not available or too expensive, and/or if scenarios with different traffic volumes need to be compared. In urban areas, the capacity approach must be used with caution, since there, link capacity may not be the limiting factor for traffic flow. Volume-to-capacity thresholds between the LOS must be critically reviewed and possibly tuned in every application case.
- The fixed shares approach can be used on the subordinate road network, for urban areas, or in application cases where spatial differences between traffic conditions do not need to be considered.
- The results of LOS classification should be validated; several methods are proposed in the main text of these guidelines.

Combinations of TS parameters

Since not all possible combinations of TS parameters form a valid TS (see Figure 2), any invalid TS resulting from the combination of single parameters have to be eliminated by changing at least one of the static parameters (area, road type, or speed limit). Strategies to do this are described in the main text of these guidelines.

Gradients

HBEFA distinguishes gradient classes in 2 % intervals up to +/- 6 %; either separate ascending and descending gradients can be used (for traffic in one direction only, or if directions of traffic are distinguished in the input activity data), or averages of both (assuming the same traffic volume in both directions). All gradient classes can be combined with any TS.

The following recommendations are made regarding gradients:

- Gradients in % are calculated as the ratio of elevation change by distance for each road segment. The resulting values are then reclassified into the HBEFA gradient classes, using 1 %, 3 %, and 5 % as thresholds between the classes.
- Use gradient or elevation information from the input road network if available;
- Otherwise, estimate gradients based on a digital elevation model.

- If road links are short and/or gradient changes within road links are insignificant, it is sufficient to use elevation information from start and end nodes of links. Otherwise,
  - Links may be subdivided into shorter links for gradient assignment (they may later be aggregated again);
  - Or, elevation information may be extracted for all vertices on each link (i. e. all coordinate points making up the link geometry), and an average gradient weighted by the distance between the vertices may be derived.
- Take into account bridges and tunnels; OpenStreetMap can be used to identify the respective road links. On bridge and tunnel links, only use the elevations of link endpoints, or set gradients to zero.

Fleet composition

The fleet composition is not a Traffic Situation parameter, but it is relevant if emission factors are aggregated.

When querying aggregated emission factors from HBEFA, the application chooses the recommended fleet composition type (motorway, rural, urban) automatically. But in some application cases, the fleet composition can/must be determined by the user.

For passenger cars and light commercial vehicles, the emission impact of the available fleet composition types is low; however, for HGV (heavy goods vehicles) and motorcycles, the emission impact is relevant, since some subtypes of these vehicle categories circulate primarily on one or two of the road categories (e. g. heavy long-range trucks drive mainly on motorways, while mopeds or e-bikes are not allowed on motorways). Generally, it is recommended to use the respective fleet composition type on each road category for fleet aggregation of emission factors, rather than using the overall average fleet composition for the country (keeping in mind that regional fleet compositions may deviate from the national one).

Zusammenfassung

Hintergrund und Ziele

Die Klassifizierung von Aktivitätsdaten (hauptsächlich Fahrzeugkilometer) entsprechend den Kategorien, nach denen Emissionsfaktoren unterschieden werden, ist eine der grössten Herausforderungen bei der Emissionsberechnung. Im Fall des Handbuchs für Emissionsfaktoren des Straßenverkehrs (HBEFA) können die Emissionsfaktoren nach „Verkehrssituationen" (VS) unterschieden werden.

Im Laufe der Zeit wurden unterschiedliche Praktiken für die Klassifizierung der Fahrleistungen nach VS entwickelt. Diese waren bisher nirgends zentral dokumentiert. Das Fehlen einer Anleitung kann u. a. das Ziel der Standardisierung – eines der Hauptmotive des HBEFA – unterlaufen.

Vor diesem Hintergrund wurde der vorliegende Leitfaden als Teil des Arbeitsprogramms für die HBEFA-Version 5.1 entwickelt. Seine Ziele sind:

- die einheitliche Anwendung der VS zwischen Anwendenden und Anwendungsfällen zu fördern;
- die im Laufe der Zeit entwickelten Methoden und Erfahrungen allen HBEFA- Anwendenden zur Verfügung zu stellen;
- den HBEFA-Anwendenden Zeit zu sparen.

HBEFA und das Verkehrssituationenschema

Das HBEFA ist eine IT-Anwendung, die Emissionsfaktoren (EF) für Treibhausgase, Luftschadstoffe und Endenergieverbrauchsfaktoren für alle relevanten Fahrzeugkategorien im Straßenverkehr bereitstellt.

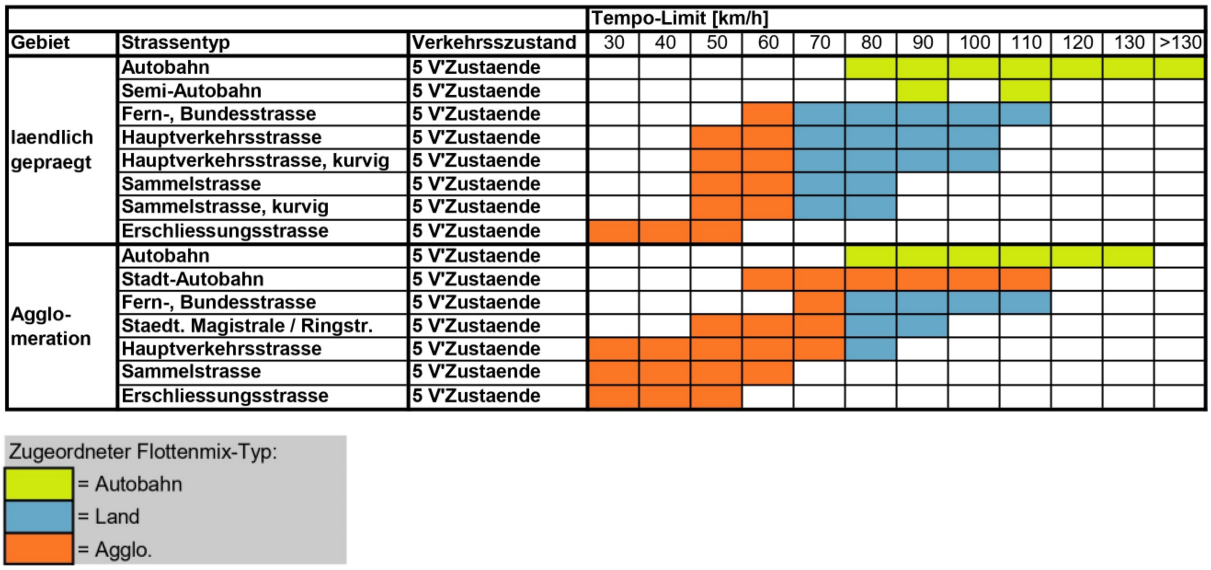
Es ist das Ergebnis einer gemeinsamen Anstrengung von Förderorganisationen und Entwicklungspartnern in sechs europäischen Ländern (Deutschland, Österreich, Schweiz, Frankreich, Schweden und Norwegen). Die Hauptmotivation besteht darin, konsistente und vergleichbare Emissionsberechnungen zu ermöglichen, indem eine einheitliche und regelmäßig aktualisierte Quelle von Emissionsfaktoren bereitgestellt wird, die dem aktuellen Wissensstand entsprechen.

Die Kategorisierung der Emissionsfaktoren nach Verkehrssituation im HBEFA berücksichtigt folgende Parameter:

- **Gebiet**: Die Umgebung eines bestimmten Straßenabschnitts (grössere städtische Ballungsräume vs. ländliche Gebiete)
- **Straßentyp**: Eine hierarchische/funktionale Kategorisierung der Straßentypen.
- **Tempolimit**: Die signalisierte Höchstgeschwindigkeit in km/h.
- **Level of Service (LOS)**: Fünf Klassen der Verkehrsdichte von freifliessendem Verkehr bis Stau.

Da nicht alle möglichen Kombinationen dieser vier Parameter in der realen Welt vorkommen, zeigt das in Abbildung 1 dargestellte „HBEFA-Verkehrssituationenschema" durch bunt eingefärbte Zellen an, welche Kombinationen in HBEFA „gültig" sind und somit Emissionsfaktoren im warmen Betriebszustand verfügbar sind. Jedes farblich hinterlegte Feld stellt eine „statische VS" dar (die einem bestimmten Straßenabschnitt zugeordnet werden kann, wobei nur die ersten drei Parameter ohne die LOS berücksichtigt werden); jede „statische VS“ umfasst fünf LOS, die zeitlich variieren können. Insgesamt gibt es **365 gültige Verkehrssituationen in HBEFA 4.x**.

Abbildung 1: Das HBEFA Verkehrssituationenschema



Die grün, blau und orange schattierten Felder zeigen gültige HBEFA-Verkehrssituationen mit verfügbaren Emissionsfaktoren an. Die Schattierungen zeigen die Flottenzusammensetzung an, die der jeweiligen Verkehrssituation zugeordnet ist, wenn die Emissionsfaktoren auf eine höhere Flottenaggregationsstufe aggregiert werden.

Quelle: HBEFA 4.2

Der Grundgedanke des Verkehrssituationsansatzes ist, dass jede Kombination dieser Parameter zu einem bestimmten Fahrverhalten führt, das durch typische Geschwindigkeitsprofile charakterisiert werden kann. Daher wird **jeder Verkehrssituation ein typisches Geschwindigkeitsprofil (oder ein Fahrzyklus) für jede Fahrzeugklasse zugeordnet.** In einigen Fällen werden identische Fahrprofile verschiedenen VS zugeordnet.

Neben dem Fahrverhalten, das in den VS erfasst wird, beeinflusst auch die Längsneigung den Energieverbrauch und die Emissionen. HBEFA unterscheidet mehrere **Längsneigungsklassen** (0 % oder ebene Straße, +/-2 %, +/-4 % und +/-6 %, s. Kap. 8.1). Bei den aggregierten Emissionsfaktoren tragen drei verschiedene **Flottenzusammensetzungen** (Autobahn, ländlich und städtisch) der Tatsache Rechnung, dass verschiedene Fahrzeugtypen unterschiedliche Anteile ihrer Gesamtfahrleistung auf verschiedenen Straßenkategorien zurücklegen. Diese sind in Abbildung 1 durch die Farben Grün, Blau und Orange gekennzeichnet.

Grundprinzipien der VS-Klassifizierung

Theoretisch sollte für einen beliebigen realen Straßenabschnitt und Zeitraum die Verkehrssituation gewählt werden, deren im HBEFA hinterlegter Fahrzyklus dem realen Fahrverhalten am besten entspricht.

In der Realität kann in einem bestimmten Zeitraum auf einem bestimmten Straßenabschnitt unterschiedliches Fahrverhalten auftreten. Da es nicht möglich ist, dieses tatsächliche Fahrverhalten in seiner ganzen Variabilität zu messen, nähern wir uns der Realität an, indem wir unsere Aktivitätsdaten durch den entsprechenden VS-Parameter in jeder Dimension klassifizieren. Wie dies umgesetzt werden kann, erläutert dieses Dokument in den Kapiteln 3 bis 7, und ist in den folgenden Abschnitten zusammengefasst.

Zusätzlich sollten die folgenden Grundprinzipien beachtet werden:

- **Massstab, verfügbare Eingangsdaten und gewünschte Resultate der Anwendung**: Im typischen Anwendungsfall der HBEFA VS-Methodik bilden Verkehrsmengendaten auf einem Strassennetz – seien dies Zählstellendaten oder die Ergebnisse eines (meist makroskopischen) Verkehrsmodells – den Input für die Emissionsberechnung. Entsprechend stellen die Straßenabschnitte im Netz die typischen Bausteine dar, denen Verkehrssituationen zugeordnet werden. Da die Fahrzyklen, die den HBEFA VS zugeordnet werden, sowohl Stopps an Kreuzungen als auch kürzere Zeiträume mit langsamerem Fahren, z. B. aufgrund von Kurven, Kreuzungen oder dichterem Verkehr, beinhalten, empfehlen wir, Straßenabschnitte nicht aufgrund lokaler oder temporärer Änderungen der Fahrzeuggeschwindigkeit zu unterteilen, sondern nur dann, wenn sich statische VS-Parameter wie Gebietstyp oder Geschwindigkeitsbegrenzung ändern.
  Bei grossmasstäblichen Anwendungen, oder wenn nur aggregierte Emissionstotale resultieren müssen, können auch Verteilungsdaten anstelle räumlich expliziter Eingangsdaten verwendet werden.

- **Berücksichtigung der Emissionssensitivität**: Da die VS-Methode eine Annäherung an die Realität darstellt, die niemals perfekt sein kann, müssen wir die grössten potenziellen Fehler minimieren, indem wir die Emissionsauswirkungen unserer Klassifizierung berücksichtigen:

  - Durch den Vergleich der Emissionsfaktoren der verschiedenen in Frage kommenden VS für einen bestimmten Fall. Beispiele für solche Vergleiche sind in diesem Dokument zu finden.

  - Durch die Bewertung der „gewichteten" Sensitivität in der aktuellen Anwendung: Ein kleiner Unterschied bei den Emissionsfaktoren kann eine grosse Auswirkung auf die Gesamtemissionen haben, wenn er sich auf eine grosse Anzahl von Kilometern auswirkt, und andersherum.

- In Zweifelsfällen kann es hilfreich sein, die **Fahrzyklen** (Geschwindigkeitsprofile) der betreffenden VS anzusehen. So können z. B. die Distanzen zwischen Abbrems-/Beschleunigungsvorgängen oder Stopps mit den Straßen in einem bestimmten Untersuchungsgebiet verglichen werden. Ab der HBEFA-Version 5.1 werden alle Fahrzyklen in der veröffentlichten HBEFA-Anwendung zugänglich sein.

Gebiet

Der VS-Parameter „Gebiet" kann entweder die Werte „ländlich" (IDArea = 1) oder „städtisch" (IDArea = 2) annehmen. Er beschreibt die Umgebung eines bestimmten Straßenabschnittes, die das Fahrverhalten durch Infrastruktur oder Hindernisse wie Ampeln, Fußgängerstreifen, usw. beeinflusst.

Unter den HBEFA-Nutzern gibt es zwei Interpretationen dieses Parameters:

- Die ursprüngliche Definition in der HBEFA-Anwendung impliziert, dass nur grössere besiedelte Gebiete als „städtisch" gelten. Diese Interpretation ist in Mitteleuropa vorherrschend. Nach dieser Definition sollte die Gesamtbevölkerung in einem zusammenhängenden „städtischen" Gebiet (potenziell aus mehreren aneinandergrenzenden Gemeinden) mindestens 10'000 Einwohner betragen;

- Vor allem in den skandinavischen Ländern ist die Auslegung vorherrschend, dass jedes bebaute Gebiet unabhängig von seiner Gesamtgrösse „städtisch" ist.

Beim Vergleich der Fahrzyklen und Emissionsfaktoren von VS desselben Straßentyps, derselben Geschwindigkeitsbegrenzung und desselben LOS, aber mit unterschiedlichem Gebiet, sind die städtischen Varianten im Allgemeinen durch niedrigere Durchschnittsgeschwindigkeiten und häufigere Stopps oder Verzögerungen gekennzeichnet. Auf Autobahnen sind Energieverbrauch und Schadstoffemissionen in der „ländlichen“ VS tendenziell höher, während auf Verteiler- und Sammelstraßen Energieverbrauch und Schadstoffemissionen in der „städtischen“ VS tendenziell höher sind. Im Stop+Go-Verkehr gibt es keinen relevanten Unterschied.

In Bezug auf das „Gebiet“ gelten die folgenden Empfehlungen:

- Für Länder mit expliziten Klassifizierungsregeln und Datenquellen, die in Kapitel 3.2 erwähnt werden, wird empfohlen, diese zu verwenden.
- Bei grossräumigen Anwendungen ist die Emissionswirkung dieses Parameters gering, da die Situationen, in denen er einen Unterschied macht, nur einen geringen Anteil an der Gesamtfahrleistung ausmachen. Daher ist es nicht so relevant, welche Klassifizierung verwendet wird – es ist lohnender, Zeit in die Klassierung anderer VS-Parameter zu investieren.
- Bei kleinräumigen Anwendungen, die sich auf Straßen mit Geschwindigkeitsbegrenzungen bis zu 60 km/h konzentrieren, sind die Emissionsauswirkungen der Wahl des „Gebietes“ relevant. Hier wird empfohlen, das geeignete „Gebiet“ auszuwählen, indem die fraglichen Zyklen - vor allem die Abstände zwischen Stopps oder Brems- und Beschleunigungsvorgängen - mit der Situation im Untersuchungsgebiet verglichen werden.

Straßentyp

Der VS-Parameter „Straßentyp“ in HBEFA folgt einer funktionalen/hierarchischen Definition, die in Tabelle 4 dargestellt ist.

Die Klassifizierung der Straßentypen erfolgt in der Regel mit Hilfe von Nachschlagetabellen, die die Input-Straßentypen den HBEFA-Straßentypen zuordnen. Diese sind entweder

- einfach, mit 1:1-Beziehungen;
- oder komplexer, d.h. mit zusätzlichen Kriterien wie Geschwindigkeitsbegrenzung oder Anzahl der Fahrspuren.

Beispiele für Nachschlagetabellen sind in Anhang A.1 zu finden. Für die „kurvenreichen“ Untertypen wird auf Kapitel 4.3.2 verwiesen. Im deutschen Kontext gibt es auch eine Zuordnung in Tabelle 10 der VDI-Richtlinie 3782 Blatt 7 (VDI 2020).

Geschwindigkeitsbegrenzung

Der HBEFA VS-Parameter „Geschwindigkeitsbegrenzung“ bezieht sich auf die signalisierte Geschwindigkeitsbegrenzung pro Straßenabschnitt in Kilometern pro Stunde (nicht auf die tatsächlich gefahrene Durchschnittsgeschwindigkeit). Es stehen Geschwindigkeitsbegrenzungen zwischen 30 und 130 km/h in 10-km/h-Schritten zur Verfügung, sowie eine Kategorie für alle Geschwindigkeitsbegrenzungen über 130 km/h (Tabelle 5). Geschwindigkeitsbegrenzungen können den Straßenabschnitten wie folgt zugewiesen werden:

- Idealerweise ist die Geschwindigkeitsbegrenzung pro Straßenabschnitt im Input-Straßennetz verfügbar;
- Die Geschwindigkeitsbegrenzung kann aus einem anderen Straßennetz, z. B. OpenStreetMap, übernommen werden;

- Die Freeflow-Geschwindigkeit aus dem Verkehrsmodell („v0") kann auf die nächste verfügbare und plausible HBEFA-Geschwindigkeitsbeschränkung aufgerundet werden.
- Wenn Daten zu Geschwindigkeitsbegrenzungen fehlen, können einfache Klassifizierungsregeln auf der Grundlage von Straßentypen und bebautem Gebiet angewandt werden, z. B. 120 km/h für ländliche Autobahnen, 80 km/h für ländliche Hauptstraßen, 50 km/h für städtische Hauptstraßen usw (je nach Land).
- Mit Online-Diensten wie Google Streetview oder Mapillary[1] können Geschwindigkeitsbegrenzungsschilder an Beispielstandorten betrachtet werden, um die Klassifizierungsregeln zu überprüfen.

Level of Service (LOS)

Der HBEFA VS-Parameter „Level of Service" (LOS) beschreibt die Verkehrsbedingungen zu einem bestimmten Zeitpunkt auf Basis der Verkehrsdichte oder anderer zeitlich variierender Hindernisse (wie Fussgänger, Baustellen, parkierte Fahrzeuge etc.). Die Definition der LOS ist frei angelehnt an diejenige des U.S. Highway Capacity Manual (US Transportation Research Board 2000).

Es können drei grundlegende Ansätze zur Schätzung des LOS angewandt werden:

- Kapazitätsansatz: Bei diesem Ansatz wird der LOS auf der Grundlage des Verhältnisses von Verkehrsaufkommen zu Streckenkapazität bestimmt, in der Regel in stündlicher Auflösung;
- Geschwindigkeitsbasierter Ansatz: Bei diesem Ansatz wird der LOS auf der Grundlage der tatsächlichen Durchschnittsgeschwindigkeit der Fahrzeuge auf einem bestimmten Straßenabschnitt ermittelt, in der Regel in stündlicher Auflösung;
- Feste Anteile basierend auf empirischen Daten oder Annahmen: Bei diesem Ansatz werden die LOS-Anteile am Verkehrsaufkommen direkt vom Benutzer eingegeben.

Es gibt auch Unterarten und Kombinationen dieser Ansätze - z. B. die Verwendung des Kapazitätsansatzes zur Klassifizierung von LOS 1-3 und die Verwendung fixer Anteile zur Differenzierung von LOS 4-5 (wie beim schwedischen Index-Ansatz) oder die Verwendung von Capacity-Restraint-Funktionen zur Schätzung der Geschwindigkeit auf der Grundlage von Volumen und Kapazität und die anschliessende Anwendung von Geschwindigkeits- anstelle von Kapazitätsschwellenwerten.

Zu den Empfehlungen bezüglich LOS gehören:

- Sofern die Emissionsberechnungen nicht sowieso in feiner (z. B. stündlicher) zeitlicher Auflösung durchgeführt werden, ist die Verwendung von Verkehrsanteilen pro LOS und Zeiteinheit der Verwendung eines statischen „durchschnittlichen" LOS auf die gesamte Verkehrsmenge vorzuziehen;
- Wenn gemessene Geschwindigkeitsdaten pro Straßen- und Zeitabschnitt verfügbar sind (was in der Praxis selten der Fall ist), ist der geschwindigkeitsbasierte Ansatz den anderen Ansätzen vorzuziehen.
- Der kapazitätsbasierte Ansatz ist vorzuziehen, wenn gemessene Geschwindigkeitsdaten nicht verfügbar oder zu teuer sind und/oder wenn Szenarien mit unterschiedlichem Verkehrsaufkommen verglichen werden müssen. In städtischen Gebieten ist der

[1] https://www.mapillary.com

Kapazitätsansatz mit Vorsicht zu verwenden, da dort die Streckenkapazität möglicherweise nicht der begrenzende Faktor für den Verkehrsfluss ist.

- Fixe/konstante LOS-Anteile können auf dem untergeordneten Straßennetz, in städtischen Gebieten oder in Anwendungsfällen, in denen räumliche Unterschiede zwischen den Verkehrsbedingungen nicht berücksichtigt werden müssen, verwendet werden.
- Die Ergebnisse der LOS-Klassifizierung sollten validiert werden; im Haupttext dieser Leitlinien werden dazu mehrere Methoden vorgeschlagen.

Kombinationen von VS-Parametern

Da nicht alle möglichen Kombinationen von VS-Parametern eine gültige VS bilden (siehe Abbildung 1), muss jede ungültige VS, die sich aus der Kombination einzelner Parameter ergibt, durch Änderung mindestens eines der statischen Parameter (Gebiet, Straßentyp oder Geschwindigkeitsbegrenzung) eliminiert werden. Entsprechende Strategien sind im Haupttext dieser Leitlinien beschrieben.

Längsneigung

HBEFA unterscheidet Längsneigungsklassen in 2 %-Schritten bis zu +/- 6 %; es können entweder getrennte Steigungs- und Gefälleklassen verwendet werden (für den Verkehr in nur einer Richtung oder wenn die Verkehrsrichtungen in den Input-Aktivitätsdaten unterschieden werden) oder Durchschnittswerte aus beiden (unter der Annahme, dass das Verkehrsaufkommen in beiden Richtungen gleich ist). Alle Längsneigungsklassen können mit beliebigen VS kombiniert werden.

Für die Längsneigungsklassen gelten folgende Empfehlungen:

- Längsneigungen in % werden als das Verhältnis von Höhenänderung zu Entfernung für jeden Straßenabschnitt berechnet. Die sich daraus ergebenden Werte werden in die HBEFA-Gefälleklassen eingeteilt, wobei 1 %, 3 % und 5 % als Schwellenwerte zwischen den Klassen verwendet werden.
- Falls verfügbar, können Längsneigungs- oder Höheninformationen aus dem Input-Straßennetz verwendet werden;
- Andernfalls kann die Längsneigung mit Hilfe eines digitalen Höhenmodells geschätzt werden.
- Wenn die Straßenabschnitten kurz sind und/oder die Längsneigungsänderungen innerhalb der Straßenabschnitten unbedeutend sind, reicht es aus, die Höheninformationen der Anfangs- und Endknoten der Verbindungen zu verwenden. Andernfalls können
  - Straßenabschnitte für die Zuweisung der Längsneigung in kürzere Abschnitte unterteilt werden (die später wieder zusammengeführt werden können);
  - Oder es können Höheninformationen für alle Knotenpunkte jeder Verbindung extrahiert werden (d. h. alle Koordinatenpunkte, aus denen sich die Verbindungsgeometrie zusammensetzt), und es kann eine gewichtete durchschnittliche Steigung hergeleitet werden, die mit dem Abstand zwischen den Knotenpunkten gewichtet ist.

Berücksichtigung von Brücken und Tunneln; Die entsprechenden Straßenabschnitte können mit OpenStreetMap identifiziert werden. Bei Brücken- und Tunnelabschnitten sollten nur die Höhen der Endpunkte verwendet oder die Längsneigung auf Null gesetzt werden.

Flottenzusammensetzung

Die Flottenzusammensetzung ist Verkehrssituationen-Parameter, aber sie ist relevant, wenn Emissionsfaktoren aggregiert werden.

Bei der Abfrage von aggregierten Emissionsfaktoren aus HBEFA wird automatisch der empfohlenen Flottenzusammensetzungstyp (Autobahn, ländlich oder städtisch) verwendet. In bestimmten Schnittstellen (z. B. PTV Visum, Emissionsmodell in der HBEFA-Expertenversion) kann/muss die Flottenzusammensetzung jedoch vom Benutzer bestimmt werden.

Bei PKWs und leichten Nutzfahrzeugen haben die verfügbaren Flottenzusammensetzungsarten geringe Auswirkungen auf die Emissionen; bei LKWs und Motorrädern ist die Emissionswirkung jedoch relevant, da einige Untertypen dieser Fahrzeugkategorien hauptsächlich auf einer oder zwei der Straßenkategorien verkehren (z. B. fahren schwere Langstrecken-LKWs hauptsächlich auf Autobahnen, während Mopeds oder E-Bikes nicht auf Autobahnen zugelassen sind). Generell wird empfohlen, für die Aggregation der Emissionsfaktoren die jeweilige Straßenkategorie-spezifische Flottenzusammensetzung und nicht die «durchschnittliche» Flottenzusammensetzung des jeweiligen Landes zu verwenden (wobei man mitbedenken sollte, dass regionale Verkehrszusammensetzungen von der nationalen abweichen können).

1 Introduction

1.1 Background of this document

1.1.1 Rationale and objectives

A principal challenge in any emission calculation is how to classify activity data (mostly mileages) by the categories that the emission factors are differentiated by. Users of the Handbook of Emission Factors for Road Transport (HBEFA) who calculate emission with spatial differentiation (i. e. on road networks) face this question in particular regarding the "Traffic Situations" (TS). These represent the most detailed spatio-temporal differentiation of activity in HBEFA.

Over time, users have developed different practices for classifying mileages by TS, resulting in a wealth of methods and experiences. But as long as these methods and experiences are not collected and documented anywhere, other users can hardly benefit from them.

In addition, standardization is one of the main objectives behind HBEFA. Lacking guidance on how to apply methodology such as the TS may lead to different emission results calculated based on the same input data, which would undermine this standardisation objective.

Against this background, the present document has been developed as part of the work program for HBEFA Version 5.1. Its objectives are:

- to promote consistent application of the "Traffic Situations" (TS) between users and use cases;
- to make methods and experiences developed over time available to all HBEFA users;
- to save HBEFA users time.

1.1.2 Approach to guideline development

A subgroup of the HBEFA workgroup[2] consisting of HBEFA developers and contributors from INFRAS, ifeu, and WSP Sweden, developed the present guidelines document using the following approach:

1. **Collection of methods and experiences**: A selection of experienced HBEFA users was interviewed on their methods and experiences in classifying activity data by HBEFA TS. The contributors interviewed are listed in Table 1. The interviewees were also asked to contribute materials, such as example analyses or reports that could be cited in the present guidelines. The authors themselves also contributed their own methods, experiences, and materials.
2. **Evaluation and development of recommendations**: The authors of this document viewed and discussed the methods, experiences and materials collected in the first step and developed recommendable approaches. This also included carrying out sensitivity analyses on selected classification steps. The result of this step was a first draft of the present guidelines.

[2] The HBEFA workgroup includes representatives from all government agencies that fund HBEFA and all organizations that contribute to its development. More information can be found at:

- https://www.hbefa.net/en/contact#funding-agencies
- https://www.hbefa.net/en/contact#development-partners

3. **Guideline elaboration**: This step involved the elaboration of the present Guidelines. The first draft was reviewed by the rest of the HBEFA workgroup (besides the authors) and the interviewees from the first step. Their feedback was integrated to form the final guidelines.

Table 1: HBEFA users interviewed for the present guidelines

Institute/organization	Person(s)
PTV	Anett Ehlert
IVU Umwelt	Anna Mahlau, Volker Diegmann
NILU	Henrik Grythe
VTI	Johan Olstam
Université Gustave Eiffel	Michel André, Boris Vansevenant, Yao Liu
Uni Stuttgart	Schmaus, Matthias
Lohmeyer/TU Dresden	Wolfram Schmidt
AVISO	Christiane Schneider
SMHI (Swedish met. institute)	Johan Arvelius
HSDAC	Heinz Steven

1.1.3 Overview of contents

After a short introduction to the HBEFA itself and the TS scheme in the following two subchapters, the present document lays out some basic principles that should be observed when applying HBEFA TS in Chapter 2. It then covers the four TS parameters "area", "road type", "speed limit", and "level of service" in Chapters 3 to 6, describing definitions, classification methods and their practical applications for each parameter. This is followed by hints on filtering out invalid combinations of parameters in Chapter 7. Chapter 8 and 9 are dedicated to road gradients and fleet compositions. Additional materials such as lookup tables or example classifications can be found in the Annex of this document.

As a new feature related to this document, the driving profiles assigned to each TS will be published in the HBEFA application itself from Version 5.1 onwards. This way, users can better determine the best-fitting TS for each case in case of doubt.

1.2 The Handbook of Emission Factors for Road Transport (HBEFA)

1.2.1 Contents

The Handbook Emission Factors for Road Transport (HBEFA) is an IT application that provides emission factors (EF) of

- greenhouse gases (GHG, such as CO_2),
- regulated (such as NO_x or PM) and non-regulated (such as NH_3 or N_2O) air pollutants
- as well as final energy consumption factors

for all relevant vehicle categories in road transport – i. e. passenger cars (PC), light commercial vehicles (LCV), heavy goods vehicles (HGV), urban buses, coaches and motorcycles.

These can be queried and exported from the application for use in emission calculations for various purposes, e. g.:

- emission inventories/national reporting to international conventions (climate conventions such as the United Nations Framework Convention on Climate Change, UNFCCC, or the convention on long-range transboundary air pollution, CLRTAP)
- emission inventories at city or province/state level
- calculation of pollutant emissions as input data for air quality modelling (from street to national level)
- ecological impact assessments, e. g. on the impact of different fleet management or traffic-related measures (e. g. related to EU air quality directives[3], or to national or local policies),
- scenario assessments, e. g. energy perspectives or decarbonization scenarios
- use in other applications (such as EcoTransIT[4], COPERT[5], IMMIS[6], PTV Visum[7], etc.)

Example applications of HBEFA can be explored under https://www.hbefa.net/en/use-cases.

HBEFA focuses on operational emissions, i. e. direct emissions from the operation of vehicles (also known as TTW, or tank-to-wheel, emissions), but also includes CO_2 equivalent emission factors from the production of energy carriers (i. e. WTT, or well-to-tank, emissions). Emission factors are available for the following emission categories, each expressed in different activity units:

- hot emissions – expressed in g/km, MJ/km (for energy consumption) or #/km (for particle number) as a primary unit. The hot "base" emission and consumption factors (i. e. valid for new vehicles at 20°C ambient temperature) for HBEFA are produced by the vehicle simulation model PHEM (Hausberger et al. 2018), based on measurements on test benches or on the road, carried out by a network of European research laboratories. These base emission factors are corrected for influences of catalyst ageing, ambient temperature, energy efficiency developments, and fuel quality based on country-specific fleet, energy, and ambient condition data (see below).
  Overall, hot emissions account for the largest share of total emissions – typically more than 95 % (except for HC emissions).
- cold start excess emissions – expressed in g/start, MJ/start, or #/start. The cold start excess emission factors up to HBEFA 4.x are based on a model developed at EMPA (Favez et al. 2008, 2009); for HBEFA 5.1, they will be produced by the PHEM model.
- evaporation emissions of hydrocarbons (HC), subdivided into soak emissions (evaporation after engine stop, when engine is still warm, expressed in g/stop), diurnal emissions (evaporation due to daily temperature fluctuations, expressed in g/day), and running losses (evaporation during driving, expressed in g/km). The evaporation emission factors in

[3] https://environment.ec.europa.eu/topics/air/air-quality_en#implementation

[4] https://www.ecotransit.org/

[5] https://copert.emisia.com/

[6] https://www.ivu-umwelt.de/front_content.php?idcat=30

[7] https://www.ptvgroup.com/en/products/ptv-visum

HBEFA are calculated based on the Tier 3 approach in the EMEP/EEA emissions inventory guidebook for gasoline evaporation (Mellios et al. 2019).

Emission factors can be queried at various aggregation levels from HBEFA, making it a suitable source for emission calculations from city to national scale. The finest level of detail differentiates:

- regarding the fleet: “subsegments”, i. e. vehicle types defined by vehicle category (e. g. PC, LCV, HGV), drivetrain technology (e. g. petrol, diesel, electricity), emission standard (e. g. Euro 5, Euro 6d) and size class. The current version HBEFA 4.2 includes 833 subsegments.
- in space/time: “Traffic situations” (TS), which this document is about. The TS scheme is described in more detail in Chapter 1.2.3.

To aggregate these emission factors to higher levels (e. g. average emission factors of Diesel PC in Germany in the year 2020), HBEFA requires country-specific activity data for all required reference years and countries. Such activity data are currently available for the years 1990 – 2050 for the following European countries:

- Germany
- Austria
- Switzerland
- France
- Sweden
- Norway

This means that aggregated outputs can be obtained from HBEFA for these six countries currently, while outputs at the most detailed level are also valid for other countries – at least those with emission standards comparable to the Euro standards.

The activity data include the following parameters:

- Fleet data: Relative stock and mileage shares of each subsegment in the fleet, cumulative mileages, efficiency correction factors for each year in the time-series
- Traffic data: Shares of traffic situations for different “aggregate traffic situations” (e. g. overall average, motorway, rural, urban)
- Ambient condition data: Climate data such as temperature and humidity, mobility parameters such as traffic volume, trip length, parking time distributions,
- Fuel/energy attributes such as heating values, densities, CO_2, SO_x, Pb contents

These data allow accounting for the influences such as ageing, ambient temperature, fuel quality or biofuel blends.

Further information on HBEFA contents and methodology can be found here: https://www.hbefa.net/en/methodology.

1.2.2 Organisation of development

HBEFA is the product of a common effort by funding agencies and development partners in several countries. The first version, published in 1995, included data from Germany and Switzerland. The primary motivation was, and has remained, the idea of standardization – i. e. enabling consistent and comparable emission calculations by different bodies by providing a unified source of emission factors that are regularly updated and thus kept at the current state of knowledge.

Since 1995, the application has been regularly updated, and more countries joined the workgroup. It currently includes the six countries listed above in Chapter 1.2.1[8]. The national environment or traffic agencies of these countries fund the development of HBEFA and also most of the measurement programs the application relies on[9]. A group of development partners, led by INFRAS in Switzerland, develops the methodology and implements it in the HBEFA software[10].

1.2.3 The HBEFA Traffic Situation scheme

The categorization of vehicle mileage and associated emission factors by Traffic Situation in HBEFA is based on a scheme originally developed within the EU ARTEMIS research project (André et al. 2006) that considers the following **parameters**, or dimensions:

- **Area**: The environment of a given road section, which influences typical driving behaviour via infrastructure or obstacles such as traffic lights, pedestrian crossings etc. It differentiates rural and urban environments.
- **Road type**: A hierarchical/functional categorization of road types.
- **Speed limit**: The signaled speed limit in km/h.
- **Level of Service (LOS)**: Five classes of traffic conditions from free-flow to heavy stop+go.

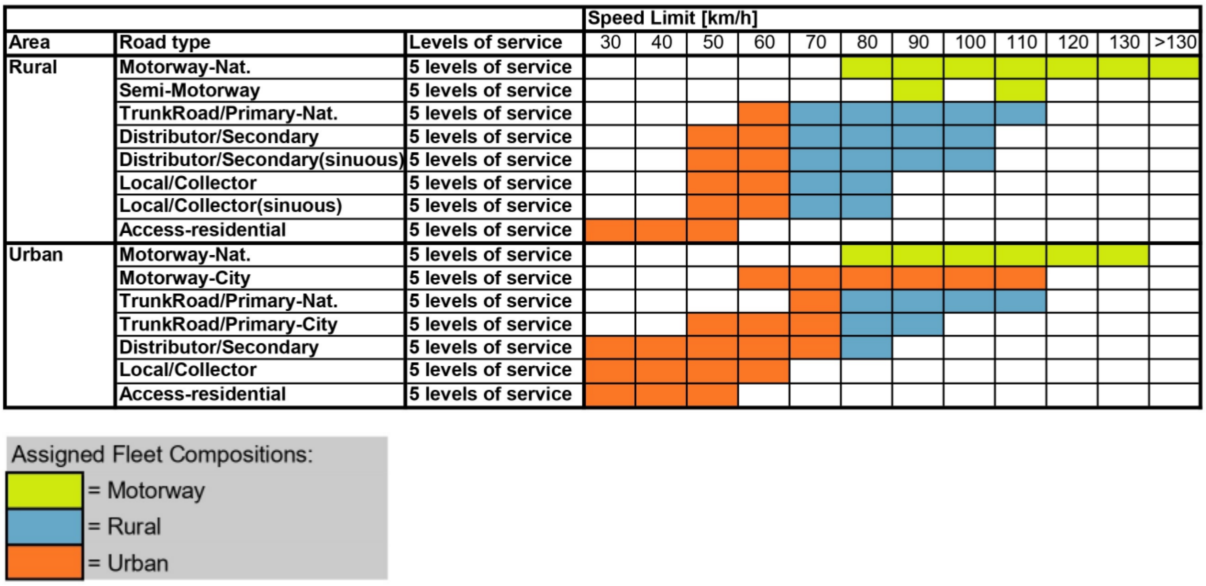
Not all possible combinations of these four parameters occur in the real-world. HBEFA contains emission factors only for those combinations that account for a relevant share of traffic. In some countries, defined parameter combinations do not occur at all or only extremely rarely. Figure 2 shows by the green/blue/orange-colored backgrounds which combinations are "valid" in HBEFA and for which hot emission factors are available. The fields with white background are "invalid" TS for which no emission factors are available, as these situations, if they occur at all, do not account for a relevant share of traffic. Each color-shaded field represents what we call a **"static TS"** (which may be assigned to a given road segment, considering only the first three parameters without the LOS); each "static TS" includes five TS due to the five LOS (which may occur on the same road segment at different times). In total (i. e. counting the LOS), **there are 365 valid Traffic Situations in HBEFA 4.x**.

[8] For an overview of HBEFA Versions, see https://www.hbefa.net/en/software#version-documentation

[9] The funding agencies and national contacts are listed in https://www.hbefa.net/en/contact#funding-agencies

[10] The HBEFA development partners are presented in https://www.hbefa.net/en/methodology#development-partners

Figure 2: The HBEFA Traffic Situation Scheme



The fields shaded in green, blue, and orange indicate valid HBEFA Traffic Situations with available emission factors. The shade colors indicate the fleet composition assigned to the respective traffic situation when emission factors are aggregated to a higher fleet aggregation level.
Source: HBEFA 4.2

The basic idea behind the Traffic Situation approach is that each combination of these parameters results in a particular driving behaviour that can be characterized by typical speed profiles. Therefore, **each Traffic Situation is assigned a typical speed profile (or driving cycle) for each vehicle category**. The speed profiles for the HBEFA TS scheme were adapted by HSDAC from those developed in the ARTEMIS research project (André et al. 2006; Boulter et al. 2007) and have been revised for HBEFA 4.1 (Ericsson et al. 2019). The **hot base emission factors** in HBEFA are produced using the detail model PHEM developed at the TU Graz (Hausberger et al. 2018) based on emission measurements and these driving profiles – they therefore **correspond to the respective speed profiles**.

It should be noted that in some cases, identical driving profiles are assigned to different TS; e. g. the speed profiles for the Level of Service (LOS) 5 ("heavy stop+go") are identical for different road types and speed limits, since in such close-to-gridlock situations the road type and speed limit do not influence the driving behaviour anymore. For TS with identical speed profiles, also the hot base emission factors are identical.

In addition to the driving behaviour captured in the TS, also **road gradients** influence energy consumption and emissions. HBEFA accounts for several gradient classes (0 % or flat road, 2 %, 4 % and 6 % and above – whereby the user can choose between ascending, descending gradients or average, implying equal traffic volumes in both directions). All hot emission factors are available for all gradient classes.

Finally, **at aggregated fleet levels** (e. g. when querying emission factors – abbreviated as "EF" in the following – for the average of a given size class, technology, vehicle category, emission standard for a given country and year), the fleet composition matters. In HBEFA, three **different fleet compositions for each road category** (motorway, rural, and urban) account for the fact that different vehicle types spend different shares of their mileage in different traffic situations: E. g. diesel passenger cars are typically used by people who drive more, which results in a higher share of mileage on motorways than for petrol cars. Accordingly, the mileage share of diesel cars on motorways is higher than for petrol cars, while in urban environments it is the other way around. The different colors of the fields (green, blue, and orange) in Figure 2 indicate the fleet composition used when aggregating the respective emission factors to a higher fleet aggregation level.

2 Basic principles

2.1 Cycles should represent real-world driving behaviour

The hot emission factors in HBEFA are based on the driving cycles behind every TS (compare Chapter 1.2.3). When applying HBEFA emission factors, we implicitly assume that the corresponding HBEFA driving cycles are representative for the actual driving behaviour of the corresponding vehicle category, on the corresponding road section(s) and time(s). Therefore, the fundamental (but in most cases, rather theoretical) guiding principle in TS assignment should be that **for any real-world road section and time period, the Traffic Situation should be chosen of which the driving cycle best matches real-world driving behaviour**.

2.2 Classification by TS parameters as feasible approach

In reality, a wide variety of driving behaviour may occur in a given time period on a given road section – every vehicle exhibits its individual driving profile with the given driver and the situation at this particular time. But it is not feasible to measure this actual driving behaviour in all its variability and to calculate individual vehicle and trip emissions.

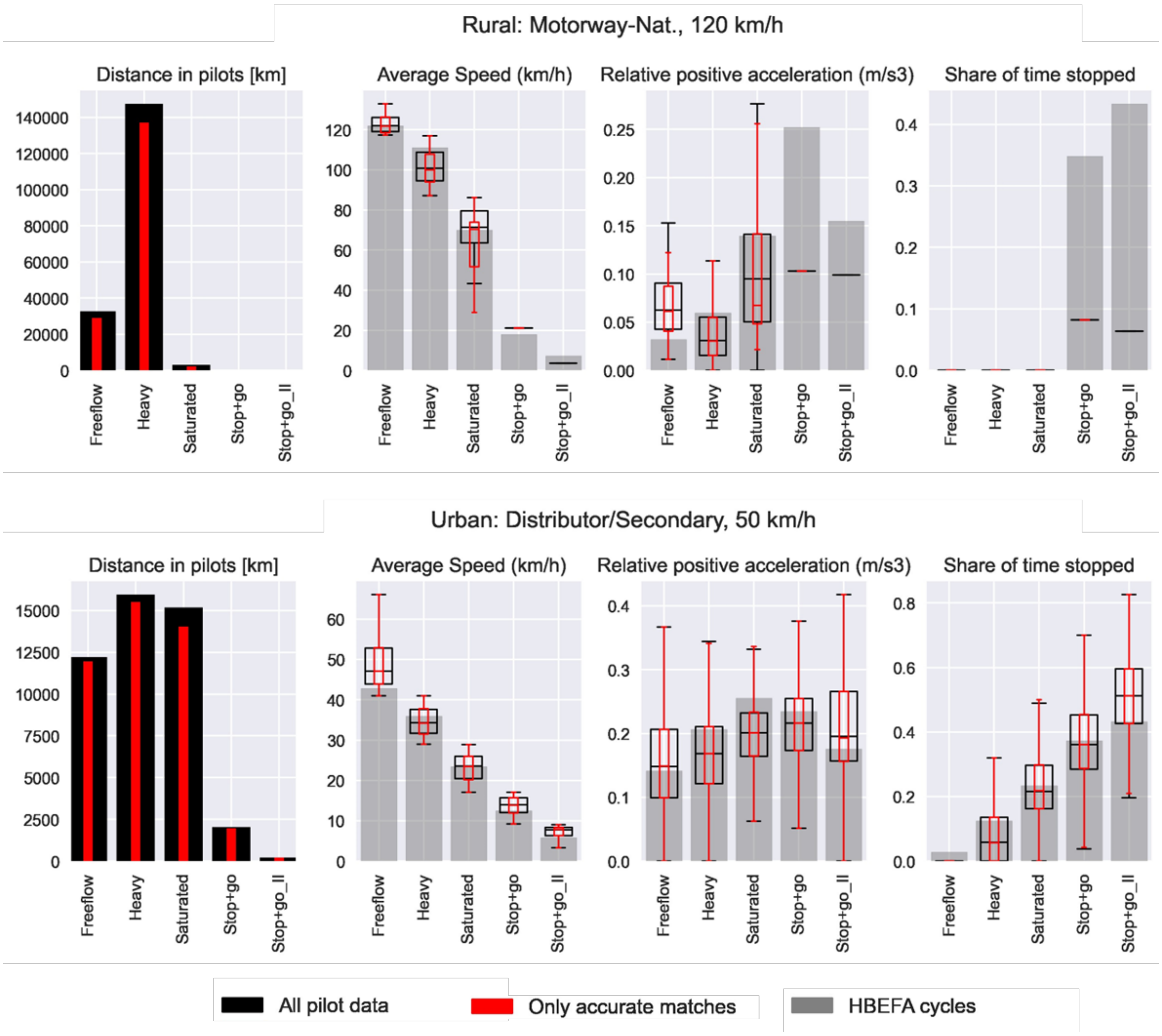
Therefore, as a feasible simplification, we **"approach" reality by selecting the appropriate TS parameter in every dimension. How this can be done is explained in the following chapters (Chapters 3 to 7) of this document**.

Figure 3 shows how key parameters of driving behaviour – average speed, relative positive acceleration, and percentage of time stopped – vary in reality with individual (passenger car) drivers and trips, and how the HBEFA driving cycles match this real-world driving behaviour. The data on individual drivers was collected in the framework of pilot studies within the EU Horizon2020 project "uCARe" (Cox et al. 2022) and is an independent dataset from the (older and much less extensive) data from which the HBEFA driving cycles were derived. We can observe that:

- The variability of real-world driving behaviour in each traffic situation is high;
- In most cases, the HBEFA driving cycle parameters lie in the middle of, or at least within the range of the values from individual drivers and trips, especially for the situations with sufficient available driving data from the pilot studies.

The data and analysis thus support the assumption that the HBEFA driving cycles are representative of real-world driving behaviour in various areas of Europe.

Figure 3: Comparison of real-world driving behaviour with HBEFA cycles



The plots on the left side show the availability of driving data from the uCARe pilot studies in km driven. The plots on the right side show the distribution of average speed, relative positive acceleration, and share of time stopped from the pilot studies as box plots, and the corresponding values from the HBEFA driving cycles as grey bars.

Source: (Cox et al. 2022), uCARe project (EU Horizon2020, GA 815002)

2.3 Scale, inputs, and outputs of TS application

Typically, the HBEFA TS methodology is applied in contexts in which **information on traffic volumes (e. g. expressed as average daily traffic, or ADT) is available on a network, along with other network attributes** that can be used for TS classification, such as road type, speed, or capacity. This input can

- either be based on measurements (traffic counts)
- or originate from a (usually macroscopic) traffic model.

The links (street segments) in such a network form the spatial units to which the static parameters of the HBEFA TS (area, road type, speed limit, gradient) are typically assigned; additionally, the traffic volumes may be stratified in time to assign levels of service (LOS).

Generally, we recommend assigning the HBEFA TS directly to the input network links, which usually start and end at intersections with other roads. In this context, it is important to note that the driving cycles in HBEFA include stops at intersections, as well as periods of slower driving at sub-link-level, e. g. due to curves, intersections, or denser traffic (see e. g. Figure 5). Links may be subdivided due to changes in one of the static TS parameters (such as e. g. the speed limit or the area type). Further subdivision based only on observed changes in average vehicle speed – such as areas around intersections, or subsections of road links in which for some reasons vehicle speed changes (e. g. due to minor obstacles such as a curve or a slope) – is generally not recommended: On one hand, such effects are already accounted for in the HBEFA driving cycles[11]. On the other hand, with very fine subdivisions (i. e. very short links), it becomes difficult to ascertain that the basic assumption of the TS approach – that the corresponding HBEFA driving cycle is representative for real-world driving behaviour – is still valid in the given application case.

It should also be noted that the lengths of the HBEFA driving cycles do not have to match the input road links. The corresponding average emission factors, since expressed in g/km, are distance independent. In most cases, the HBEFA driving cycles are longer than the typical input road links. This doesn’t matter, however, since we use the distance-independent emission factor in g/km from the cycle.

For **larger-scale applications and/or in applications in which only spatially aggregated emission results are required** (e. g. for studies focusing on greenhouse gases, for which the location of the emission is irrelevant, or for air pollutant emission inventories only requiring the emission totals in a given area), spatially/temporally “fuzzy” or **aggregated TS assignment approaches may be appropriate**: Of certain TS parameters such as LOS, gradients, or level of service, a distribution may be known, but not exactly to which street links the respective values apply. In such cases, the distribution may be applied to all corresponding traffic volumes, or road links. The “aggregate traffic situations” in the HBEFA application (Menu *Info > Aggregate Traffic situations* in HBEFA up to 4.2; menu *Traffic conditions > Aggregate Traffic situations* from HBEFA 5.1), or statistical data, may provide the required distribution information.

For **detailed applications in which specific or individual driving behaviour is relevant** (such as investigating the effects of intersection design or management, or of different driving styles), or if the “previous trip history” of vehicles deviates from the statistical average (e. g. in locations where the SCR catalysts of trucks have cooled down after a long descent), HBEFA may not be the most suitable choice of emission model, since it does not account for such effects. In such cases, it may be advisable to use an individual vehicle emission model such as PHEM (Hausberger et al. 2018).

2.4 Consider emission sensitivity

Given that the TS approach is a simplification, another guiding principle (especially for larger-scale assessments and/or in case of limited resources) should be that we should **focus on the TS parameters** where we can potentially make the largest errors – i. e. those **with the highest sensitivity.**

Sensitivity can be considered in two ways:

[11] It has been proposed by some HBEFA users that finer subdivisions could enable a spatially more detailed depiction of emissions. This could e. g. be achieved by a system of “traffic situation building blocks” consisting of shorter driving cycles containing e. g. only phases of rather constant speed, or only acceleration/ deceleration phases – similar to the methodology of the US EPA road emission model MOVES (EPA 2024). However, this would introduce heavier input data requirements and a more complex classification methodology. Overall, the simplicity of application was given a higher priority in the decision for the current methodology than spatial detail, given the focus of HBEFA on city to national scale applications.

- By comparing the emission factors of the different TS in question for a particular case. Examples of such comparisons are shown throughout the present guidelines, and they can also be carried out by HBEFA users using the HBEFA software.

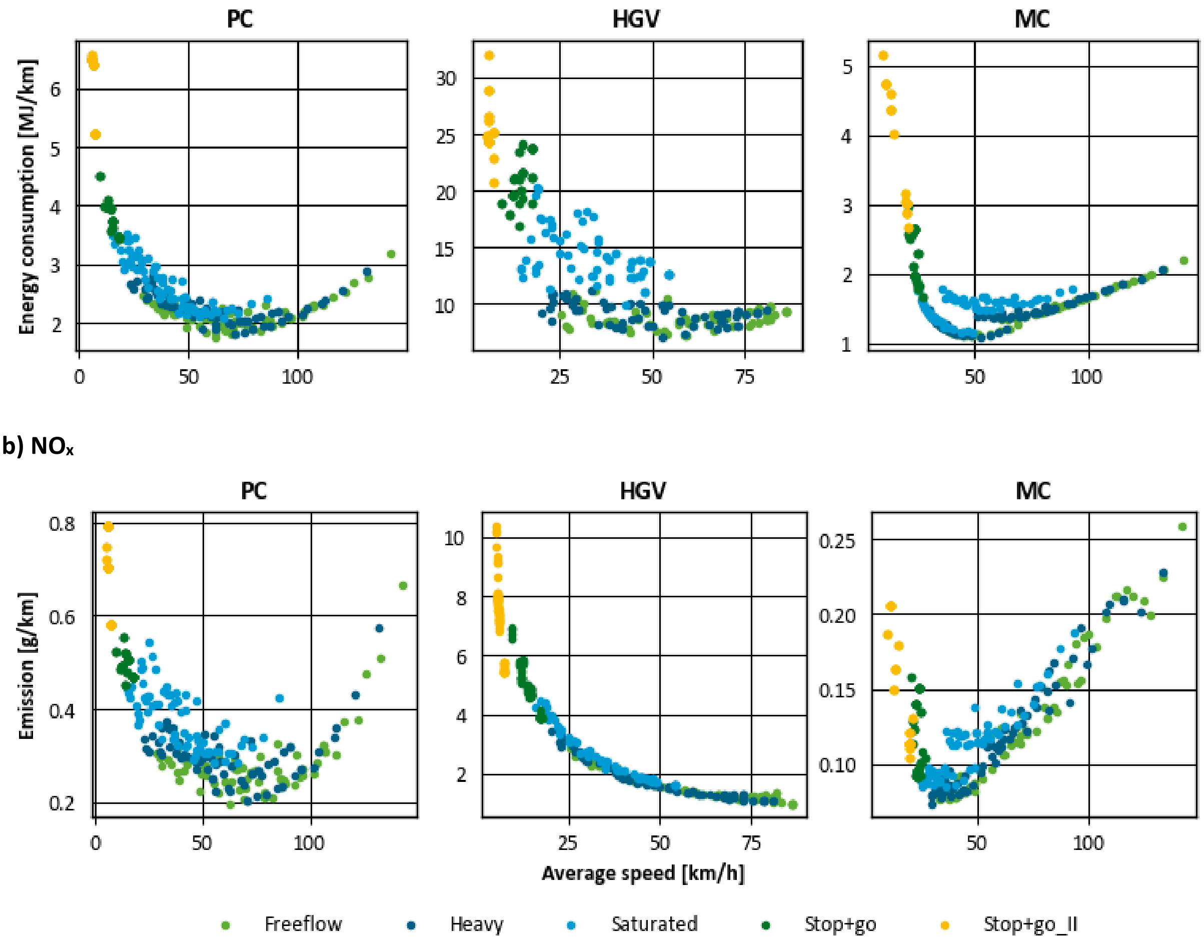
- However, which traffic situations account for a high or a low share of total mileage in a given study – or, expressed differently, how the different TS and emission factors are weighted – will greatly influence which parameters are most sensitive: A small difference in EF between two traffic situations in question may have a higher impact on total emissions than a larger difference between two other traffic situations, if the former account for a much higher mileage share than the latter.
  Obviously the mileage share of traffic situations will vary between individual studies. Therefore, no sensitivity ranking can be valid for all application cases – which means that **HBEFA users should explore the sensitivities in each application case individually**. The present guidelines include a few sensitivity analyses for typical application cases that give hints on the "weighted" sensitivity.

- To get a general impression of energy consumption and emission sensitivity, it can be helpful to **visualize emissions and emission factors**.
  For example, emission factors can be visualized in scatterplots by traffic situation and by average speed on the x-axis and energy consumption or emission per km on the y-axis. Often, a **"U"-shape** can be seen on such plots: Energy consumption and emissions are highest at the lowest and highest average speed and lowest at medium speeds. The speed range with the lowest emissions varies with the weight of the vehicles – for motorcycles, it is lowest and for HGV it is highest. For the latter, the right side of the "U" is often cut off since they are not allowed to drive faster than the speed at which emissions are lowest. With more dynamic driving, i. e. more acceleration and deceleration at the same average speed – which usually corresponds to higher LOS – energy consumption and emissions also rise. These effects are shown for energy consumption (EC) and NO_x in Figure 4.

Orders of magnitude of the sensitivity of an *immission* result (pollutant concentration/air quality) to various input data types are presented in Chapter 4 of a Guideline by the Baden-Württemberg Environmental Agency (Diegmann et al. 2015); their relative ranking is also valid for emission results.

Figure 4: Energy consumption and NO_x emission factors by traffic situation and vehicle category, plotted by average speed

a) Energy consumption



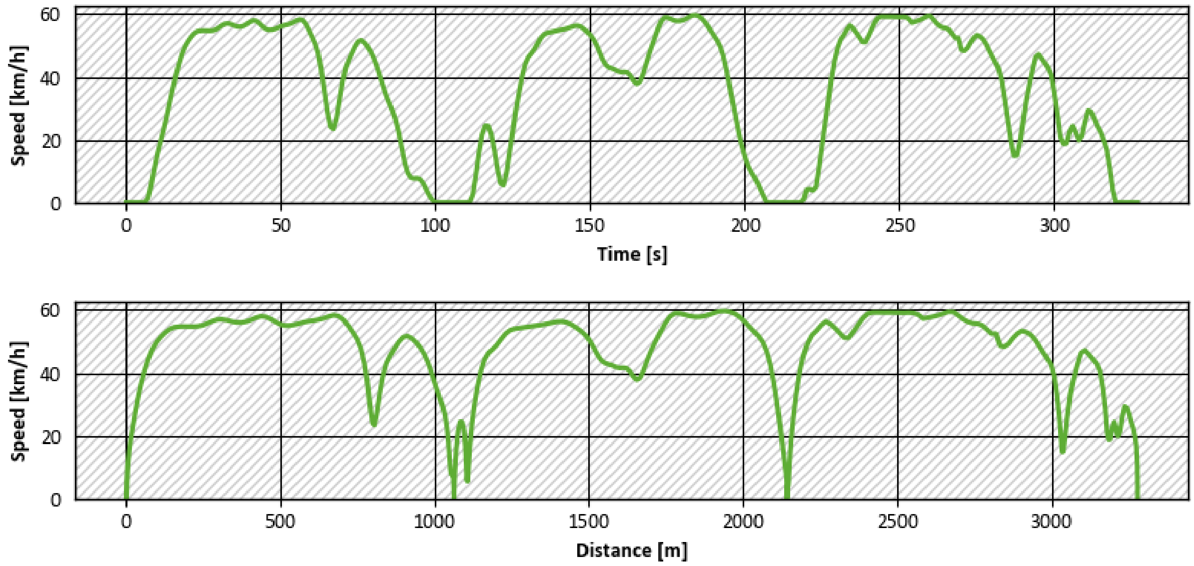
The plots show average emission factors for the year 2020 based on the German fleet composition.
Source: HBEFA 4.2

2.5 Look at driving cycles

Finally, in cases of doubt, it **can be helpful to look at the driving cycles (speed profiles) of the TS in question**, even if no driving behaviour data from our particular study case is available. E. g. the distances between deceleration and acceleration phases, in particular stops at intersections, can be compared with the roads in a given application. For this, it can be useful to visualize the driving profiles by distance (instead of by time). The constant speeds reached, or other patterns in the driving cycles, can also deliver hints on which cycle and thus TS may be more appropriate for a given context.

From HBEFA Version 5.1 onwards, the driving cycles will be accessible to users and can be displayed either by time (seconds on x-axis) or distance (metres on x-axis) (see also Figure 5).

Figure 5: Example driving cycle (Urban distributor/secondary road, 50 km/h, LOS "heavy") plotted by time (seconds, above) and distance (metres, below)



Source: HBEFA 4.2

3 Area

3.1 Definition

The TS parameter "area" can take either the values "rural" (IDArea = 1) or "urban" (IDArea = 2). It describes the environment of a given road link, which influences typical driving behaviour via infrastructure or obstacles such as traffic lights, pedestrian crossings etc.

The definition in the HBEFA application (based on the definition proposed in ARTEMIS, (André et al. 2006)) is given in Table 2.

Table 2: Definition of the TS parameter "area" in HBEFA

IDArea	Area	Description
1	Rural	"non-urban area" in a functional sense, including small villages
2	Urban	urban in the sense of a functional urban area (agglomeration)

Source: HBEFA 4.2

3.2 Classification methods and rules

"Area" is usually classified by an intersection of the input road network with polygons of areas classified as "urban" and/or "rural" in a GIS system or using a geospatial software library.

Regarding which areas should be classified as "urban", two main different interpretations of „area" are used within the HBEFA user community, which result in different possible classification rules:

- The original definition given in the HBEFA application implies that only larger settled areas are "urban". This interpretation is prevalent in central Europe. The "functional urban area" affects driving behaviour mainly via infrastructural elements: More frequent intersections with traffic lights, or frequently used pedestrian crossings cause more deceleration/acceleration events or full stops in larger towns than in small villages – in the latter, roundabouts are more frequent at intersections and stops are necessary only rarely. Rules used for classifying an area as "urban" in this sense include:
  - The total population in an "urban" area (possibly the total of several contiguous municipalities) should exceed 10'000 inhabitants. The built-up areas within the respective municipalities should be defined as "urban".
  - Germany: Urban areas can be classified based on the "Regionalstatistische Raumtypologie" (RegioStaR, (BMDV 2021))[12]. RegioStaR is used to generate representative results for settlement-structural spatial types, i. e. for groups of cities and municipalities with similar spatial and settlement structures - e. g. rural municipalities or large cities - in order to transfer mobility parameters for transport planning to locations with comparable settlement-structural characteristics. At present, however, only the metropolises are divided into city centre, city centre fringe and city fringe. High-density, urban and rural clusters are determined on the level of geographical grid cells at a resolution of 1 km by 1 km and on the basis of population density in order to differentiate between urban versus small-town/village. The municipalities or associations of municipalities are then grouped into urban, semi-urban and rural

[12] https://bmdv.bund.de/SharedDocs/DE/Artikel/G/regionalstatistische-raumtypologie

according to their population share in these clusters. The municipalities and associations of municipalities identified as semi-urban are labelled as 'urban'. In the future, other cities and municipalities could also be further subdivided in order to differentiate between small towns (up to 20,000 inhabitants) and villages, for example (BMVI 2018). The category 'small-town area, village area' can therefore serve as an indicator for the rural area type in order to distinguish it from the other urban area types, like the RegioStar categories i. e. metropolises, large and medium-sized cites. If the examined route network is located within one of the classified municipalities, the corresponding area type can be assigned to it.
Furthermore, information on the distinction between roads that run through settlements and open stretches of road may be available in geodata sets of the federal states of Germany on the road network.13

- Switzerland: Urban areas can be classified based on the national "Gemeindetypologie" (ARE 2014)[14] as built-up areas within municipalities classified as "Grosszentren", "Nebenzentren der Grosszentren" or "Mittelzentren". As a GIS datasource for built-up areas, the areas classified with 'OBJEKTKLAS == "TLM_SIEDLUNGSNAME"' in the "Swissnames-3D" dataset (swisstopo 2020) can be used.

- France: INSEE defines an urban unit as a municipality, or group of municipalities, with a continuous built-up area (no more than 200 meters between two buildings) and at least 2,000 inhabitants. The respective areas in Excel and Shapefile format can be obtained from the INSEE website[15] . In addition, a Eurostat-based classification of urban municipalities based on population density (>300 inhabitants per km^2) is also available from the INSEE website[16].

► Mainly in Scandinavian countries, the interpretation is prevalent that any built-up area is "urban" regardless of its total size. Roads in smaller villages can also be classified as "urban" according to this interpretation.

- Sweden: The official Swedish classification of urban areas is used (Statistics Sweden 2024). It is based on density of inhabitants.

- Norway: The official Norwegian classification of urban areas is used (Reid 2021)[17]. It is mainly based on density of housing.

- In the absence of national definitions, a population density threshold of 300 persons per square kilometre can be applied. This was e. g. done for a Europe-wide classification in the uCARe project by Cox and Notter (2022); as a GIS datasource, the Eurostat population raster at 1 km resolution from 2018 (Eurostat 2018) was used.

[13] E. g. https://www.opengeodata.nrw.de/produkte/transport_verkehr/strassennetz/; https://www.mobidata-bw.de/dataset/strassennetz-netzknoten-baden-wuerttemberg

[14] https://opendata.swiss/de/dataset/gemeindetypologie-are

[15] https://www.insee.fr/fr/information/4802589

[16] https://www.insee.fr/fr/information/6439600

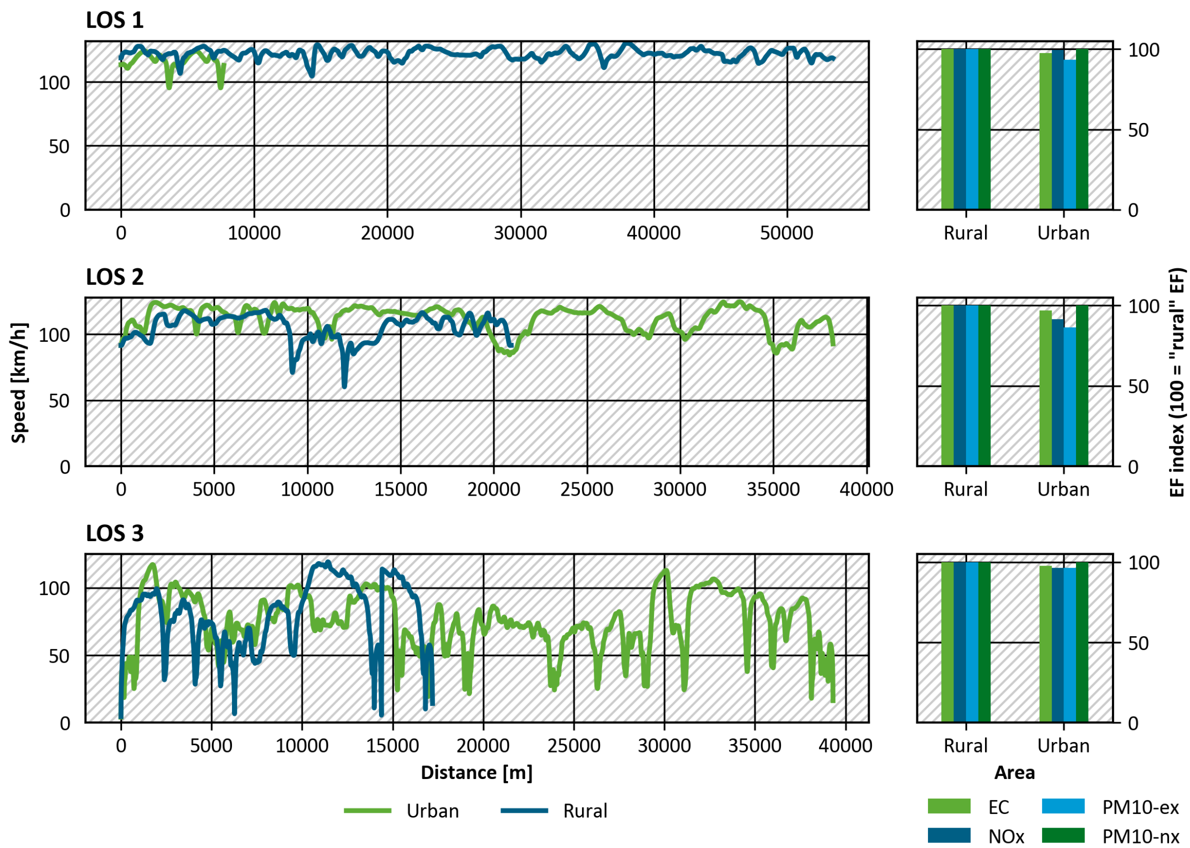
[17] https://www.ssb.no/natur-og-miljo/areal/artikler/tettbygde-omrader-for-2021-kartlagt

3.3 Driving behaviour and emission sensitivity

The following differences in driving cycles and emission factors can be observed at the level of individual TS when comparing the “urban” and “rural” TS for the same road type/speed limit/LOS (see Figure 6 and Figure 7):

- The urban variants are generally characterized by lower average speeds;
- On motorways, energy consumption and pollutant emissions tend to be higher on the “rural” TS (energy consumption by 2-3 %, NO_x by 0 – 8 %), since they include more acceleration events to high speeds (see Figure 6);
- On distributors and collectors, the urban variants are characterized by more frequent stops, even in freeflow conditions (while the rural TS have few or no stops at all in these conditions).
  As a consequence, energy consumption is higher on the urban TS in freeflow and heavy traffic conditions (7 % to 20 % on distributor in LOS 1 and 2 for passenger cars), and so are NO_x emissions (22 % - 26 % on distributor in LOS 1 and 2 for passenger cars; see Figure 7). The vehicle category with the highest impact are the Urban buses, for which energy consumption increases by up to 28 % in urban areas, and NO_x by up to 29 %, which is due to the more frequent stops.
- The denser LOS often share similar cycle parameters and emission factors, or are even assigned identical driving cycles. This is valid for all road types.

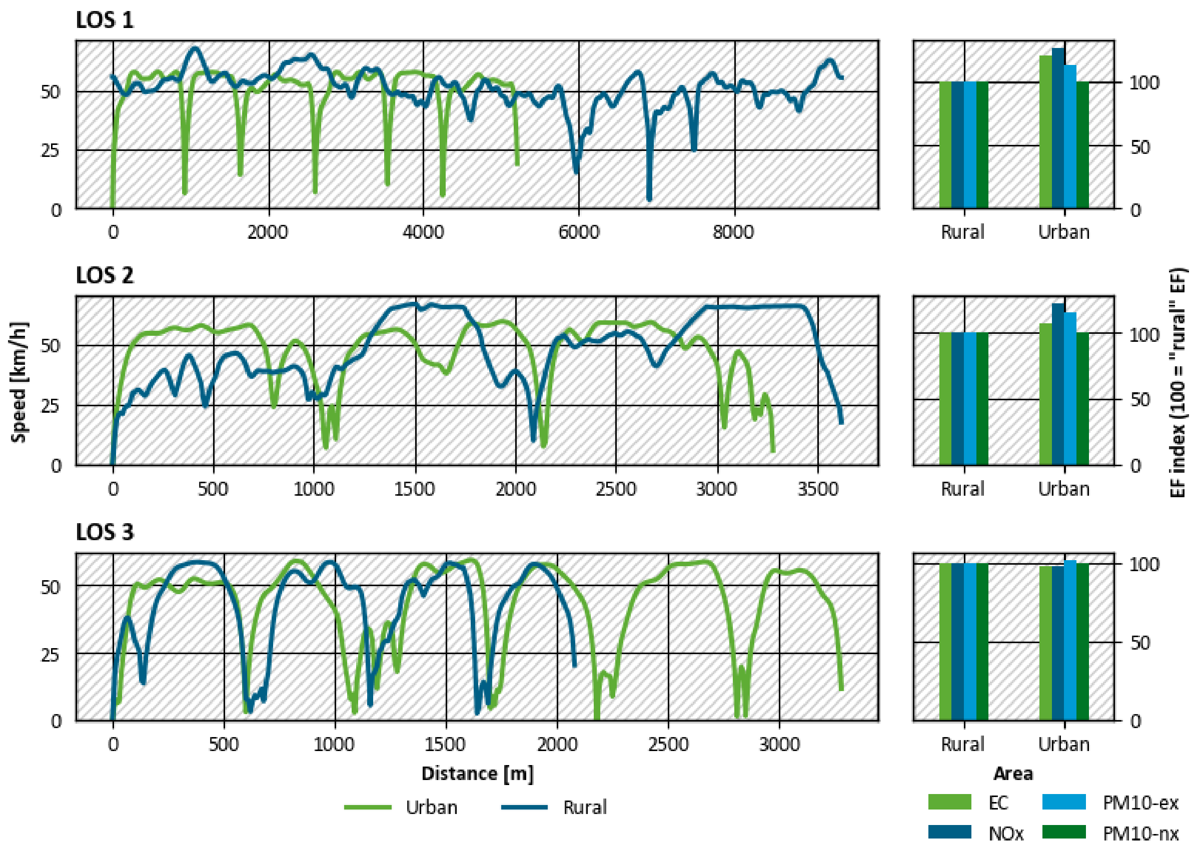
Figure 6: Speed profiles and relative EF differences "rural" vs. "urban" for a motorway with speed limit 120 km/h



Note: Only LOS 1-3 shown since cycles/EF for LOS 4+5 are identical for urban/rural. EF indexes shown are valid for average PC in Germany, 2020. PM10-ex = PM10 from exhaust; PM10-nx = PM10 non-exhaust (Brake, tire, road and abrasion, resuspension)

Source: HBEFA 4.2

Figure 7: Speed profiles and relative EF differences “rural” vs. “urban” for a distributor/secondary road with speed limit 50 km/h



Note: Only LOS 1-3 shown since cycles/EF for LOS 4+5 are identical for urban/rural. EF indexes shown are valid for average PC in Germany, 2020.
Source: HBEFA 4.2

In larger-scale application cases, which of the two interpretations and proposed classification rules described in Chapter 3.2 is chosen will likely have a minor emission impact. In a sensitivity analysis carried out for these Guidelines, we compared two classification rules for the Canton of Lucerne in Switzerland:

- In the original calculation, built-up areas in centres with at least 10’000 inhabitants were classified as “urban”; this resulted in 21 % of total mileage being assigned to the “urban” area.
- In a comparison run, ALL built-up areas, including small villages, were classified as urban. This encompassed 36 % of total mileage.

Since the change therefore affected roughly 15 % of total mileage, of which changes occur mainly in the LOS 1-2, and which partly compensate each other due to the different emission impacts on higher vs. lower speed limits (see above), the total impact on energy consumption and emissions is low: The sensitivity run classifying all built-up areas as “urban” results in only 0.7 % higher energy consumption and CO_2 emissions, and an air pollutant emissions increase by 0.2 % to 1.1 % for the most important pollutants (Table 3).

Table 3: Emission impact of classifying all built-up areas as "urban" vs. only built-up areas in urban agglomerations with >10'000 inhabitants in an example case study

Veh. Category	CO_2(rep)	EC	NO_x	PM10 exhaust	PM10 non-exhaust
Pass. car	0.8 %	0.8 %	0.8 %	0.6 %	0.0 %
LCV	0.7 %	0.7 %	0.7 %	0.4 %	0.0 %
Coach	0.4 %	0.4 %	1.4 %	0.6 %	0.0 %
Urban bus	2.5 %	2.1 %	3.5 %	2.8 %	3.2 %
Motorcycle	0.4 %	0.4 %	0.5 %	0.1 %	0.8 %
HGV	0.3 %	0.3 %	1.8 %	0.5 %	0.0 %
TOTAL	**0.7 %**	**0.7 %**	**1.1 %**	**0.5 %**	**0.2 %**

Example of the Canton of Lucerne, Switzerland, year 2022, calculated with HBEFA 4.2 (INFRAS 2024).
Table INFRAS. Source: Own calculation

3.4 Recommendations

- For countries with explicit classification rules and data sources mentioned in Chapter 3.2, it is recommended to use these.
- For larger-scale applications, given the relatively low energy use and emission impact demonstrated above, it is not so relevant which classification rule is used – other TS parameters may be more worthwhile to invest classification effort in. As a default, we recommend using the definition given in the HBEFA application, with "urban" assigned to built-up areas in agglomerations from 10'000 inhabitants upwards.
- For smaller-scale applications focusing on roads with speed limits up to 60 km/h, the "urban" TS result in significantly higher emissions than their "rural" counterparts, especially for urban buses. In such cases we recommend selecting the appropriate "area" by comparing the cycles (especially the distances between decelerations/stops) to the situation in the study area.

4 Road type

4.1 Definition

The "road type" in HBEFA follows a functional/hierarchical definition that is given in Table 4. It basically differentiates five hierarchical levels, denoted by the first position of the IDRoadType, with subtypes denoted by the second position of the IDRoadType. Table 4 also contains the German names/descriptions for those cases that do not correspond to the literal translation from English.

Regarding the second hierarchical level ("Primary non-motorway"), it can be noted that it used to be called "trunk road" in HBEFA versions up to 3.3. It was then renamed following the recommendation of Ericsson et al. (2019) due to the fact that the word "trunk" road is used differently in different countries and the term could cause confusion.

Table 4: Definition of the TS parameter "road type" in HBEFA

ID RoadType	Road type	Description
10	Motorway-Nat.	motorway, ≥ 2x2 lanes, grade separated
11	Motorway-City	motorway, high-speed/high capacity road, expressway/major artery/ring road; ≥ 2x2 lanes; always grade separated; In German definition: "Magistrale/RingStraße mit hoher Kapazität"
12	Semi-Motorway	variable nr of lanes (Sweden,rural areas)
20	Primary-nat. non-motorway (German: "Fern-/Bundesstraße")	express motor road, grade separated or low disturbance interchanges, ≥ 2x1 lanes, speedlimit 80-100 km/h (formerly "trunk road")
21	Primary-city non-motorway (German: "Städt. Magistrale/Ringstraße")	high-speed/high capacity road, expressway/major artery/primary road (but not motorway); ≥ 2x1 lanes; may be grade separated (formerly "trunk road")
30	Distributor/Secondary	medium capacity road, minor artery/distributor/district connector; ≥ 2x1 or ≥ 1x2 lanes
31	Distributor/Secondary(sinuous)	medium capacity road, minor artery/distributor/district connector; ≥ 2x1 or ≥ 1x2 lanes / with curves
40	Local/Collector	connection between villages; access to/from district distributors; ≤ 2x1lanes
41	Local/Collector(sinuous)	connection between villages; access to/from district distributors; ≤ 2x1lanes / with curves
50	Access-residential	residential road, mostly priority rule, ≤ 2x1 lanes

Source: HBEFA 4.2

4.2 Classification methods and rules

Road types are usually classified from the input road network by using lookup tables that relate source road types to HBEFA road types. These can be

- simple, with 1:1 relationships

- more complex, i. e. using additional criteria like speed limit or the number of lanes

Examples of lookup tables are presented in Appendix A.1. In the German context, there is also an allocation in Table 10 of VDI Guideline 3782 Part 7[18]. These can be used for orientation – but it is always recommended to look at the definitions in Table 4 whether they match the road types in the given application area.

Please note that if "area" or "speed limit" are not explicitly included in a lookup table, invalid TS may result in case of a road type/area/speed limit combination that is not covered in HBEFA (compare Figure 2). In such cases, the road type classification may need to be finetuned with additional criteria for the concrete application case, or invalid TS may be reclassified as described in Chapter 7.

In general, road type classification is quite straightforward. The most frequently mentioned challenges are:

- The distinction between "Distributor/secondary" and "Primary non-motorway" (or "trunk") on one hand, and "Local/collector" on the other hand; this is discussed in Chapter 4.3.1.
- The "sinuous" subtypes, which are available for Distributor/secondary and Local/collector road types. Sinuosity refers to the curviness of roads; therefore, a threshold related to curviness should be applied. This is discussed in Chapter 4.3.2.
- Highway ramps: We recommend using the "Primary non-motorway" (or "trunk") road type on highway ramps, as it includes the acceleration and deceleration phases typical for highway ramps (see also Table 14).

4.3 Driving behaviour and emission sensitivity

4.3.1 Secondary/Distributor vs. Primary non-MW and Local/Collector

Figure 8 and Figure 9 show the driving cycles (speed profiles) and the relative emission factor differences on one hand for 80 km/h speed limit in a rural area (Figure 8) and on the other and for 50 km/h in an urban area (Figure 9). It becomes obvious that the main difference in driving behaviour are the more frequent deceleration/acceleration events or even full stops in the lower hierarchy road types:

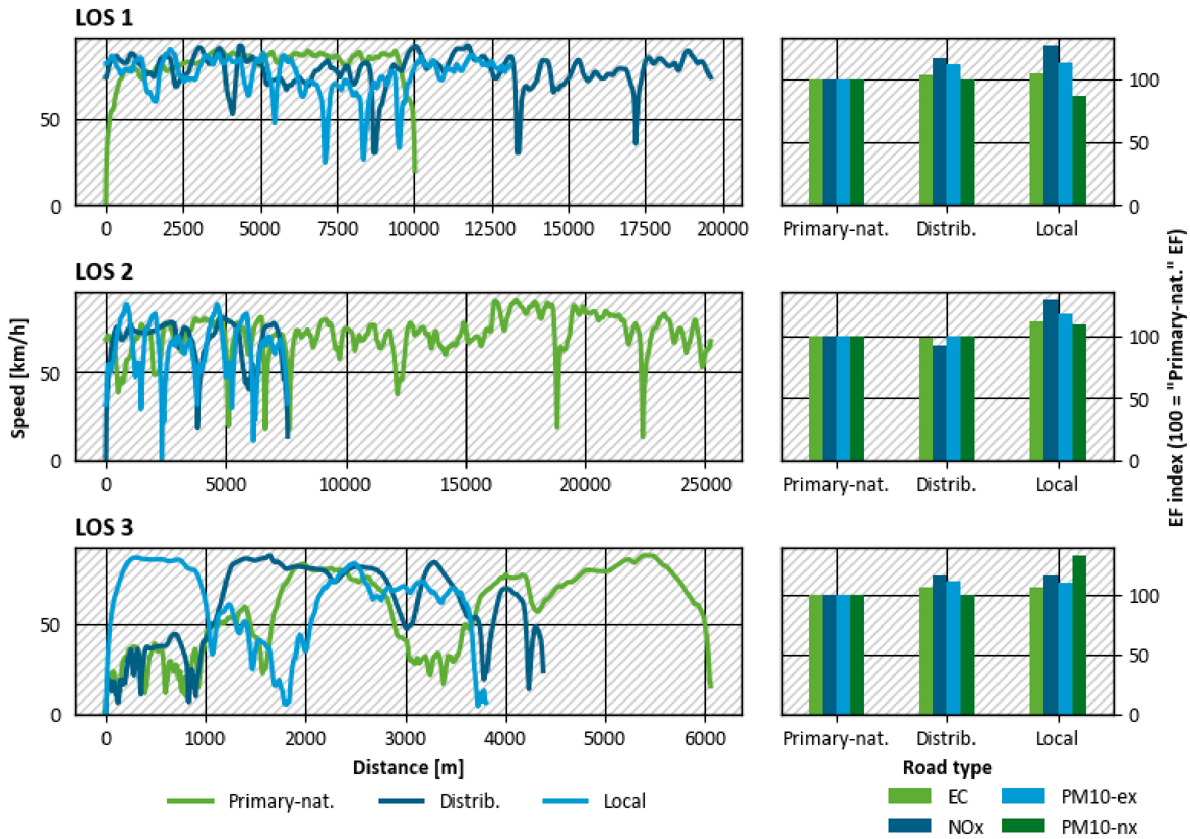
- In the rural area at 80 km/h speed limit, in freeflow conditions, speed is quite constant around 80 km/h on the rural primary non-motorway road – a stop occurs only after 10 km. On Distributor and Local roads, slow-down events are more frequent, about every km. Energy consumption and emissions tend to be higher by about 10-30 % on the Distributor and Local roads compared to the Primary non-motorway.
- On the urban area at 50 km/h, we observe the same increase in deceleration/acceleration events with lower road hierarchy; in addition, the maximum speed is markedly higher on the primary non-motorway. The energy consumption/emission difference is less marked than at 80 km/h, the differences in EF are generally in the range of 10 % and remain below 20 %.

For classification, the main aspect to consider should therefore be the distance between intersections and the type of intersections (i. e. what deceleration they cause). The distance between acceleration/deceleration events should match the conditions in the application area as closely as possible. This is e. g. why in Table 15 (Appendix A.1), FRC (Functional Road Category)

[18] https://www.vdi.de/richtlinien/details/vdi-3782-blatt-7-umweltmeteorologie-kfz-emissionsbestimmung-luftbeimengungen

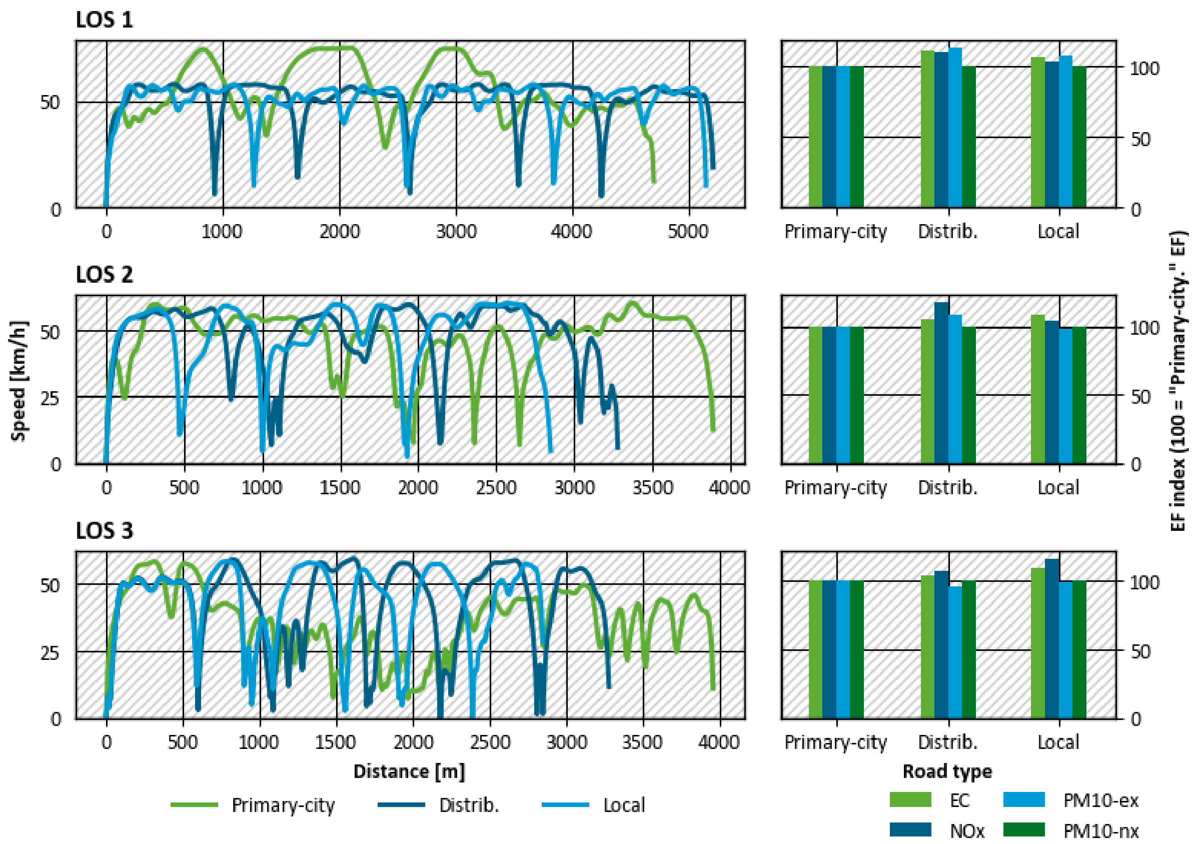
classes 1 and 2 were classified as HBEFA road type "Distributor/Secondary" rather than "Primary non-motorway" (which may have been the more obvious choice at first sight and may be more appropriate in other application cases).

Figure 8: Speed profiles and relative EF differences between Primary non-motorway, Distributor/Secondary, and Local/Collector road types at 80 km/h (rural area)



Note: Only LOS 1-3 shown since cycles/EF for LOS 4+5 are identical or similar between road types. EF indexes shown are valid for average PC in Germany, 2020.
Source: HBEFA 4.2

Figure 9: Speed profiles and relative EF differences between Primary non-motorway, Distributor/Secondary, and Local/Collector road types at 50 km/h (urban area)



Note: Only LOS 1-3 shown since cycles/EF for LOS 4+5 are identical or similar between road types. EF indexes shown are valid for average PC in Germany, 2020.
Source: HBEFA 4.2

4.3.2 "Sinuous" subtypes

The differences in speed profiles and emission factors between the "non-sinous" and the "sinuous" subtype of road type Distributor/Secondary are shown in Figure 10. The "sinuous" speed profile shows marked speed reductions due to curves. This causes higher energy consumption and emissions by about 10 to 20 % for PC.

For the Local/Collector road type, the "sinuous" speed profiles are very similar as for Distributor/Secondary; the energy consumption and emission difference for PC is less pronounced (below 10 %) because the "non-sinuous" subtype itself is more dynamic than for Distributor/Secondary.

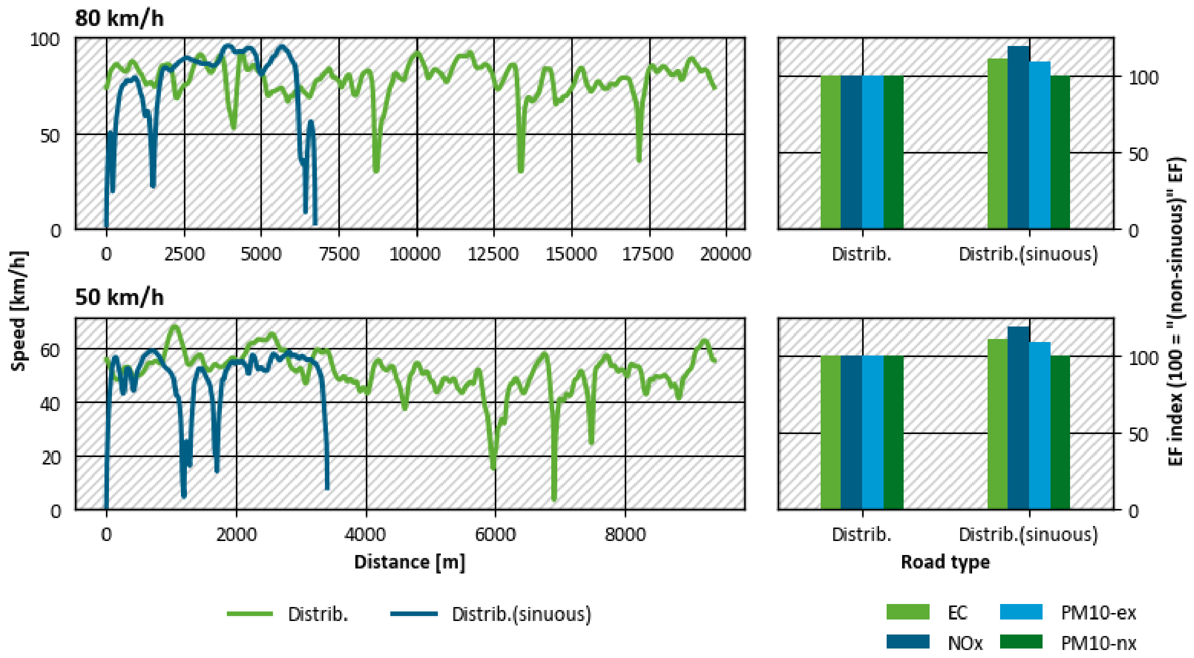
The following approaches may be used to distinguish "sinuous" from "non-sinuous" Distributor and Local roads:

- Determine ratio of link length to straight-line distance between end nodes; if this ratio is above a certain threshold, use the "sinuous" subtypes. A threshold of 120 % (for short links) to 140 % (for longer road links) is generally appropriate.
- In a more complex approach, the curvature may be determined numerically, e. g. in gon/km (as e. g. in (Schmaus et al. 2023)); however, this will require advanced GIS programming and longer computation time. No tool or script could be made available for the current guidelines that calculate curvature this way.

- In Germany, road networks with curvature classes according to HBS (Handbuch für die Bemessung von Straßenverkehrsanlagen) can be used. Road segments ≥ 100 gon/km (corresponding to curvature classes 3-4) are classified as "sinuous" (Schmaus et al. 2023, Table 15). It should be noted, that the curvature thresholds in the HBS changed between the 2009 Version ("sinuous" > 150 gon/km) and the current version ("sinuous" > 100 gon/km).

In flat countries with predominantly straight roads, the "sinuous" subtypes may not be applicable and may thus be ignored.

Figure 10: Speed profiles and relative EF differences between the "non-sinuous" and the "sinuous" subtypes of Distributor/Secondary at 50 km/h and 80 km/h speed limit (rural area, LOS = freeflow)



Note: EF indexes shown are valid for average PC in Germany, 2020.
Source: HBEFA 4.2

4.4 Recommendations

- For each application case, a lookup table from the road types in the input network to HBEFA road types should be developed. The example lookup tables in Appendix A.1 can be used for orientation but should be reviewed and adapted by comparing the HBEFA definitions in Table 4, and possibly the respective driving cycles (mainly the distances between slow-down events and full stops) to the roads in the given application area.
- For the sinuous subtypes, please refer to Chapter 4.3.2.

5 Speed limit

5.1 Definition

The definition of speed limit is straightforward. It refers to the signaled speed limit per road link in kilometre per hour – and NOT the actually driven average speed (the latter varies on each road link depending on the LOS, compare Chapter 6). Where different speed limits apply for different vehicle categories (e. g. in the case of lower speed limits for trucks on highways), the speed limit signaled for PC is relevant and must be selected for this parameter (because the HBEFA cycles for the other vehicle categories take into account their possibly lower speed limit).

Table 5: Definition of the TS parameter "speed limit" in HBEFA

Speed limits between 30 and 130 km/h in 10 km/h intervals are available in HBEFA, plus one category for all speed limits above 130 km/h (Figure 2).

idspeedlimit	Speed limit
3	30 km/h
4	40 km/h
5	50 km/h
6	60 km/h
7	70 km/h
8	80 km/h
9	90 km/h
10	100 km/h
11	110 km/h
12	120 km/h
13	130 km/h
14	>130 km/h

Note: Speed limits 10 and 20 km/h are also listed in the HBEFA application, but cannot be used because no valid traffic situation uses them (see Traffic Situation scheme in Figure 2).
Source: HBEFA 4.2

5.2 Classification methods and rules

The following classification methods and rules for the TS parameter "speed limit" can be used. The methods should be prioritized by the order in which they are listed here:

- In some application cases, the speed limit per road segment is directly available on the input road network. This is e. g. the case in German cities, or when using the Norwegian/Swedish national road database (NPRA 2023; Trafikverket 2024). If this is the case, it is obviously best and easiest option to use.
- If the speed limit is not available on the input road network that also contains the traffic volumes, it may be transferred from another road network. E. g. OpenStreetMap (OSM[19])

[19] www.openstreetmap.org; for data download of larger regions, visit e. g. https://download.geofabrik.de/

contains speed limits for most road segments. However, this method may have its practical challenges: E. g. if the geometries of the input network and the network containing the speed limits are too far apart, large buffers will be required that will decrease the accuracy of the result.

- Often, input road networks that are outputs of traffic models may not contain the signaled speed limit, but the freeflow speed from the traffic model (“v0”). This can be rounded up to the next available and plausible HBEFA speed limit.
  One should use caution, though, because the next higher available HBEFA speed limit may not be the most plausible/likely one. E. g. a speed limit of 70 km/h is quite rare in Switzerland (it would be more likely that a v0 of e. g. 65 km/h is in an 80 km/h signalled speed limit zone), but frequent in France and Germany.
  - When a traffic model output is used as emission calculation input, sometimes useful information on roadside conditions is available: e. g. if the roadside of a link is "anbaufrei" (non-built-up), the speed limit may be >50 km/h even within a settled area. In Germany, such information may be available in the road databases of the federal government (BASt 2024) or the state governments.[20]
- In data-scarce situations, simple classification rules based on road types and built-up area may be applied (with thresholds depending on the country), e. g.
  - rural highway = 120 or 130 km/h,
  - urban highway 80 km/h,
  - rural main road = 80 or 90 km/h,
  - main road in built-up area = 50 km/h
  - residential roads = 30 km/h.
  - Online services such as Google Streetview or Mapillary[21] may be used to look at the speed limit signs at sample locations to check classification rules.

On some roads, dynamically varying speed limits may apply. This is usually done as a measure to keep traffic flowing in denser conditions. Such situations can be considered in emission modelling if the necessary information is available – which is primarily the share of traffic volume affected by the different speed limits. In such a case, the affected traffic situation(s) in the emission calculation input may be split into multiple records using the different speed limits.

5.3 Driving behaviour and emission sensitivity

The speed limit strongly influences driving behaviour, especially in freeflow conditions, and is therefore a sensitive parameter in general, although its impact on energy consumption and emissions varies with the speed range (compare the U-shapes of emission factors vs. average speed in Figure 4):

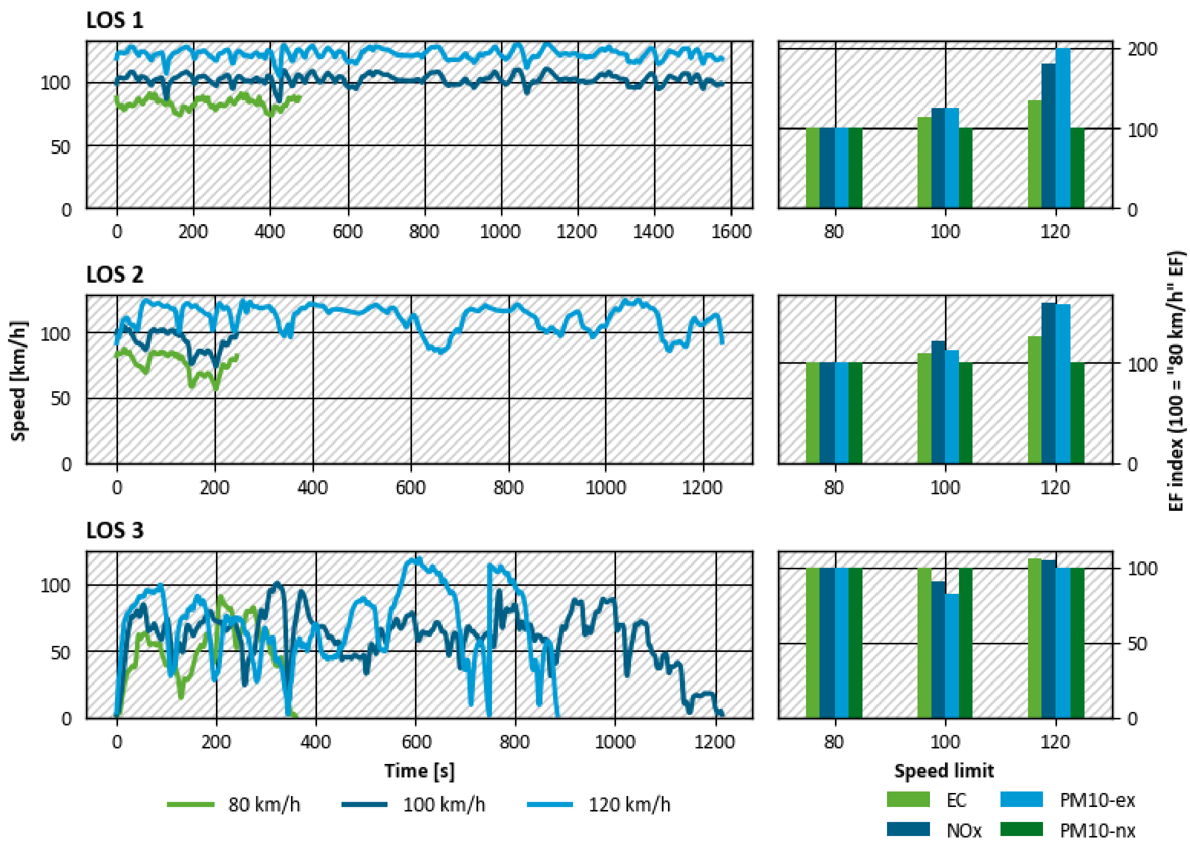
At higher speed limits (> 80 km/h, i. e. on motorways), energy consumptions and emissions increase significantly with a higher speed limit (Figure 11). E. g. on a rural motorway in freeflow

[20] Maybe not be publicly available, but on request.

[21] https://www.google.com/maps; https://www.mapillary.com; or visit https://www.instantstreetview.com/ to type an address and instantly see the location

conditions, energy consumption increases by about 13 % at 100 km/h compared to 80 km/h, and by 34 % at 120 compared to 80 km/h. For NO_x and PM emissions, the increases are even more pronounced – NO_x EF are 80 % higher in a 120 km/h speed limit than at 80 km/h, and PM10 exhaust EF are even 100 % higher.
In denser traffic conditions, these differences decrease; in LOS 3 (saturated conditions), NO_x and PM10 exhaust emissions are even lower at 100 km/h than at 80 km/h.
Obviously, these effects are mostly valid for light duty vehicles and motorcycles; for HGV, emissions and energy consumption only increase slightly at signaled speed limits above 80 km/h because the vehicles themselves are not allowed to drive faster; the highest speeds in HBEFA cycles for HDV reach about 90 km/h.

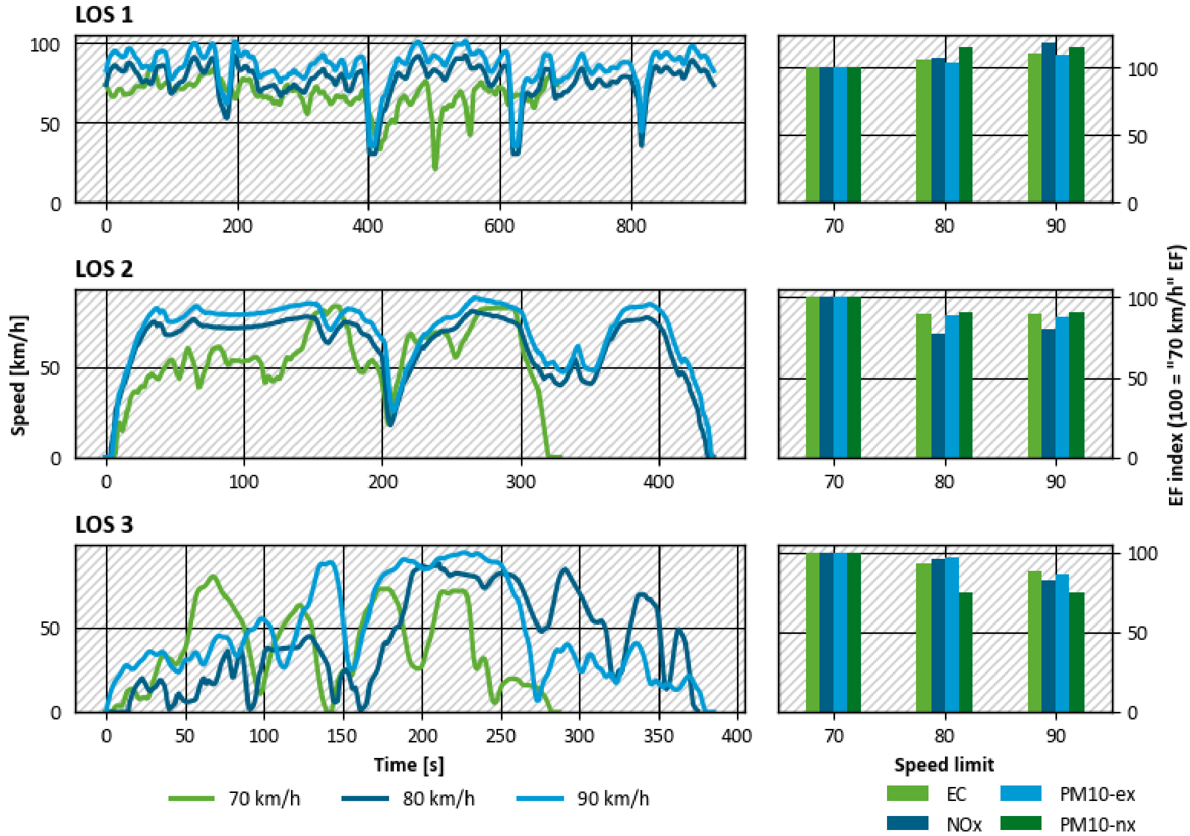
Figure 11: Speed profiles and relative EF differences on a motorway at higher speed limits (>80 km/h, rural area)



Note: Only LOS 1-3 shown since cycles/EF for LOS 4+5 are identical or similar between speed limits. EF indexes shown are valid for average PC in Germany, 2020.
Source: HBEFA 4.2

- At intermediate speed limits (70-90 km/h, i. e. on Distributor/secondary roads), energy consumptions and emissions only increase slightly with a higher speed limit in freeflow conditions – in the range of 5-15 % at 80 or 90 km/h compared to 70 km/h (Figure 12). In denser traffic conditions, energy consumption and emissions decrease because acceleration is not so strong.

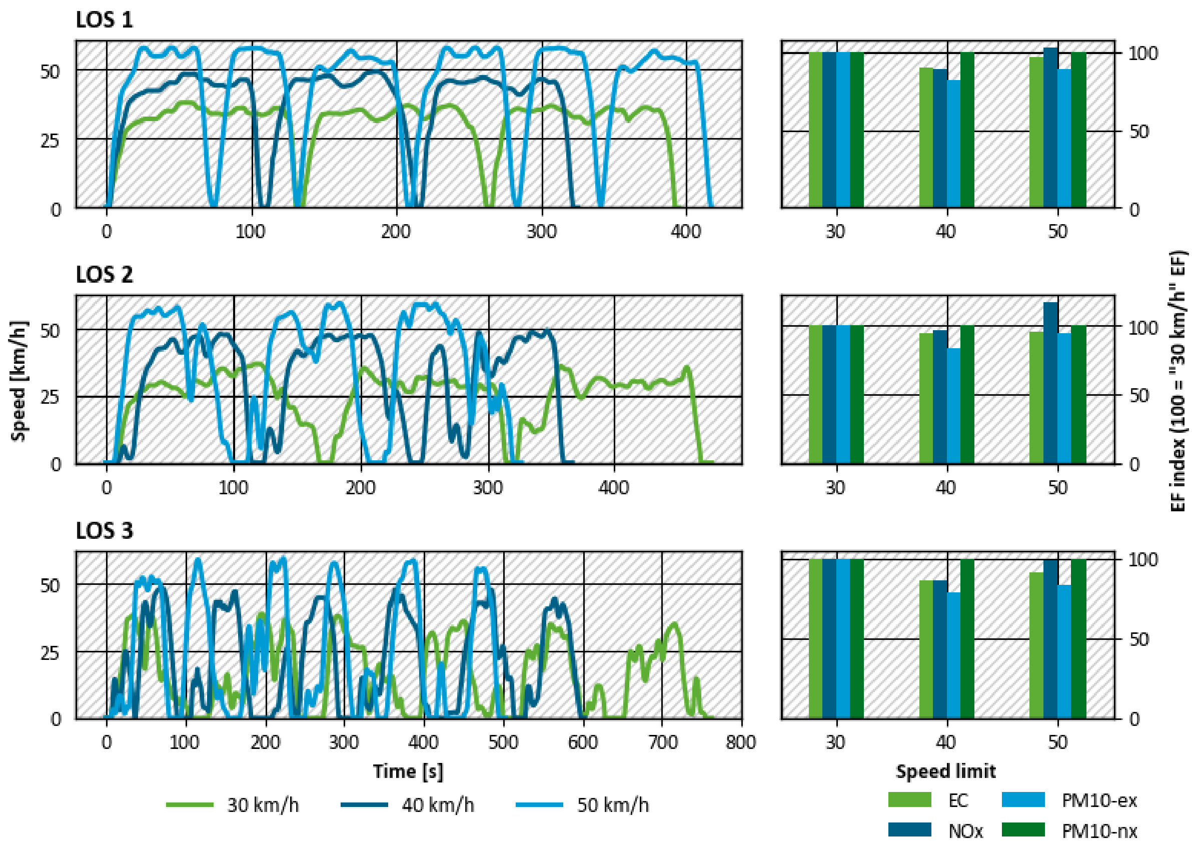
Figure 12: Speed profiles and relative EF differences on a Distributor/secondary road at intermediate speed limits (70 to 90 km/h, rural area)



Note: Only LOS 1-3 shown since cycles/EF for LOS 4+5 are identical or similar between speed limits. EF indexes shown are valid for average PC in Germany, 2020.
Source: HBEFA 4.2

At low speed limits (30-50 km/h, i. e. on urban Distributor/secondary roads), energy consumptions and emissions tend to slightly decrease with increasing speed limits (Figure 13). But the picture is not clear: in these speed ranges, the emissions mostly depend on the dynamics of driving – the more acceleration events and the higher the speed accelerated to, the higher energy consumption and emissions tend to be. Therefore, real emissions and energy consumption will strongly depend on the distance between intersections or other obstacles. In addition, air pollutant emissions depend on the performance of catalysts, which may not warm up to full capacity at low average speeds. The effect that NO_x EF are about 3 % higher on a Distributor at 50 km/h than at 30 km/h is therefore a rather arbitrary result based on the particular driving cycles chosen in HBEFA and may not hold true for all Distributor roads (LUBW 2012). An individual vehicle emission model such as PHEM (Hausberger and Rexeis 2018) would have to be used to take into account such effects.

Figure 13: Speed profiles and relative EF differences on a Distributor/secondary road at low speed limits (30-50 km/h, urban area)



Note: Only LOS 1-3 shown since cycles/EF for LOS 4+5 are identical or similar between speed limits. EF indexes shown are valid for average PC in Germany, 2020.
Source: HBEFA 4.2

5.4 Recommendations

- The classification methods/rules described in Chapter 5.2 should be applied in the priority by the order in which they are listed.

6 Level of service (LOS)

6.1 Definition

The level of service (LOS) in HBEFA describes the traffic conditions at a given time based on traffic density or other temporally varying obstacles (such as pedestrians, construction sites, parked vehicles, etc.). The definition of LOS in HBEFA is loosely based on the U.S. Highway Capacity Manual (US Transportation Research Board 2000) and also refers to these classes in its descriptions (Table 6).

Since the LOS varies with time at the same location, it is (in most cases) the only dynamic parameter of the HBEFA TS, as opposed to the three static parameters area, road type, and speed limit, which are (usually[22]) geographically defined. Therefore, when modelling emissions for average conditions – e. g. based on average daily traffic (ADT), which is the usual case – not a single LOS should be defined per road link, but a distribution, i. e. shares (percentages) of traffic volume of all occurring LOS on any given road link.

Table 6: Definition of the TS parameter "Level of service" in HBEFA

idlos	LOS	Description
1	Freeflow	Free flowing conditions, low and steady traffic flow. Constant and quite high speed. Indicative speeds: 90-120 km/h on motorways, 45-60 km/h on a road with speed limit of 50 km/h. LOS A-B according to HCM.
2	Heavy	Free flow conditions with heavy traffic, fairly constant speed, Indicative speeds: 70-90 km/h on motorways, 30-45 km/h on a road with speed limit of 50 km/h. LOS C-D according to HCM.
3	Saturated	Unsteady flow, saturated traffic. Variable intermediate speeds, with possible stops. Indicative speeds: 30-70 km/h on motorways, 15-30 km/h on a road with speed limit of 50 km/h. LOS E according to HCM.
4	Stop+go	Stop and go. Heavily congested flow, stop and go or gridlock. Variable and low speed and stops. Indicative speeds: 5-30 km/h on motorways, 5-15 km/h on a road with speed limit of 50 km/h.
5	Stop+go_II	Gridlock with speeds <10 km/h. Also referred to as "Heavy stop+go".

Note: The "indicative speeds" refer to average speed.

Source: HBEFA 4.2

LOS can be expressed in different metrics, e. g.

- traffic density in passenger car units per km and lane [PCU/km*ln]
- average actual speed [km/h]
- volume to capacity ratio [%]

The first of these metrics describes the underlying cause of a given LOS (and corresponding driving behaviour) most closely but is usually not available in input data; for the latter two metrics input data are more commonly available.

[22] In some places, speed limits also vary dynamically in time – usually as a measure to keep traffic flowing in denser conditions). See also Chapter 5.2

For the purpose of emission modelling, obviously also the parameters RPA (relative positive acceleration) and share of stop time (which are specified for all HBEFA traffic situations) are important LOS parameters, but they are hardly ever available in empirical data (even speed data from telecommunication are usually aggregated so that driving dynamics cannot be assessed).

6.2 Classification methods and rules

6.2.1 Overview of approaches

We identified three fundamental approaches to estimate LOS that are applied among HBEFA users:

- Capacity approach
- Speed-based approach
- Fixed shares based on empirical data or assumptions

The following subchapters describe and discuss each approach.

In any application case (emission calculation), different approaches can be used for different subsets of road links (e. g. the capacity or speed-based approach for the main road network and the fixed shares approach for the subordinate road network).

6.2.2 Capacity approach

Under the capacity approach, the LOS is estimated based on the degree to which the road link capacity is used, i. e. the **volume-capacity ratio (V/C**, also sometimes referred to as "alpha"). This is **usually done at hourly resolution** (or higher if input data are available). It involves the following steps for each road link (see also Figure 14):

- Volume-capacity ratio (V/C) thresholds between the LOS are defined, possibly differentiated by road type or area type.
- It is important to note that since the source of road link capacities are usually traffic models, and capacities may be tuned in the process of traffic model calibration, different capacities can be used for the same road link from in traffic models. Accordingly, the **V/C thresholds cannot be fixed once and then re-used in another application**, but the capacity information from the input traffic model should always be reviewed and compared to other applications! Another source of road capacity values is deriving those from characteristic q-v-functions of defined road types, which are assigned to the examined road sections. Examples of those characteristic functions and corresponding road types can be found in methodology report and its Appendix B of the German Federal Transport Infrastructure Plan 2030.[23]
  - In this context, it should be noted that the way traffic model outputs are converted e. g. to shapefiles can create pitfalls. For example, capacity information may be valid for the total of both directions, but the shapefile contains two different geometries for each link, which both carry the capacity information valid for the total. Therefore**, it is important to have a critical look at the capacity information from traffic models**.
    Typical capacities per road type are presented in Table 17 (Appendix A.2).

[23] https://bmdv.bund.de/SharedDocs/DE/Artikel/G/BVWP/bundesverkehrswegeplan-2030-inhalte-herunterladen.html

   - Example V/C thresholds are presented in Table 7. It can be seen that different thresholds can be found appropriate in different case studies, which is why a validation of LOS shares and emission results, and calibration/tuning of the thresholds is necessary (see below).
   - It should also be noted that it is possible for the hourly traffic volume disaggregated from ADT (see below) to exceed the capacity of a given road link. As a consequence, volume-capacity ratio thresholds may exceed 100 % (see also Table 7).

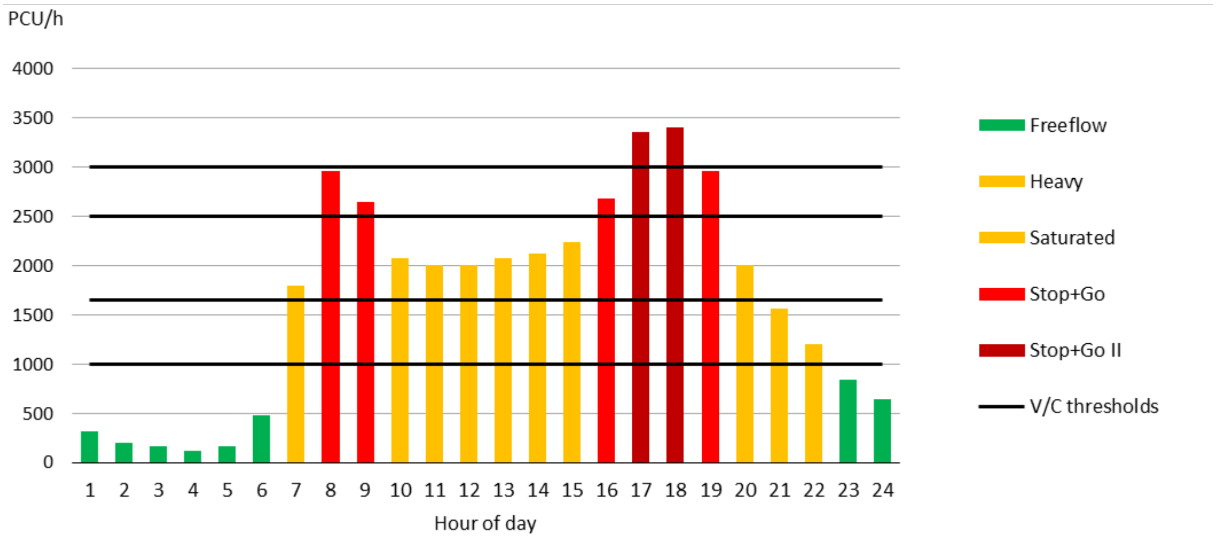
- Average daily traffic (ADT) is disaggregated to hourly traffic volumes based on traffic counts, or – more accurately in the case of the majority of links that do not have a counting station – **relative traffic flow curves** that specify the share of daily traffic per hour. Usually, different flow curves are used for weekdays and weekends, because on weekdays typically two rush-hour peaks can be identified in the morning and in the evening, which is typically not the case on weekends. Furthermore, variations in daily traffic volumes between weekdays or months can be considered, which may be relevant to capture congestion events e. g. due to weekend commuters, or holidays.
  The ADT of different vehicle categories should be disaggregated by specific flow curves and traffic variation patterns, because e. g. goods transport (mostly by HGV) follows different temporal patterns from individual passenger transport.
- Hourly traffic volumes of different vehicle categories are converted to passenger car units (PCU), since capacities are also expressed in this unit. Suggested conversion factors are shown in Table 8.
- Hourly total traffic volumes (from all vehicle categories) in PCU are related to – i. e. divided by – the corresponding hourly capacity, yielding the volume-to-capacity ratio.
- Each hour or time slice considered is assigned a LOS by comparing the volume-to-capacity ratio to the corresponding V/C thresholds.
- The traffic volumes by LOS and vehicle category in each time slice are weighted if necessary (e. g. a weekday hour-of-day gets a relative weight of 5, while a weekend hour gets a relative weight of 2), summed up, and divided by the total traffic volume of all time slices of the corresponding vehicle category, to derive the LOS share per vehicle category on the road link in question.
- The resulting LOS shares have to be validated. This can e. g. be done by
   - comparing overall LOS shares in the application case to those from other studies. Examples from previous studies are presented in Appendix A.2 (e. g. Figure 21 – however, be aware that LOS shares can vary between different areas!).
   - mapping the resulting LOS shares on the road network (e. g. the sum of Stop+Go and Stop+Go II). An example of such a visualization is shown in Figure 23 (Appendix A.2). Such map outputs may also be discussed with local traffic authorities who can give feedback on whether the resulting shares are plausible.

     Please also see the additional measures in the "Recommendations" subchapter in LOS (Chapter 6.4), bulletpoint "Validate…".

  Possibly, the input V/C thresholds have to be adapted based on this validation and the LOS classification as well as the emission calculation have to be repeated.

It is encouraged anyway to carry out sensitivity analyses with different V/C thresholds (see also Chapter 6.3).

Figure 14: Illustration of the capacity approach for an example road link on an average weekday



Depending on the hourly traffic volume (PCU/h) and the volume to capacity (V/C) thresholds, each hour is assigned a LOS, shown here in different colours. It should be noted that two hours of Stop+Go II represent a rather extreme case in the European context.
Source: INFRAS (2024)

Table 7: Example volume/capacity ratio (V/C) thresholds between LOS differentiated by road type, comparing different sources

Road type	Freeflow - heavy (B - C)	Heavy - saturated (D - E)	Saturated - stop+go (E - F)	Stop+go - Stop+go II
Motorway (INFRAS 2024)	0.60	0.86	1.20	1.40
Motorway (Notter et al. 2024)	0.40	0.66	0.95	1.05
Motorway (SN 640 020a)	0.60	0.90	1.00	n/a
Motorway (HBS 2015)	0.55	0.90	1.00	n/a
Primary non-Motorway (INFRAS 2024)	0.30	0.55	0.95	1.05
Distributor, Local (INFRAS 2024)	0.20	0.45	0.80	0.90
Distributor, 80 km/h (HBS 2015)*	0.38	0.68	n/a (conversion result = 0.44)	n/a
Distributor, 50 km/h (HBS 2015)*	0.21	0.38	n/a (conversion result = 0.30)	n/a

NOTE:

- The values from sources INFRAS (2024) and Notter et al. (2024) are calibrated values from two different case studies, which used inputs from different traffic models with different capacity information (even for the same road links in overlapping areas)
- The sources SN 640 020a and HBS 2015 are Swiss and German norms for traffic planning
- The capital letters in the column titles (B, C, D, E, F) correspond to the LOS definitions in the norms (which use the same classification as the U.S. Highway Capacity Manual)
- * Last two lines (marked with asterisk *): For non-highways, the norms (HBS 2015 and SN 640 020a) do not specify V/C thresholds, but density thresholds of PCU/km (identical values in both norms). These have been converted to V/C thresholds by multiplying with the corresponding average speed from Table 9 and dividing by capacity from Table 17. It can be noted that the thus calculated thresholds for "Saturated - Stop+Go" are lower than for "Heavy – Saturated", which does not make sense. Probably a different average speed value should be used, but this is not specified anywhere.

Sources: Notter et al. (2024), HBS 2015, Swiss norm SN 640 020a, INFRAS calculations

Table 8: Suggested passenger car units (PCU) by vehicle category

ehicle category	Passenger car units (PCU)
Passenger car	1.0
Light commercial vehicle	1.0
Heavy goods vehicle	3.0
Urban bus	3.0
Coach	3.0
Motorcycle	0.9

Source: HBEFA 4.2

6.2.3 Speed-based approach

In the speed-based approach, average vehicle-speed in km/h is related to speed thresholds between the LOS. This is **also usually done at (at least) hourly resolution**.

Speed information can be obtained from various sources:

- **Ideally, measured speeds are used as inputs**. Such measured speed data by link over a larger area are usually available as floating car data from mobile phone operators or traffic data/navigation companies (such as TomTom, Inrix, Garmin, or HERE). The main disadvantage of such data is their high price: Hourly information for average weekdays for the main road network (i. e. Local roads and upwards in the hierarchy, without Access roads) for an area the size of Switzerland will likely incur a cost in the order of magnitude of several 10'000 EUR. Prices may be different in other countries, however, and may be negotiable.
  Ideally, not only average speed data are obtained, but also percentiles: From this information, also sub-hourly congestion events or irregularly occurring congestion events can be estimated (see e. g. (Schmaus et al. 2023)).
- **Speed information may be available from traffic models**. However, this is usually only the case for average daily, or peak hour states. Since average daily speed will not help with the distribution of LOS over the day, peak hour information usually remains, and therefore has to be complemented with other estimates for the rest of the day (e. g. the capacity approach, thus forming a "hybrid" approach).

In addition, speed from traffic models is not the observed actual speed but calculated based on capacity-restraint (CR) functions. These depend on the capacity information in the traffic model, and this in turn may be calibrated (see also previous subchapter).

- Instead of speed information, **travel time information may also be used** – it is the inverse of speed.
- In another "hybrid" approach, **speed can be calculated from volume and capacity using the CR functions** (which are also used in traffic models). This approach is very close to the capacity approach (apart from the CR function parameters, which need to be known additionally, it uses the same input data). Its advantage is that instead of V/C ratios – which include guesswork and calibration iterations – speed thresholds between LOS (as in Table 9) can be used, which may save calibration time.

To implement the speed-based approach, the following steps are carried out:

- As in the capacity approach, ADT must be disaggregated to the timescale of the speed data (usually hourly). Often, information on the share of traffic per hour is included with the speed data:
- If the speed data source is telecommunication data, information on how many vehicles sent speed signals is also available and often included. Since the speed signals are available only from a sample of vehicles (typically 1-5 %), the hourly traffic flow information may not be as reliable as from traffic counts; on the other hand, the advantage over traffic count data is, however, that this information is available for each road link. In tests carried out by INFRAS on data from HERE (Greinus et al. 2022), it was found to be sufficiently reliable.
  - If the speed data is from traffic models, the traffic flow in the time slice in question is available anyway, as this is the main output from traffic models.
- Hourly speed is related to speed thresholds between LOS, and LOS are thus assigned to each hour on each road link. Suggested speed thresholds have been derived by INFRAS in the framework of the uCARe project (Cox et al. 2022) and are presented in Table 9.
- As in the capacity approach, the last step is to weight traffic volumes by LOS and vehicle category in each time slice if necessary (e. g. a weekday hour-of-day gets a relative weight of 5, while a weekend hour gets a relative weight of 2), sum them up, and divide them by the total traffic volume of all time slices of the corresponding vehicle category, to derive the LOS share per vehicle category on the road link in question.
- Care should be taken with very short road segments between two nodes. In such places, the LOS may be misallocated, especially in front of junctions or (temporary) narrow points with associated speed reduction, even though there is hardly any traffic during the period under consideration.

Table 9: Suggested average speed thresholds (in km/h) between LOS, by speed limit

Speed limit (km/h)	Freeflow - heavy	Heavy - saturated	Saturated - stop+go	Stop+go - Stop+go II
30	28.0	20.2	12.4	7.6
40	34.0	25.3	15.5	8.7
50	41.0	29.0	17.1	9.2
60	54.0	37.9	19.8	9.2
70	62.0	45.1	23.0	10.1
80	72.0	52.2	25.5	10.5
90	83.0	60.0	26.0	11.0
100	92.0	66.3	26.0	11.0
110	106.0	77.1	26.0	11.0
120	117.0	87.1	26.0	11.0
130	127.0	95.3	26.0	11.0
140	135.0	108.6	26.0	11.0

These average speed thresholds in [km/h] can be applied to all static TS with the given speed limit.
Source: INFRAS, own analyses

6.2.4 Fixed shares approach

Under the fixed shares approach, fixed shares of the mileage by LOS in a given static TS (or set of static TS) are assumed. This approach is typically used:

- for the subordinate road network (e. g. Local/Collector and Access/Residential roads), which only account for a small share of the total mileage in an area;
- for all urban areas, following the argument that the capacity approach is fundamentally unsuited for urban areas due to the fact that link capacity is not the limiting factor for traffic flow in urban areas, but rather node capacity and other obstacles.
- The fixed shares approach can also be an option for entire application case with limited resources if it is not important to spatially differentiate areas with denser traffic from those with less dense traffic.

Fixed shares can be obtained e. g. from:

- Literature (other/previous studies)
- The HBEFA application (Menu *Info > Aggregate Traffic situations* in HBEFA up to 4.2; menu *Traffic conditions > Aggregate Traffic situations* from HBEFA 5.1): The mileage shares of each traffic situation/gradient per traffic situation by vehicle category (adding up to a total of 100 % per vehicle category) can be converted to percentages per static TS (adding up to a total of 100 % per vehicle category and static TS) if they are divided by the sum of shares in each static TS/vehicle category.

An example of fixed shares for the subordinate road network (Local/Collector and Access/Residential roads) used in national emissions modelling for Switzerland is presented in Table 10.

Table 10: Fixed LOS shares used on local and access roads in Switzerland

Road type (speed limit)	Freeflow	Heavy	Saturated	Stop+Go	Stop+Go II
Access/residential (all speed limits)	31 %	34 %	34 %	0 %	0 %
Local/collector (<70 km/h)	39 %	36 %	20 %	4 %	2 %
Local/collector (>=70 km/h)	18 %	27 %	37 %	13 %	6 %

Source: Notter et al. (2024)

6.2.5 Further approaches

In addition to the above-described fundamental approaches, there are a number of further approaches that require specific input data:

- Swedish index approach: In this approach, which could be categorized as a subtype of the capacity approach, so-called traffic flow ranks (ranked/cumulative distribution curves of hourly traffic indices, in all comprising the year's 8760 hours) are derived from traffic count data. Traffic volumes by LOS 1-3 (Freeflow to Saturated) are determined by applying thresholds (derived from fundamental diagrams for different road categories and speed limits) to these curves. Volumes in LOS 4-5 (Stop+go, Stop+go II) are determined as fixed shares of LOS 3 (Jerksjö et al. 2022).
- Germany: Options for determining the LOS are described in detail in VDI Guideline 3782 Sheet 7, Chapter 8.3 (VDI 2020).
- In scenario assessments, it has been found that sometimes minor differences in input data could lead to different LOS, with a disproportionate emission impact. In such cases, emission factors between the different LOS have been interpolated to smoothen the stepwise emission effect (see e. g. (Tsanakas et al. 2017)).
- Google maps: A frequently mentioned idea is to use the information on traffic conditions available from Google maps. This is available almost world-wide and it is based on measured speed from mobile phones.
  The following factors, however, usually prevent the use of this information source:
  - Costs: Querying the information from the Google API for every road link in question and every hour will lead to high costs. An "intelligent" approach to minimize the number of API queries and save on those costs, on the other hand, requires development time.
  - Reference timeframe not selectable: The Google API does not allow selecting an explicit timeframe for which the travel time information can be queried. This would be a requirement in most application cases.
  - Unclear reference timeframe and reliability: Google does not disclose the methodology by which the travel times are calculated, or which timeframe the observed data behind the travel times are based on. Transparency on these points is a requirement, however, in most applications.

- TomTom provides several API endpoints and online tools for observing traffic conditions on the road network. As opposed to the Google API, the reference timeframe can be specified; however, also here the cost may be a limiting factor when working with large road networks.
  - The Traffic Flow service returns flow data of road segments in real time closest to given coordinates, which can be used to observe the traffic conditions over a given period of time. The response contains freeflow speed and travel time as well as the relating current values. (https://developer.tomtom.com/traffic-api/documentation/traffic-flow/traffic-flow-service, https://developer.tomtom.com/traffic-api/documentation/traffic-flow/flow-segment-data)
  - The Route Analysis endpoint of the Traffic Stats API delivers statistics and attributes of route segments, like speed limit, functional road class, length of segment, distributions of travel time and speed as well as sample sizes for a given timeframe. A timeframe can be defined as reference, which is used for calculating and returning the ratio of travel time in the current timeframe to travel time in the reference set. (https://developer.tomtom.com/traffic-stats/documentation/product-information/introduction, https://developer.tomtom.com/traffic-stats/documentation/api/route-analysis)
- Expensive (mostly not practicable) approach: Carry out measurement drives on target road network at different times of day.

6.2.6 Discussion of approaches

Table 11 presents an overview of the advantages and disadvantages of the fundamental approaches described in the previous subchapters.

Table 11: Advantages and disadvantages of LOS classification approaches

LOS classification approach	Advantages	Disadvantages/challenges
Capacity-based	▪ Input data (link capacities, ADT, hourly flow profiles) is usually available, or estimable/transferrable from other studies ▪ Approach is sensitive to changes in traffic volumes and can therefore be applied for future/hypothetical scenarios in which changes in traffic volumes are estimated. ▪ V/C thresholds can be tuned to achieve plausible LOS shares	▪ The approach may not be suitable where possible travel speed is not governed by link capacity, but rather by node capacities or other factors (like random obstacles on the road). Therefore, especially in urban areas, the results of the capacity approach are not accurate – but they still represent the “best available estimate” in many cases ▪ The capacity approach cannot capture congestion resulting from capacity restraints on neighboring road links ▪ Capacity information from traffic models needs to be verified, and sometimes recalculated ▪ The possible range for V/C thresholds is large; they need to be validated and possibly tuned, which introduces an additional degree of freedom and uncertainty

LOS classification approach	Advantages	Disadvantages/challenges
		▪ Appropriate hourly flow profiles must be selected for each road segment and may differ by direction of traffic. ▪ If measured traffic volume data are used as input, only LOS up to 3 (saturated) can be classified with the capacity approach, since by definition, observed traffic volume cannot exceed capacity. In this case, LOS 4-5 must be separated from LOS 3 using fixed shares (as e. g. in the Swedish Index approach).
Speed-based	▪ Most direct approach: Speed can be directly compared to speed thresholds (see Table 9) ▪ If speed is measured (e. g. by mobile phones), no calibration or tuning is required	▪ Measured speed data over entire networks and time periods are expensive or may not be available ▪ Due to the masking of shorter and irregular stop+go events when using hourly average speeds, certain stop+go shares may need to be added "manually" to the result ▪ When using input speeds from traffic model, these may need to be tuned; in addition, they are usually only available for average states or peak hours, so another approach is required for the rest of the time
Fixed shares	▪ More appropriate than capacity-based approach for subordinate road network (access roads, possibly collectors or all urban roads) ▪ Fixed LOS shares by area, road type, speed limit, and vehicle category are available for all "HBEFA countries" in the "aggregate traffic situation" patterns provided in the HBEFA app)	▪ Not sensitive to spatial differences in traffic volumes and capacities, or to changes in time or between scenarios ▪ Source of fixed LOS shares may not be better than any of the above methods

Source: HBEFA workgroup, interview partners.

Some additional remarks:

- An hourly resolution is not sufficient to capture short stop+go events, especially if averaged for typical day types over the year, may mask shorter stop+go events or events occurring irregularly (e. g. on certain weekdays, holidays etc.). This applies to both the speed-based and the capacity approach. However, more detailed data are only rarely available.
- Therefore, it is both a disadvantage and an advantage of the capacity approach that V/C thresholds can, or must be calibrated or tuned:
    - The disadvantage is that the high possible range of the V/C thresholds introduces uncertainty;

- The fact that they can be tuned/adapted allows for adjustments if the result is not plausible. This can e. g. be the case when hourly average flow profiles mask shorter or irregularly occurring stop+go events – in this case stop+go thresholds may be lowered. to consider this effect.

► Comparisons in Switzerland between the capacity approach, the speed-based approach, and the "hybrid" approach in which speed is calculated from CR functions, have shown that – apart from other differences, which depend on the exact settings used (mainly V/C thresholds), implausibly low stop+go shares result with the speed-based approach, as well as the "hybrid" CR-based speed approach. This is likely due to the fact that temporal averaging masks short, or irregularly occurring stop+go events (compare Figure 21 and Figure 22 in Appendix A.2). This problem could be resolved by

- Adding certain stop+go shares in a post-processing step (e. g. based on more detailed data available from certain locations)
- Using measured distribution information of speed, such as percentiles (see e. g. Schmaus et al. 2023)

  Overall, in the example shown, roughly 3 % lower energy consumption and emissions resulted from the LOS shares calculated with the speed-based approach compared to those from the capacity approach.

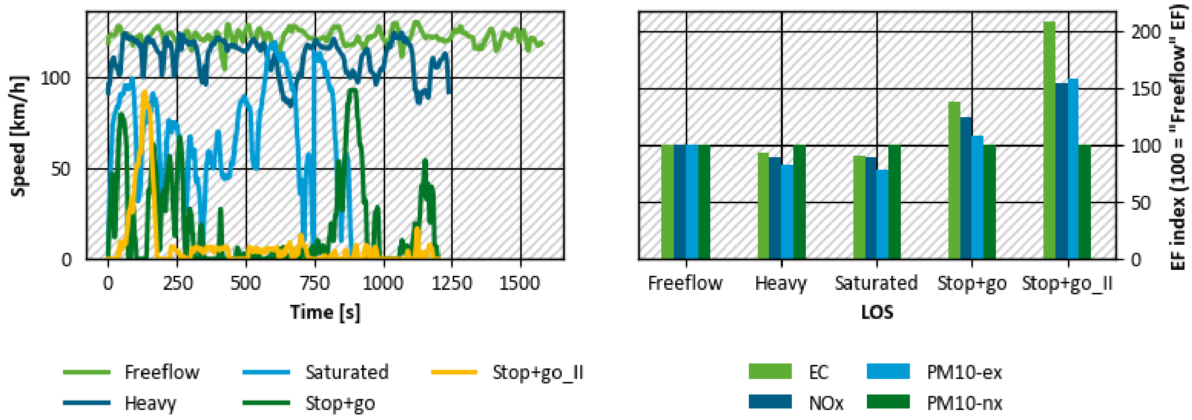
6.3 Driving behaviour and emission sensitivity

The Level of Service (LOS) influences driving behaviour greatly; correspondingly, individual emission factors are very sensitive to LOS choice – they can be twice or even thrice as high in "heavy stop+go" conditions (LOS 5) as in freeflow.

This can be seen in the examples of a rural motorway at 120 km/h (Figure 15) and an urban distributor at 50 km/h (Figure 16). Additional figures in A.2 (Figure 24 for a rural distributor at 80 km/h, and Figure 25 for an urban access road at 30 km/h) confirm the general picture.

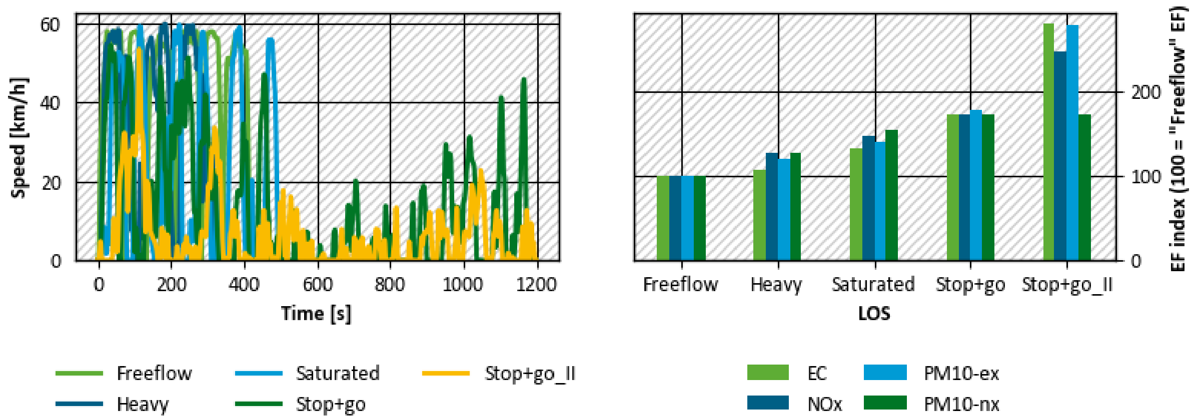
Generally, energy consumption and emissions increase with the higher driving dynamics in denser traffic conditions. It is noteworthy, though, that at high speed limits, freeflow energy consumption and emissions are higher than in heavy or saturated LOS conditions (Figure 15). This is due to the fact that in heavy or saturated traffic, cars do not accelerate to such high speeds as in freeflow conditions.

Figure 15: Speed profiles and relative EF differences on a rural motorway at speed limit 120 km/h in different LOS



Note: EF indexes shown are valid for average PC in Germany, 2020.
Source: HBEFA 4.2

Figure 16: Speed profiles and relative EF differences on an urban distributor at speed limit 50 km/h in different LOS



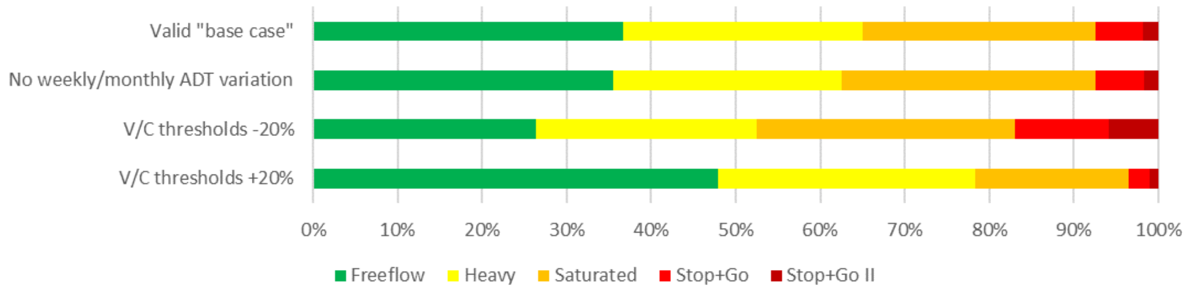
Note: EF indexes shown are valid for average PC in Germany, 2020.
Source: HBEFA 4.2

For total emissions in a given area, the high sensitivity of the higher LOS is partly compensated by the fact that usually, these conditions only affect a small share of total mileage.

Nevertheless, emissions and energy consumption are sensitive to LOS classification. E. g. the choice of V/C thresholds when using the capacity approach can have a high impact. In sensitivity calculations carried out for the Canton of Lucerne in Switzerland, mileage shares of the denser LOS increased significantly when lowering the V/C thresholds by 20 % (Figure 17), and energy consumption and emissions increased by roughly 5-10 % (Table 12). Conversely, increasing the V/C thresholds by 20 % had a similarly high impact on LOS shares of mileage, but a less than half the impact on energy consumption and emissions because Stop+go shares, which have the highest emission impact, were less strongly affected.

On the other hand, ignoring monthly and weekly variations in traffic volumes (ADT) had a negligible impact on both LOS mileage shares and energy consumption/emissions.

Figure 17: Mileage shares by LOS in different sensitivity calculations for the Canton of Lucerne in Switzerland



Source: INFRAS (own calculations)

Table 12: Energy consumption and emission changes compared to the valid base case in sensitivity calculations for the Canton of Lucerne in Switzerland

Sensitivity case	CO_2(rep)	EC	NO_x	PM10-ex	PM10-nx
No weekly/monthly ADT variation	-0.2 %	-0.2 %	-0.3 %	-0.3 %	0.0 %
Alpha thresholds -20 %	9.2 %	9.2 %	9.0 %	8.5 %	4.1 %
Alpha thresholds +20 %	-3.7 %	-3.7 %	-3.6 %	-3.0 %	-2.7 %

Source: INFRAS (own calculations)

6.4 Recommendations

- Unless emission calculations are carried out at fine (e. g. hourly) temporal resolution anyway, distinguishing multiple LOS shares per time unit is preferrable over using a static “average” LOS. The latter can lead to underestimation of energy consumption and emissions especially on motorways at high speeds, where the intermediate LOS have the lowest energy consumption and emissions.
- If measured speed data are available, they are preferrable over other approaches to classify LOS.
- If using hourly average speeds, stop+go shares may need to be adapted in a post-processing step, since hourly averages will mask short and irregular stop+go events. This can be avoided if not only averages, but also distribution information (percentiles) of measured speeds is obtained with the input data.
- The capacity approach is preferrable if measured speed data is not available or prohibitively expensive, and/or if scenarios with different traffic volumes need to be compared. In urban areas, the capacity approach must be used with caution, since there, link capacity may not be the limiting factor for traffic flow.
  - When using the capacity approach,
    - The input capacities need to be checked for plausibility;
    - The V/C thresholds need to be tuned by checking the resulting LOS shares and energy consumption results (see below).
- The fixed shares approach can be used

- On the subordinate road network;
- For urban areas;
- In application cases where spatial differences between traffic conditions do not need to be considered.

► Validate the results of LOS classification:

- By comparison of overall LOS shares to other studies (e. g. Figure 21 in Appendix A.2 – but be aware that LOS shares can vary between different areas!) or to the "Aggregate traffic situations" available for each country in the HBEFA application;
- By comparison of average CO_2 emissions by vehicle category in your application to national averages. In case of relevant deviations, these deviations should be explainable (e. g. by differing shares of rural/urban/motorway mileage in the study area compared to national average, different gradients, different fleets, …);
- By verification with local knowledge (e. g. local authorities, traffic planners). Prepare as inputs:
  - Visualizations of LOS shares, e. g. LOS 4+5 shares, on maps;
  - Visualizations of hourly traffic flow profiles and LOS classification for known hotspots.
- By comparison of resulting average speed (weighted average of study area) to respective info from national statistics if available (André et al. 2000)

► Carry out sensitivity analyses with different settings.

7 Combinations of parameters

Not all possible combinations of TS parameters form a valid TS (compare the TS scheme in Figure 2). After classifying the static parameters on an input road network one-by-one, usually some invalid TS will result when combining them. Such invalid TS have to be eliminated by changing at least one of the static parameters (area, road type, or speed limit) so that a valid TS results.

The priority in which parameters should be adapted is as follows:

- Generally, the most unreliable or uncertain parameter should be adapted. For example, if road types could be classified reliably based on the input data but the speed limit had to be estimated roughly, rather the speed limit should be adapted.
- If no priority can be identified based on input reliability, the less sensitive parameters should be varied. Under this premise, road type or area should in tendency be adapted before the speed limit.

8 Gradients

8.1 Definition

Road gradients are defined based on % slope (i. e. vertical elevation change / distance) in four classes, whereby the non-flat classes are available as ascending only (referring to emission factors for climbing vehicles), descending only (referring to emission factors for vehicles going downslope), or both (referring to average emission factors for the same traffic volume in both directions) (Table 12).

Gradients are not part of the "Traffic Situation Scheme" because in HBEFA, they do not affect the choice of the input driving cycle. They can be combined with any TS or driving cycle, respectively. The hot base emission factors are produced in the PHEM model by assuming a constant gradient over the entire driving cycle. If the engine power of a vehicle is not sufficient to reach the speed prescribed by the driving cycle in an ascending gradient, PHEM decreases the speed to the possible maximum. Therefore, the actual speed profile used is adapted to the gradient. In this case, the output column "v" (average speed) in HBEFA contains the speed adapted by PHEM – it is the reason why the values in this column can deviate from the input speed of the driving cycles.

Table 13: Definition of gradient classes in HBEFA

idgrad	Gradient class	Remark
30	0 %	flat
32	+/-2 %	ascending/descending
34	+/-4 %	ascending/descending
36	+/-6 %	ascending/descending
54	-6 %	descending
56	-4 %	descending
58	-2 %	descending
62	2 %	ascending
64	4 %	ascending
66	6 %	ascending

Source: HBEFA 4.2

8.2 Classification methods and rules

In some application cases, road link gradients, or elevation of road link end nodes, are available in the input road network. E. g. in Sweden and Norway, z-values of endpoints are available in the national road databases (NPRA 2023; Trafikverket 2024).

Gradients are calculated as the ratio of elevation change by distance for each road segment. They are then reclassed into the HBEFA gradient classes, using 1 %, 3 %, and 5 % as thresholds between the classes.

If no gradient or elevation information is available on the road network yet, elevation information has to be assigned to road links based on a digital elevation model (DEM). This can be done in various ways:

- Elevation information can be assigned to the end nodes of each road link. In this case, care should be taken not to average out down- and uphill slopes, or changing slopes, in the same link. Therefore, when assigning elevation information only to end nodes, links may have to be subdivided into shorter segments for gradient classification.
- Elevation information can be assigned to all vertices of road links. In this case, separate gradients can be calculated for all subsections between vertices, and a weighted average gradient is calculated for the link.
  This method will take care of slope changes within links so that subdividing links should not be necessary (unless, very long straight link sections without vertices occur).
  However, this method should only be applied if the road network and the digital elevation model match and are rather accurate. Otherwise, it may occur that vertices are "off the road" (at least from the perspective of the digital elevation model), and in such cases unrealistically high gradients may occur.
- Bridges and tunnels have to be considered as special cases, since the surface elevation shown in the digital elevation model does not correspond to the road elevation for the respective road links. Therefore:
  - Bridge and tunnel road links have to be identified. If the information whether a link is a bridge or tunnel is not included in the road network, it may be transferred e. g. from OpenStreetMap[24].
  - Either the gradient of bridges and tunnels can be set to 0 %, or it can be calculated based on the start and end elevation. However, the latter can often not easily be identified automatically in scripts, because the road link segmentation usually does not coincide well with the start and end of bridges and tunnels. Therefore, it can be done manually for important known cases (i. e. longer bridges or tunnels with significant gradients and high traffic volume), and for the rest of bridges and tunnels, the gradient is set to 0 %.

If the input traffic information differentiates direction of travel, the positive ("climbing") and ("descending") gradients can be assigned. The +/- (average climbing/descending) gradient classes can be used if there is no information on which share of the traffic goes in which direction on a road segment. The respective emission factors assume a 50:50 percent share of both directions.

8.3 Emission sensitivity

Energy consumption and emissions are quite sensitive to changes in road gradient.

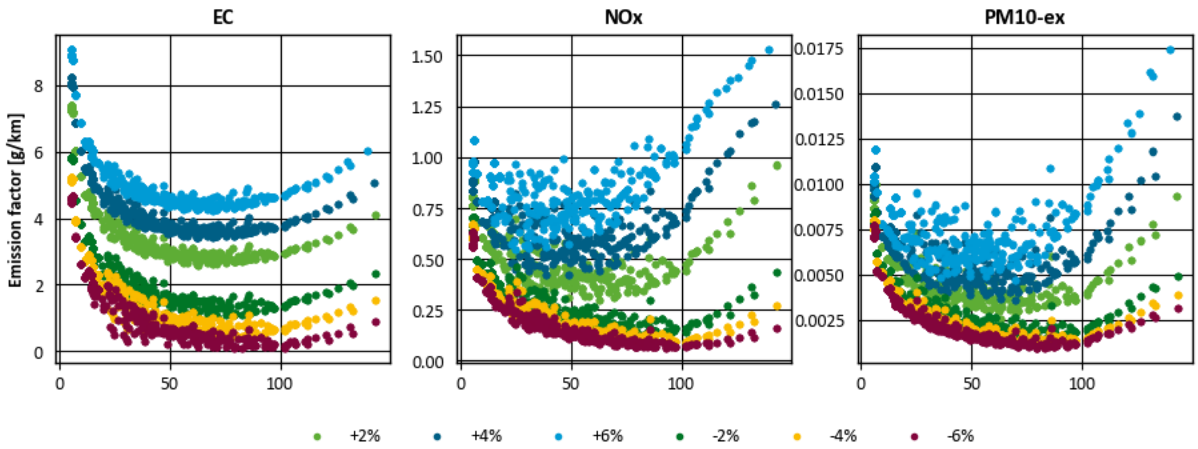
As Figure 18 shows, energy consumption factors for average PC are almost linearly shifted upwards with each higher ascending gradient class. The inverse is true for the descending gradient classes, although not as markedly. For NO_x and PM10 exhaust, this finding applies as well, but the changes get even more pronounced at higher speeds.

[24] www.openstreetmap.org; for data download of larger regions, visit e. g. https://download.geofabrik.de/

For averaged factors by direction (i. e. ascending/descending average), these differences partially compensate each other. But still, steeper gradients result in higher energy consumption and markedly higher emissions – particularly for NO_x (Figure 19).

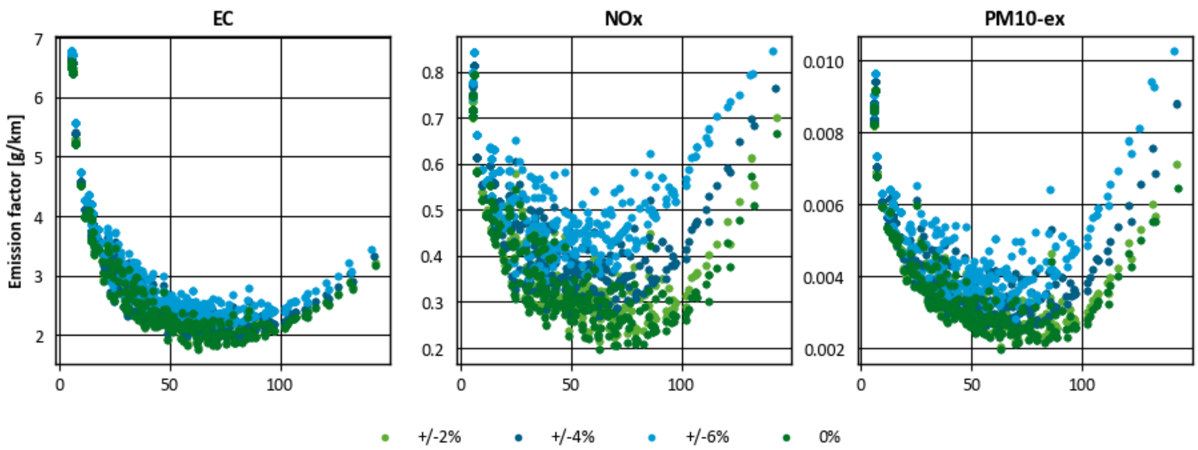
For other vehicle categories, the effects are similar. For HGV, analogous plots are shown in Appendix A.3 (Figure 26, Figure 27). The difference to PC is that gradient effects are most pronounced for energy consumption and less strong for NO_x and PM10 exhaust. For ascending/descending average NO_x and PM10 emission factors, the differences between gradients almost disappear. The reason is the high share of new HGV with very efficient SCR catalysts and particle filters in the fleet.

Figure 18: Energy consumption and emission factors of average PC for selected components plotted by average speed and gradient classes differentiating ascending and descending driving direction.



Note: EF shown are valid for average PC in Germany, 2020. EF for 0 % are not shown here because the figure aims to show the difference between ascending and descending gradients.
Source: HBEFA 4.2

Figure 19: Energy consumption and emission factors of average PC for selected components plotted by average speed and average ascending/descending gradient classes



Note: EF shown are valid for average PC in Germany, 2020.
Source: HBEFA 4.2

8.4 Recommendations

- Use gradient or elevation information from road network if available; otherwise, assign from a digital elevation model.
- If road links are short and/or gradient changes within road links are insignificant, it is sufficient to use elevation information from start and end nodes of links. Otherwise,
  - Links may be subdivided into shorter links for gradient assignment (they may later be aggregated again);
  - Or, elevation information may be extracted for all vertices on each link (i. e. all coordinate points making up the link geometry), and an average gradient weighted by the distance between the vertices may be derived.
- Take into account bridges and tunnels; OpenStreetMap can be used to identify the respective road links. On bridge and tunnel links, only use the elevations of link endpoints, or set gradients to zero.

9 Fleet composition

Fleet composition is actually not directly related to the choice of traffic situation. However, due to how vehicles of different technologies are used, the typical fleet composition varies by road category (i. e. motorway, rural, or urban). This is reflected in HBEFA in the manner that for each country and traffic scenario, an overall average fleet composition is available as well as three fleet compositions for the three road categories (see also Chapter 1.2.3).

If emission factors at higher fleet aggregation levels than subsegment level are queried from HBEFA, the weights used in aggregation correspond to the fleet composition indicated in color (green, blue, orange) on the TS scheme (Figure 2). These are the default/recommended fleet compositions per TS.

However, users may query emission factors at subsegment level from HBEFA and aggregate such emission factors to higher fleet aggregation levels; in that case they may use any fleet composition.

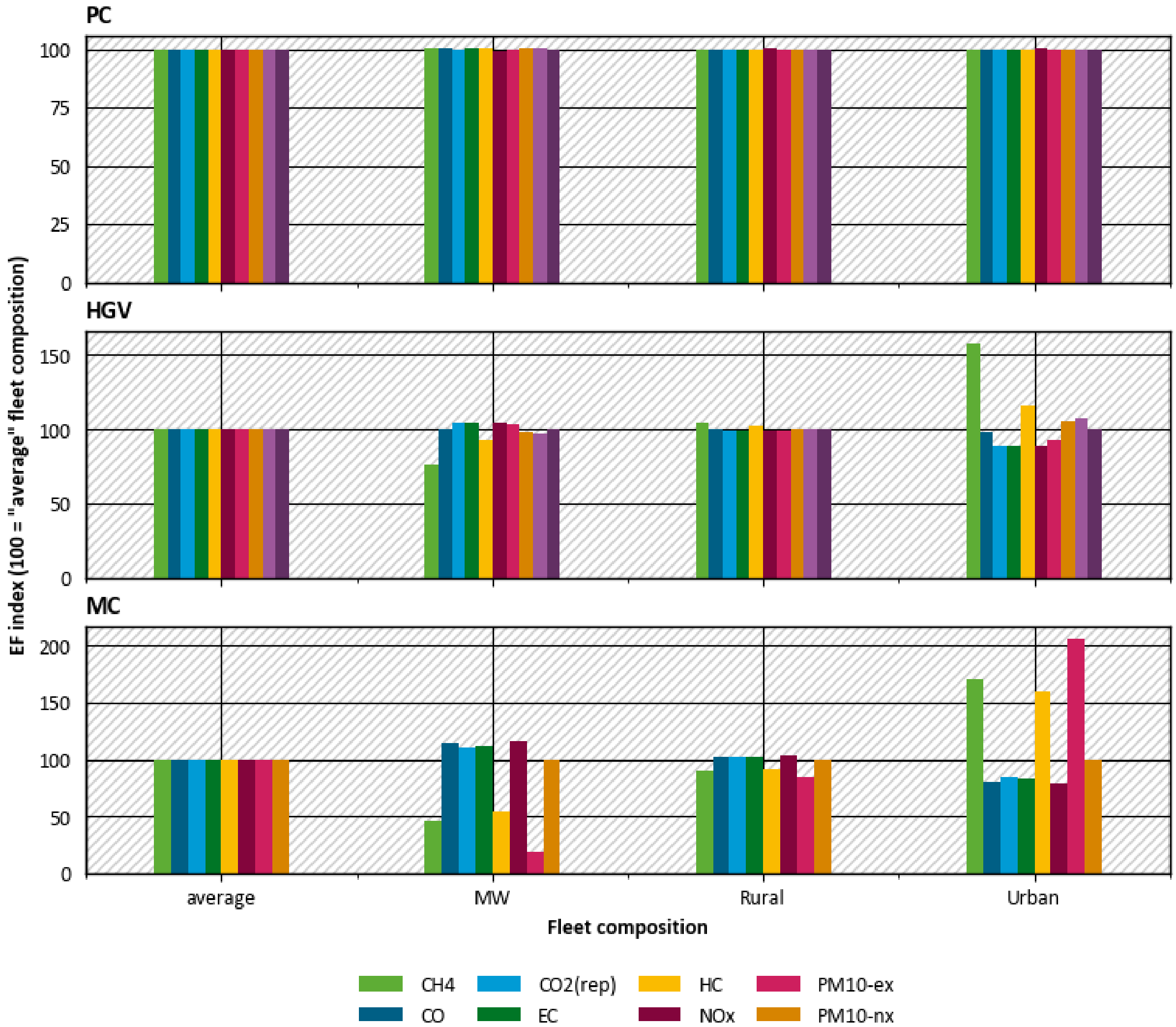
Therefore, users should be aware of the emission and energy consumption impact of different fleet compositions. Figure 20 shows the relative differences in emission factors of different pollutants as well as energy consumption (EC) between the fleet compositions for the example of Germany and the year 2020, for a rural motorway at 120 km/h in freeflow conditions. We can observe that:

- For passenger cars, the differences between the fleet compositions are so small that they are almost negligible;
- For HGV and MC, however, we see significant differences for some components:
  - For HGV, it is mainly CH4 (and to a lesser extent HC) that is significantly higher with the urban than the motorway fleet composition. This is due to a higher share of CNG (natural gas) vehicles on urban roads;
  - For MC, it is mainly CH4, HC, and PM10-exhaust that are significantly higher with the urban than the motorway fleet composition. This is due to the higher fleet share of mopeds and 2-stroke motorcycles on urban roads (in the case of PM10-exhaust, mainly due to the mopeds because these have the highest PM10-exhaust EF).

Of course, these effects may vary with the fleet composition, i. e. by country and reference year.

It should be kept in mind that regional fleet compositions may deviate from the national one; the differences between regions may even be more relevant than between the road categories at national level. If corresponding input data are available, it is advisable to query emission factors from HBEFA at subsegment level and account for fleet weights outside the HBEFA application.

Figure 20: Relative energy consumption and emission factors by fleet composition type for a rural motorway at 120 km/h in freeflow conditions



Note: EF shown are valid for the German fleet in the year 2020. “average” (left-most category) means the overall average fleet composition for all road categories.
Source: HBEFA 4.2

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A Appendix: Additional materials

A.1 Road type

Table 14: **Lookup table between a road type classification in a traffic model implemented in PTV Visum and HBEFA road types, considering also speed limit and assigned area type.**

Straßentyp_GVM	Speedlimit_GVM	Area_HBEFA	IDRoadType_HBEFA	RoadType_HBEFA
Autobahn	120	Rural	10	Motorway-Nat.
Autobahn	100	Rural	10	Motorway-Nat.
Autobahn	80	Rural	10	Motorway-Nat.
Autobahn	100	Urban	10	Motorway-City
Autobahn	80	Urban	10	Motorway-City
Autobahn	60	Urban	11	Motorway-City
Autobahn-Rampe	80	Urban+Rural	20	Primary-nat. non-motorway
AutoStraße	100	Urban+Rural	20	Primary-nat. non-motorway
AutoStraße	80	Urban+Rural	20	Primary-nat. non-motorway
AutoStraße	60	Urban	30	Distributor/Secondary
AutoStraße-Anschluss	80	Urban+Rural	30	Distributor/Secondary
HauptStraße	80	Urban+Rural	30	Distributor/Secondary
HauptStraße	50	Urban+Rural	30	Distributor/Secondary
VerbindungsStraße	80	Urban+Rural	40	Local/Collector
VerbindungsStraße	50	Urban+Rural	40	Local/Collector
Lokale VerbindungsStraße	80	Urban+Rural	40	Local/Collector
Lokale VerbindungsStraße	50	Urban+Rural	40	Local/Collector
SammelStraße	80	Urban+Rural	40	Local/Collector
SammelStraße	50	Urban+Rural	40	Local/Collector
ErschliessungsStraße	80	Urban+Rural	50	Access-residential
ErschliessungsStraße	50	Urban+Rural	50	Access-residential
ZufahrtsStraße	30	Urban+Rural	50	Access-residential
Gesperrte Gegenrichtung	30	Urban+Rural	50	Access-residential

Straßentyp_GVM	Speedlimit_ GVM	Area_HBEFA	IDRoadType_ HBEFA	RoadType_HBEFA
Velo	30	Urban+Rural	50	Access-residential
Fussgängerzone / Fussweg	30	Urban+Rural	50	Access-residential

Note: "GVM" = "Gesamtverkehrsmodell", i. e. traffic model in German

Source: INFRAS (2024)

Table 15: Lookup table between the TomTom FRC (Functional Road Category) classification and HBEFA road types, considering also speed limits.

FRC	FRC description	min. speed limit	max. speed limit	IDRoadType HBEFA	RoadType HBEFA
0	Motorways; Freeways; Major Roads	80	999	10	Motorway-Nat.
1	Major Roads less important than Motorways	50	100	30	Distributor/Secondary
2	Other Major Roads	50	100	30	Distributor/Secondary
3	Secondary Roads	50	100	30	Distributor/Secondary
4	Local Connecting Roads	50	80	40	Local/Collector
5	Local Roads of High Importance	50	80	40	Local/Collector
6	Local Roads	51	80	40	Local/Collector
6	Local Roads	30	50	50	Access-residential
7	Local Roads of Minor Importance	51	80	40	Local/Collector
7	Local Roads of Minor Importance	30	50	50	Access-residential

NOTE: FRC 1 and 2 could also be assigned HBEFA road type "Primary non-motorway"; however, comparing the definition given in HBEFA and the assigned speed profiles to the roads classified in Switzerland with these codes in the TomTom network, "Distributor/secondary" seemed more appropriate. In other countries, "Primary non-motorway" may be more appropriate.

Source: INFRAS (own analyses)

Table 16: Lookup table between the HERE road type classification and HBEFA road types.

HERE ID	HERE Description	HBEFA IDRoadType(s)
1	A road with high volume, maximum speed traffic	10 (if rural), 11 (if urban)
2	A road with high volume, high speed traffic	20 (if rural), 21 (if urban)
3	A road with high volume traffic	30 (default), 31 (if sinuous)
4	A road with high volume traffic at moderate speeds between neighborhoods	40 (default), 41 (if sinuous)

HERE ID	HERE Description	HBEFA IDRoadType(s)
5	A road whose volume and traffic flow are below the level of any other functional class	50

Source: Cox and Notter (2022)

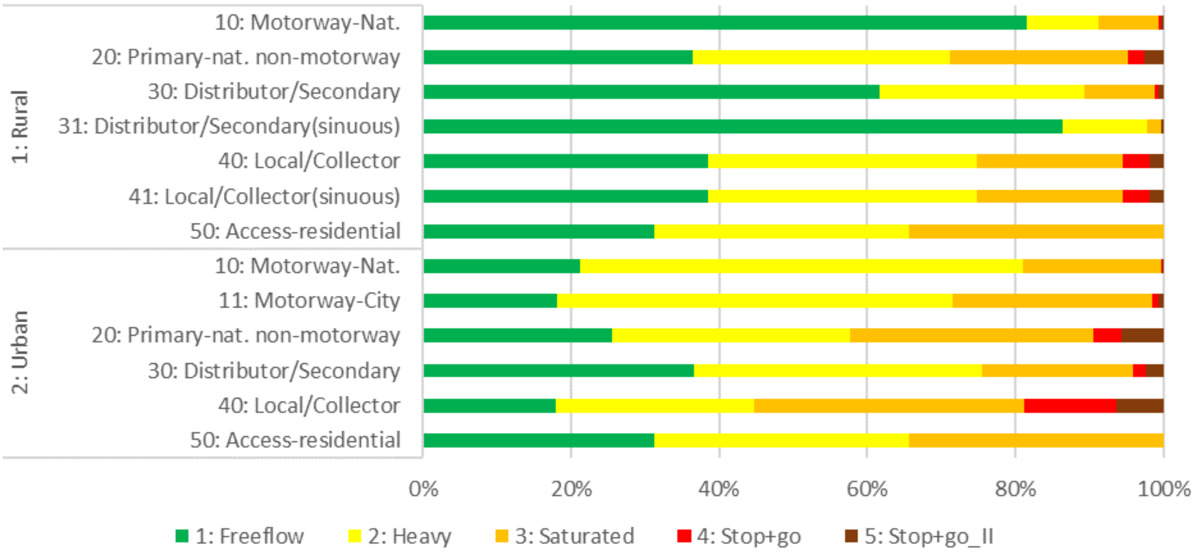
A.2 LOS

Table 17: Typical hourly capacities by road type and number of lanes in PCU/h

Road type (+ area, speed limit)	1 lane	2 lanes	3 lanes	4 lanes
Highway	1200	3950	5750	7 750.00
Distributor (rural, 50-80 km/h)	1150	2150	3250	n/a
Distributor (urban, 50-80 km/h)	1100	1700	2800	n/a
Other (rural+urban, 30-80 km/h)	1100	1700	2800	n/a

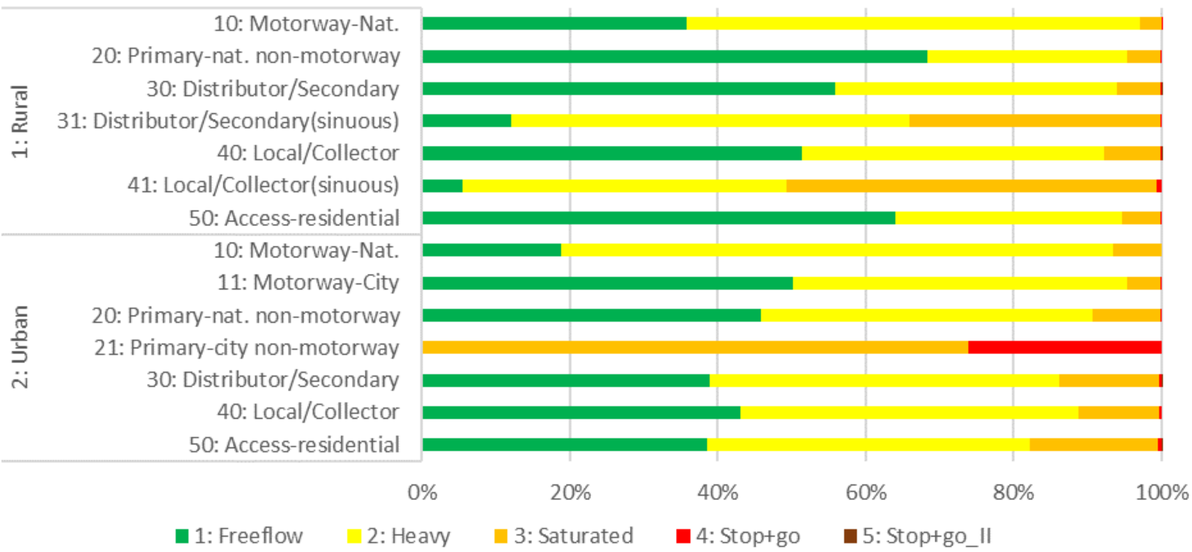
Source: TransOptima et al. (2020)

Figure 21: LOS shares by road type and area for Switzerland, 2017, derived with the capacity approach for the main road network.



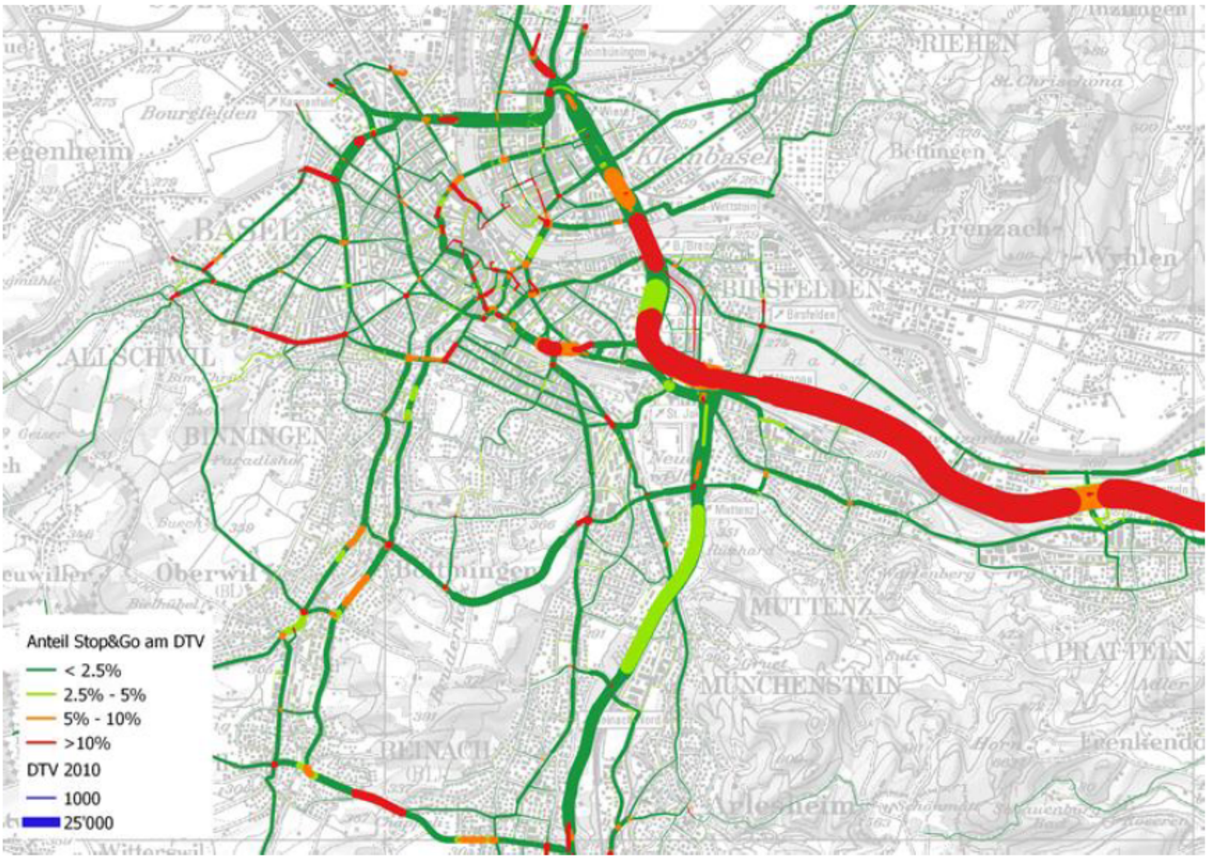
LOS shares have been derived by the capacity approach for motorways, primary non-motorway, and distributor roads, and with fixed shares for local and access roads.
Source: Notter et al. (2024)

Figure 22: LOS shares by road type and area for Switzerland, 2017, derived with the speed-based approach for the main road network.



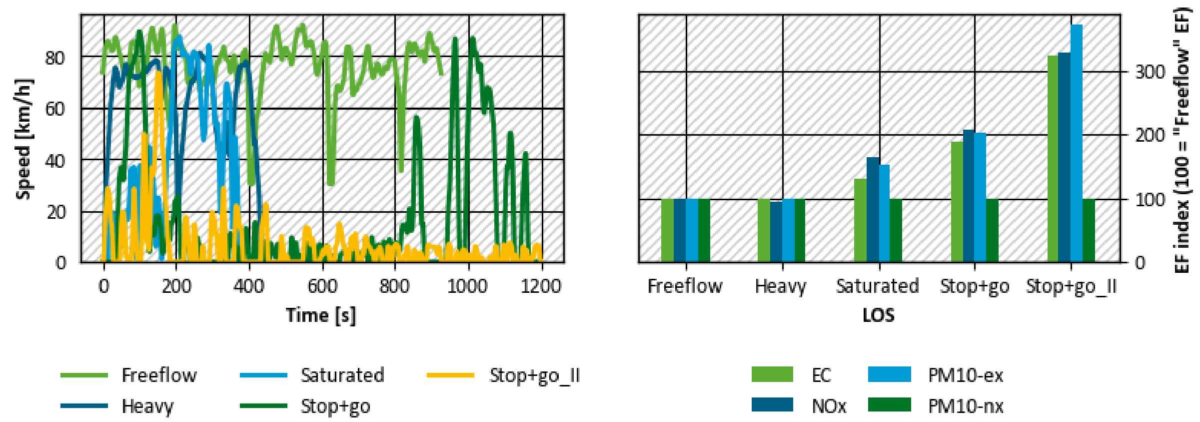
LOS shares have been derived by the speed-based approach for motorways, primary non-motorway, and distributor roads, and with fixed shares for local and access roads. Please note that IDRoadType=21 (Primary-city non-motorway), which exhibits a conspicuous pattern, only includes a very low share of mileage.
Source: INFRAS (own calculations)

Figure 23: Stop+Go shares on the road network for the Basel area, 2014.



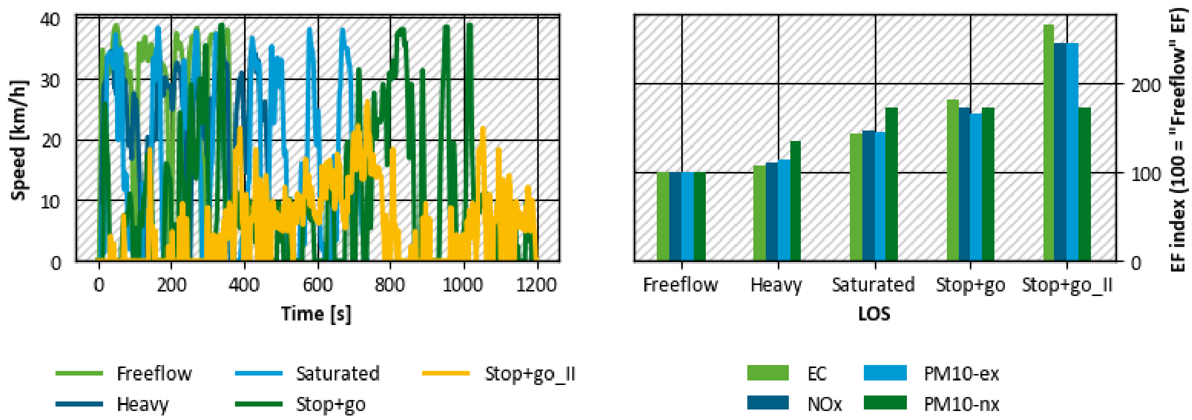
The mapped shares include Stop+Go and Stop+Go II.
Source: INFRAS (own analysis)

Figure 24: Speed profiles and relative EF differences on a rural distributor at speed limit 80 km/h in different LOS for PC



Note: EF indexes shown are valid for average PC (passenger cars) in Germany, 2020.
Source: HBEFA 4.2

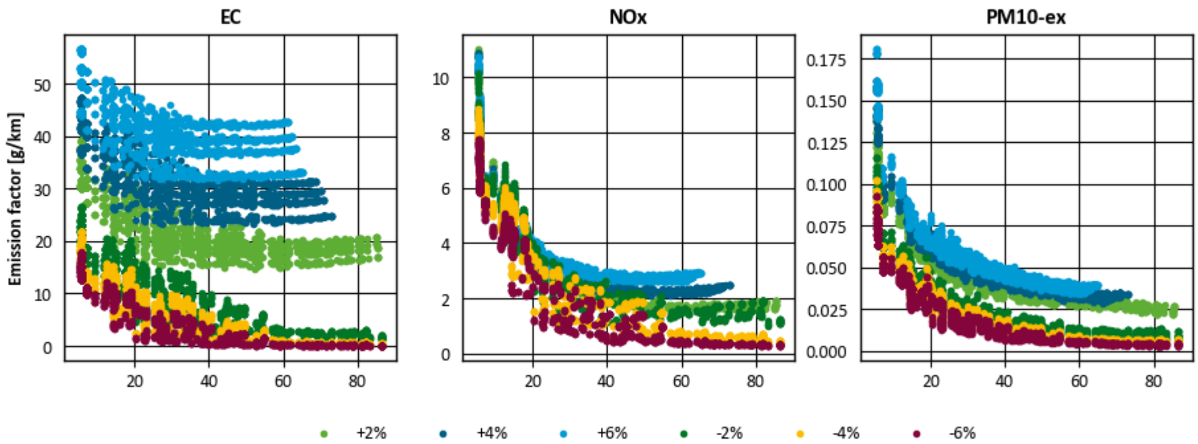
Figure 25: Speed profiles and relative EF differences on an urban access road at speed limit 30 km/h in different LOS for PC



Note: EF indexes shown are valid for average PC (passenger cars) in Germany, 2020.
Source: HBEFA 4.2

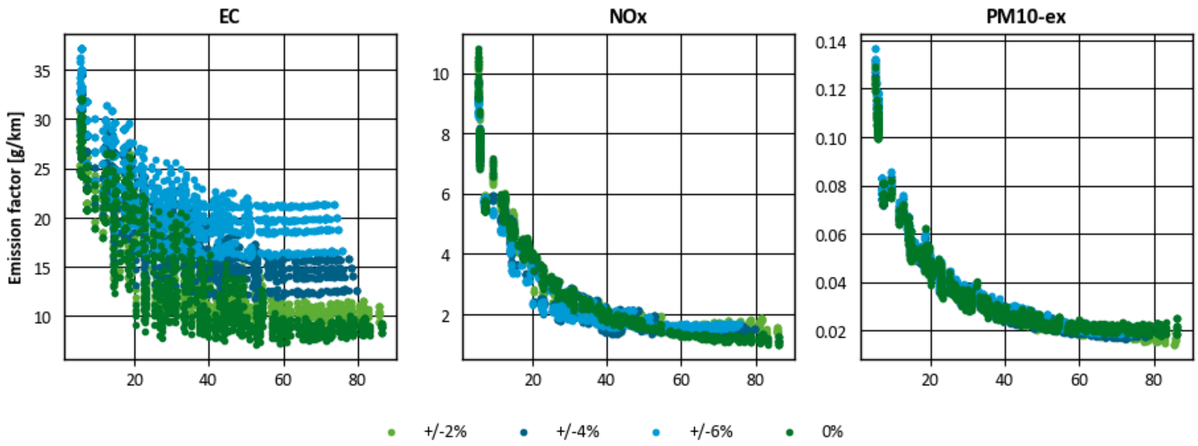
A.3 Gradients

Figure 26: Energy consumption and emission factors of average HGV for selected components plotted by average speed and gradient classes differentiating ascending and descending driving direction.



Note: EF shown are valid for average HGV in Germany, 2020. EF for 0 % are not shown here because the figure aims to show the difference between ascending and descending gradients.
Source: HBEFA 4.2

Figure 27: Energy consumption and emission factors of average HGV for selected components plotted by average speed and average ascending/descending gradient classes



Note: EF shown are valid for average HGV in Germany, 2020.

Source: HBEFA 4.2