Monitoring emission savings from low rolling resistance tire labelling and phase-out schemes

MRV Blueprint based on an example from the European Union

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1 Scope and objectives of the MRV blueprint

In 2012, the European Union introduced mandatory labelling and phase-out regulations for tires of all road vehicle classes aiming at a wider application of low rolling resistance tires and, through this efficiency measure, at a reduction of greenhouse gas (GHG) emissions [EP, 2009a; b]. These regulations received considerable international attention and could inspire similar legislation in other countries.

The present **MRV blueprint** shows how a Measurement, Reporting and Verification (MRV) process could be designed for tire labelling and phase out regulations, using the European Union as example. The scope of this MRV blueprint is limited to tire-labelling and phase-out concerning heavy-duty trucks with a gross vehicle weight (GVW) > 3.5 tons. A recent related GHG impact assessment study on this topic [IFEU, 2015] serves as a basis for the calculation of GHG emissions through the use of low rolling resistance tires within this MRV blueprint.

The Project Context

The TRANSfer project is a project implemented by GIZ and funded through the International Climate Initiative of the German Ministry for the Environment, Nature Conversation, Building and Nuclear Safety (BMUB). Its objective is to support developing countries to develop climate change strategies in the transport sector as „Nationally Appropriate Mitigation Actions“(NAMAs). The project provides technical assistance in the partner countries Indonesia, The Philippines Columbia, Peru and South Africa. Therefore, the project closely cooperates with other projects under the International Climate Initiative of BMUB, including China. TRANSfer in China will explore the synergies with ongoing projects and extract lessons learned for greenhouse gas (GHG) accounting and implementation of local actions. Sustainable transport projects in China provide plenty of experiences on quantifying GHG emissions and implementation of mitigation actions in urban transport, vehicle technology and logistics. Mitigation actions in China are currently not registered as single NAMAs, but serve to achieve the national target to decrease carbon intensity by 40-45 percent until 2020 (compared to 2005). Similar actions could, however, be developed as NAMAs in other countries.

TRANSfer also supports mutual international learning. MRV remains one of the greatest challenges to NAMA development in the transport sector. The TRANSfer project therefore established an MRV workstream in order to lower the barriers to establishing MRV sys-tems and hence make it easier to develop and implement transport NAMAs. This includes an international expert group from developing and developed countries. To encourage NAMA development worldwide, TRANSfer has set out to develop a first set of so-called MRV blueprints for transport NAMAs – a description of the MRV methodology and calcula-tion of emission reductions for different NAMA types in the transport sector. http://www.transferproject.org.

2 Background and description of the measure

2.1 Current situation in the transport sector in Europe and needs for action

The transport sector was responsible for approx. 33 % of final energy consumption and 26 % of greenhouse gas emissions in Europe in the year 2010. In this context, road transportation accounts for the largest share with 72 % of total GHG emissions from transport [EU, 2013]. Heavy-duty trucks (>3.5 t GVW) account for about a quarter of energy consumption and GHG emissions in road transport at present [Emisia, 2013]. Current projections expect substantial increases of HDV transport in the future (2010 to 2050: +55 %) [COM, 2013]. In consequence, compliance with climate change mitigation goals and the minimisation of final energy consumption require a substantial reduction of the fuel consumption and GHG emissions associated with road freight transport.

GHG mitigation pathways in the transport sector

The amount of GHG emissions caused by motorised transport depends on the extent of transport activities, the specific energy consumption of the used means of transportation and on the specific GHG emissions intensity of the final energy carriers. Accordingly, there are different mechanisms of action for the reduction of GHG emissions:

- Avoid motorized transport (less trips, reduced distances, higher loads)
- Shift transport demand to low-emitting transport modes
- Improve energy efficiency of the vehicle fleet and lowering the specific energy demand per transport activity
- Improve specific GHG emissions per energy consumption by using alternative energy carriers (e.g. biofuels, electricity).

European policies for GHG mitigation in the road freight sector

European policies for GHG mitigation in the road freight so far focus primarily on affirmative action for avoiding road transport activity by increasing vehicle loads and shifting to more environmentally-friendly transport modes (train, shipping). Improving energy efficiency of trucks has not been the main concern of policy measures in the past; instead technical improvements of heavy-duty vehicles focused on the reduction of air pollutant emissions. Despite the focus on air pollutants, some individual policies have been implemented that support vehicle manufacturers and suppliers in the development of more energy-efficient trucks and truck components, e.g. a flexibilisation of vehicle dimensions enabling aerodynamic improvements and the labelling and phase-out regulations for road vehicle tires.

In 2014, the European Commission has started to devise strategies for the reduction of CO_2 emissions from heavy-duty vehicles in collaboration with its member states and published an initial Key Issues Paper [EC, 2014]. This strategic process will probably lead to further efficiency measures in the future.

2.2 European tire labelling and phase-out regulations

One of the major contributors to fuel consumption of road vehicles is rolling resistance. Low rolling resistance tires reduce the rolling resistance of a vehicle and related fuel consumption. The wide application of low rolling resistance tires in vehicle fleets can therefore considerably reduce fuel consumption and GHG emissions in the transport sector. As a co-benefit, transportation costs for the vehicle owners decrease considerably.

In 2009 and 2011, the European Union introduced and amended regulations, which include technical specifications of new tires for most on-road vehicle types, i.e. tires for cars (c1), vans (C2) and trucks (C3) [EC, 2009a; b, 2011]. Main objectives of these regulations regarding tires are:

- Improving tire-related fuel efficiency by improving rolling resistance coefficients RRC (in kg/t)[1], which is the key factor for the fuel efficiency of a tire,
- Improving road safety of vehicles, using the wet grip index as indicator for braking performance of a tire under wet conditions, defined by comparison with a predefined reference tire,
- Reducing external rolling noise of tires, defined by the drive-by noise generated by a tire (in dB).

European tire regulations as a whole concern passenger cars, vans, trucks and buses. However, the present MRV blueprint addresses only those measures within European tire regulations concerning heavy-duty road freight transport. Therefore, following descriptions of the configuration of the measure refer only to C3 tires, which are used on heavy-duty trucks >3.5 tons GVW.

Section 2.2.1 gives an overview of the relevant European tire regulations for heavy-duty trucks including requirements on rolling resistance coefficients. Section 2.2.2 gives additional general information about the role of rolling resistance for fuel consumption and GHG emissions of heavy-duty trucks for an improved understanding of the GHG impacts of the European measure.

2.2.1 Requirements of the European tire regulations on truck tires

This section gives an overview of the relevant European tire regulations for heavy-duty trucks including requirements on rolling resistance coefficients.

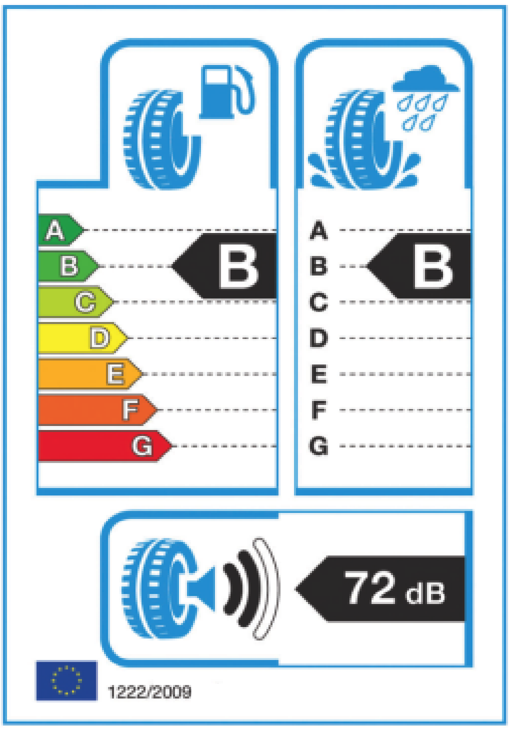
In the first regulation step in [EC, 2009a], limit values of the defined parameters have been specified in order to induce a phase-out of particularly inefficient tire models. For truck tires, only limit values for rolling resistance and external rolling noise have been defined. These are shown in Table 1.

[1] RRCs are actually dimensionless coefficients. However, in most literature sources such as in present EC regulations, they are expressed in kg/t or in N/kN, which results in 1000-fold higher values.

Table 1: European limit values for rolling resistance coefficients and external rolling noise of C3 tires [EC, 2009a]

Rolling Resistance coefficient	
8.0 kg/t	01.11.2016 for original equipment of new vehicles and replacement tires (sale & entry into service)
6.5 kg/t	01.11.2016 for new types of tires (type approval) and 01.11.2020 for original equipment of new vehicles and replacement tires (sale and entry into service)
External rolling noise (as from 01.11.2016)	
73 dB(A)	Normal tires
75 dB(A)	Traction tires

Second regulation step was the introduction of a standardised tire label including the three defined tire parameters, effective as from the year 2012 [EC, 2009b, 2011]. This label is mandatory for all tires except for retreated tires, motorcycles and special applications. The tire label must be made available for all tire types from the manufacturers and be provided to the end users from the tire dealers before the sale. In this way, vehicle owners get supporting information regarding the three aspects fuel efficiency, road safety and external rolling noise for their tire buying decision. Figure 1 shows the tire label and the defined label classes of each parameter for C3 tires of heavy-duty trucks that are on the focus of the present study.



Label class	Energy efficiency	Wet grip
	RRC in kg/t	G
A	<= 4	1.25 ≤ G
B	> 4 <= 5	1.10 ≤ G ≤ 1.24
C	> 5 <= 6	0.95 ≤ G ≤ 1.09
D	> 6 <= 7	0.80 ≤ G ≤ 0.94
E	> 7 <= 8	0.65 ≤ G ≤ 0.79
F	> 8	G ≤ 0.64
G	empty	empty

3dB or more below the European limit from 2016

Between the European limit from 206 and 3dB below

Above the European limit from 2016

Figure 1: Exemplary EU tire label with explanation of segments for C3 truck tires [EC, 2009b, 2011]

2.2.2 Role of rolling resistance for fuel consumption and GHG emissions

Contribution of rolling resistance to fuel consumption and GHG emissions of heavy-duty trucks

Specific energy consumption of heavy-duty trucks depends primarily on the total driving resistance of the vehicle and the resulting mechanical energy demand and on the power-train efficiency (conversion efficiency of the engine, power losses in gearbox and axles) to provide this mechanical energy. Furthermore, specific energy demand of auxiliary consumers (e.g. air conditioning, steering pump) contributes to energy consumption. Total driving resistance of a truck consists of rolling resistance, aerodynamic drag and acceleration and braking losses. Contributions of particular driving resistances vary highly depending on the technical characteristics of the vehicle as well as on the driving profile (velocity, acceleration, topography).

Figure 2 shows contributions of different driving resistances for European EURO VI heavy-duty trucks of different size and with different mission profiles to fuel consumption. Contribution of rolling resistance is in the range of about 20 % for urban delivery trucks up to 35 % for large semi-trailer trucks in long-haul transport and contributes therefore considerably to fuel consumption and GHG emissions in all truck segments.

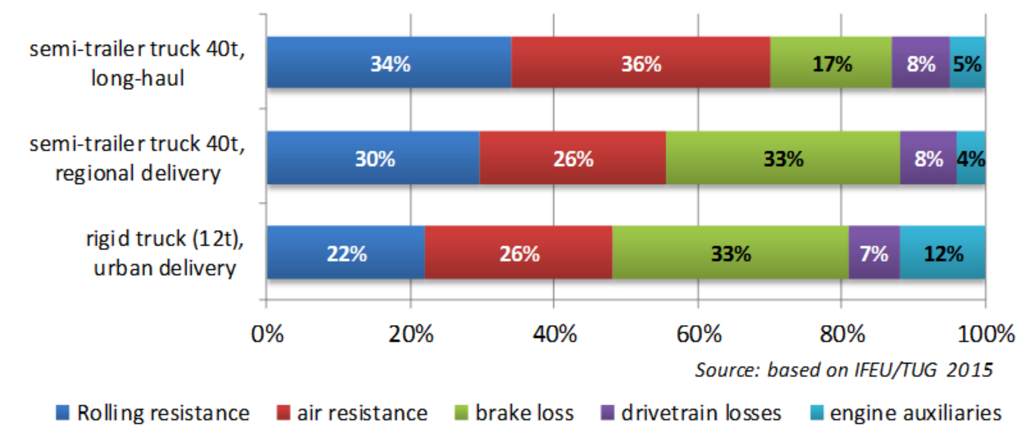


Figure 2: Contributions to fuel consumption of EURO VI heavy-duty trucks

Influencing parameters on rolling resistance related fuel consumption

Rolling resistance of a heavy-duty truck is directly correlated with the rolling resistance coefficients (RRC) of the tires, vehicle mass and driving speed. As with higher speeds also the covered distance increases, the rolling resistance related fuel consumption per distance travelled is widely speed-independent.

The vehicle weight depends on the vehicle empty weight and on the actual loading weight. The rolling resistance coefficient depends primarily on the technical characteristics of the tire. There are several technical requirements on truck tires including rolling resistance coefficients, but also e.g. road grip and braking performance, durability, noise generation and riding comfort. Different requirements can be interdependent (e.g. possible trade-offs between reducing rolling resistance and at the same time improving wet grip; influence of wet grip improvements on tire noise [EPEC, 2008]). Due to these interdependencies between different technical requirements and different needs of vehicle owners rolling resistance coefficients vary considerably for different truck segments, operation fields and even for different axles. Tires for drive axles have generally higher RRCs than steer and trailer tires. For that reason and also for the weight distribution in the vehicles, tires on different axles can contribute divergent shares to the overall rolling resistance of a truck (see example for a semi-trailer truck in Figure 3). Actual rolling resistance coefficient of a vehicle during use is additionally influenced by the individual operation conditions (e.g. tire pressure, road gradient and surface).

Besides the rolling resistance, also the powertrain efficiency of the vehicle, i.e. the conversion efficiency of the engine and the power losses in gearbox and axles in order to provide the mechanical energy are relevant for the contribution of rolling resistance to fuel consumption of the vehicle.

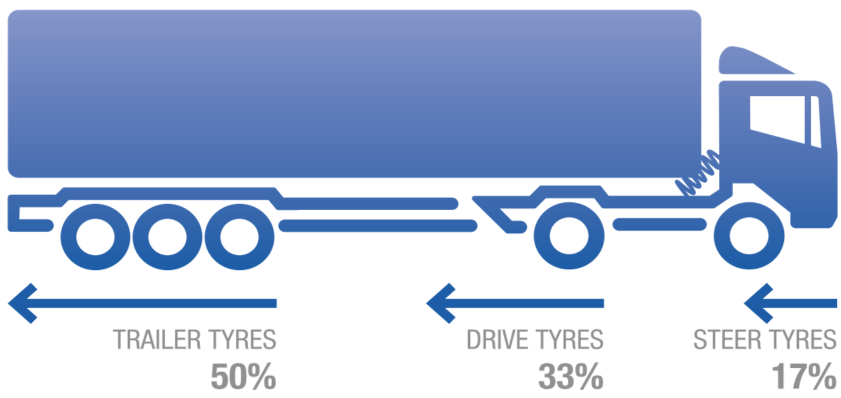


Figure 3: Contribution of tires on different axles to total vehicle rolling resistance on a typical 40 t semi-trailer truck [Goodyear, 2012]

2.3 Potential translation of the European measure into a NAMA

The European tire labelling and phase-out regulations could be a basis for implementing comparable measures in other countries within the NAMA framework. The primary objective of a NAMA based on the European program would be the reduction of greenhouse gas emissions via promoting the introduction of low rolling resistance tires in heavy-duty truck traffic. This should be achieved by the mandatory introduction of energy efficiency labels and a related phase out scheme for inefficient tires. The efficiency measure intends to reduce the modal energy intensity of the concerned traffic, i.e. the fuel consumption per kilometre travelled. These fuel savings may lead to targeted side-effects such as the reduction of operating costs for road transportation. In most cases, required investments are so low that a reduction of total costs can be achieved within a short payback period.

3 GHG and non-GHG impacts of the measure

The European tire labelling and phase-out regulations aim at additional technological efficiency improvements for heavy-duty trucks. This has direct impacts on fuel consumption and related GHG emissions of the vehicles, but can also cause indirect GHG impacts (see chapter 3.1). These GHG impacts can also be affected by other GHG saving measures. Furthermore, the measure can cause impacts on non-GHG topics, especially road safety, external noise and vehicle operation costs (see chapter 3.2). As a first step in the MRV process of the measure, both direct and indirect GHG impacts as well as non-GHG impacts need to be identified and assessed for their relevance. This is an essential basis for the definition of assessment boundaries for the continuous MRV process.

3.1 GHG impacts of the measure

The amount of GHG emissions caused by motorised transport depends on the extent of transport activities with different means of transportation, the specific energy consumption of each means of transportation and on the specific GHG emission intensity of the final energy carriers. According to the ASIF framework (see e.g. [GIZ, 2014]), impacts of GHG mitigation measures on the following elements, influencing GHG emissions from transport activities have to be analysed:

- **Activity:** Does the measure reduce or increase transport activities (VKT), influencing number or distance of trips or vehicle load factors?
- **Structure:** Does the measure induce a shift of transport activities between transport modes with different specific GHG emissions?
- **Intensity:** Does the measure lead to changes of energy efficiency of the vehicle fleet?
- **Fuels:** Does the measure induce a change to energy carriers with different GHG emissions intensity per energy consumption?

For each of these four elements, direct and indirect impacts of the measure and their relevance for the total GHG impact need to be analysed. Impacts of the measure do not necessarily concern only those means of transportation (= emission sources), which are directly addressed by the measure. This analysis of GHG impact chains from the measure is an essential basis for the definition of GHG assessment boundaries in the MRV process.

3.1.1 Direct and indirect GHG impacts

The intended main impact of the European tire labelling and phase-out regulations regarding energy efficiency is to improve the rolling resistance coefficients of vehicle tires. In this way, total rolling resistance of the vehicles is reduced leading to reduced specific fuel consumption (see explanations in section 2.2.2). Direct GHG impact of the measure is accordingly an **improvement of specific fuel efficiency (= Intensity) of heavy-duty trucks**. There are no substantial direct impacts on other GHG relevant parameters of vehicle operation to be expected.

Further direct GHG impacts may arise from other life cycle stages (production, recycling), including impacts of a different durability of low rolling resistance tires compared to conventional tires. However, GHG impacts from other phases in the life of a tire are very low compared to impacts during tire use [Continental, 1999] and tire durability of modern low rolling resistance tires does not differ considerably to conventional tires [M.Kern, 2014]. Accordingly, direct GHG impacts from other life cycle stages can be omitted in the MRV process.

Table 2: Impact chain: Direct GHG Impacts

Emission source	ASIF parameter	GHG impact
Heavy-duty trucks	Intensity: Specific fuel consumption per VKT	Improvement

Besides the direct GHG impacts of the measure, additional indirect GHG impacts are possible, primarily due to rebound effects. Fuel-saving tires reduce the costs of truck operation considerably [ifeu, / TU Graz, 2015]. This could lead to a reduction of road freight transport prices and, in consequence, induce additional or longer freight transports, but also a modal shift from competing modes of transportation such as rail or inland navigation to road transport. This would increase GHG emissions in freight transport because specific GHG emissions per transport demand (ton.km) are higher in road freight transport compared to other transport modes. How far expected cost reductions would lead to such indirect GHG impacts is very hard to estimate and would require in-depth economic modelling of the concerned transportation sectors.

Table 3: Impact chain: Indirect GHG Impacts

Emission source	ASIF parameter	GHG impact
Heavy-duty trucks	Activity: Induced additional road freight transports	Deterioration
Train, inland navigation	Structure: Shift of freight transport activities from train or inland navigation to road transport	Deterioration

3.1.2 Interaction with other measures in the transport sector

GHG saving potentials in road freight traffic from the European tire labelling and phase-out regulations also depend on the effectiveness of other existing or future measures. These are mainly:

Measures with effects on vehicle technology: The European Commission is devising strategies for the reduction of CO_2 emissions from heavy-duty vehicles in collaboration with its member states and published an initial Key Issues Paper in 2014 [EC, 2014]. Currently, there are no further specific political measures to reduce fuel consumption and GHG emissions from heavy-duty vehicles in Europe. However, in the future this process will probably lead to further efficiency measures. Improved rolling resistance interacts with other measures which affect the same vehicle parameters that are relevant for energy consumption from rolling resistance (see section 2.2.2):

- First of all, future political action regarding specific fuel consumption and GHG emissions from heavy-duty vehicles could accelerate the introduction and dissemination of fuel saving tires and, in consequence, intensify the impacts of the existing tire labelling program.
- Future introduction of additional fuel-saving powertrain technologies (including alternative drive concepts) will improve the tank-to-wheel powertrain efficiency and, therefore, reduce specific fuel saving potentials from improved tires compared to a vehicle with unimproved powertrain.
- Light weighting reduces vehicle empty weight and in consequence rolling resistance (assuming unchanged load factors). Equipping light-weighted truck with low rolling resistance tires can therefore bring less GHG savings than for a standard truck.
- Aerodynamic improvements, in contrast, have no impact on the GHG potentials of low rolling resistance tires, as both kinds of measures aim at parallel driving resistances.

Alternative fuels (biofuels, synthetic fuels) do not affect the final energy consumption of the vehicle, but reduce the specific GHG emission intensity per energy demand. In consequence, GHG savings potentials from reducing fuel consumption with low rolling resistance tires decrease with increasing shares of such alternative fuels.

Finally, **avoid and shift measures** in the freight transport sector have no direct interaction with GHG savings per vehicle as from improved tires. However, they affect total GHG savings potentials of the heavy-duty truck fleet by reducing transport activities (VKT). In consequence, measures causing a relevant modal-shift from road to other transport modes would reduce transport activities with heavy-duty trucks that can be affected by the tire labelling as well as other efficiency measures.

All of these measures will influence the effectiveness of the European tire regulations. As these measures also work without European tire regulations, their impacts have to be considered in the MRV process both in the analysis of real GHG emission developments and in the analysis of baseline GHG emissions.

3.1.3 Relevance of GHG impacts for MRV

As discussed in section 3.1.1, the main and intended direct impact of European tire labelling and phase-out regulations on GHG emissions concerns the reduction of fuel consumption during vehicle use by initiating a wider application of low rolling resistance tires. Their consideration in the MRV process is essential for the assessment of relevant GHG impacts from the measure.

Further direct impacts may arise from other life cycle stages. These potential further direct impacts, however, are very low compared to the impacts during the use phase and could only be analysed with detailed knowledge of production processes and material composition of tires. Due to their low relevance they can be omitted in the MRV process.

Also indirect GHG impacts identified in section 3.1.2 of the measure are possible, resulting from rebound effects due to the reduction of vehicle operation costs resulting from lowered fuel consumption. This can potentially induce additional or longer trips in road freight transport or lead to a modal shift from low-emitting rail and inland navigation to road transport. How far expected vehicle operation cost reductions would lead also to reductions of road freight transport prices and, in consequence, increased road freight transport activities is very hard to estimate and would require in-depth economic modelling of the concerned transportation sectors. As fuel costs are only a part of total vehicle operation costs, possible reductions in transportation prices are expected to be rather low, too. Related possible indirect GHG impacts might therefore be omitted in the calculation of GHG impacts in the MRV initial phase. However, an amendment of the GHG impact assessment in later phases, e.g. when additional information on the effectiveness of the measure and influences on road freight transport prices are available, could be recommendable.

The relevance of interactions with other policy measures is very specific for each of the measures. Several interactions with potential future legislation and regulation measures are discussed in chapter 3.1.2 Effects of avoid and shift measures or increased use of alternative fuels should be reflected in the developments of transport activities and GHG conversion factors both in monitoring of real GHG emissions and in baseline calculations without measure. They need therefore, no special consideration in the MRV. Currently, there are no other policy measures with direct impacts on fuel efficiency of heavy-duty trucks that need to be considered in the quantification of GHG impacts. However, in future European strategies for the reduction of CO_2 emissions from heavy-duty vehicles process will probably lead to further efficiency measures. If new measures with focus on energy efficiency of heavy-duty trucks are implemented in Europe, their potential interaction with the existing tire labelling measure will have to be analysed and, if relevant, have to be regarded also in the quantification of GHG emission savings from the European tire regulations.

Table 4 summarises the relevance of direct and indirect GHG impacts and of interactions with other GHG mitigation measures for the MRV process.

Table 4: Overview of GHG impacts and their relevance for MRV

Kind of GHG impact	Direction of GHG impact	Priority for inclusion in MRV
Direct impact via fuel savings in the use phase	GHG reduction	Essential
Direct impacts from other life cycle stages	Positive or negative	Negligible
Indirect impacts via vehicle cost reduction (rebound effect)	GHG increase	Optional
Interaction with other GHG mitigation measures in freight transport	Weakening of GHG reducing impacts	Relevance depends on individual measures and their impacts on transport activities, modal split, fuel efficiency and GHG conversion factors.

3.2 Non-GHG impacts

GHG mitigation measures can also have other environmental as well as economic and social impacts. These can be co-benefits, but might also be adverse impacts causing a trade-off for different political (and social) objectives. For that reason, the impact assessment of the tire labelling and phase-out regulations cannot focus only on GHG impacts, but must also consider non-GHG impacts.

Non-GHG environmental impacts

Typical non-GHG environmental impacts concern direct impacts of the transport activities on air quality and noise, but might also include indirect impacts from provision of energy carriers and production and recycling of vehicles and infrastructure.

- NO_x and soot particle exhaust emissions: Reducing the mechanical energy demand with low rolling resistance tires reduces the engine load and can therefore lead to a reduction of engine-out emissions of NO_x and particles. However, exhaust emissions depend primarily on the efficiency of the downstream exhaust treatment system. If the reduction efficiency of the exhaust treatment remains unchanged, also exhaust emissions will decrease. As modern particle filters reduce particle emissions by 99 % low rolling resistance tires have no considerable impact on soot particle emissions. However, a reduction of NO_x exhaust emissions is possible.
- Emissions from tire abrasion (particulate matter PM10, PM2.5 and embedded heavy metals) depend on the abrasion characteristics of the tires and on their material composition. Differences of low rolling resistance to conventional tires can therefore also have impacts on emissions from tire abrasion. However, data situation on PM and heavy metal emissions from tire abrasion is generally uncertain with large bandwidths of emission factors (see [EMEP-EEA, 2013] part B 1.A.3.b.vi-vii). Tire abrasion contributes only a small fraction to PM air quality problems and no reliable information on the contribution of heavy metal emissions from road transport at all to pollution of soil and water is available [IFEU, 2013]. Therefore, impacts on air quality due to low rolling resistance tires can be estimated negligible.
- Noise: As explained in ([EPEC, 2008], p. 11), no direct correlation was found between RR and tyre noise. However, tire noise is influenced by wet grip requirements, which in turn can have a trade-off with rolling resistance ([EPEC, 2008], p. 63). The European tire labelling and phase-out regulations also include requirements for wet grip and external noise, hence noise levels might be influenced by the parallel optimization of rolling resistance and wet grip. Actual noise impacts of the European regulations could be analysed using the noise label, which has to be published for all tires if according statistical or market information is available.
- Environmental impacts from other life cycle stages of a tire are generally very low compared to impacts during tire use [Continental, 1999]. Though different materials and production processes between conventional and low rolling resistance tires lead to differences of environmental impacts in production and recycling processes these can be neglected compared to impacts in the phase of tire use.

Road safety and vehicle operation costs

Important non-environmental topics that are affected by the European tire labelling and phase-out regulations are road safety and vehicle operation costs.

- **Road safety:** The EU tire labelling regulation also includes a label scheme for wet grip, which is an important indicator for road safety of tires. As analysed in [EPEC, 2008], "the key trade-offs that are likely to arise from a focus on reducing rolling resistance are a reduced level of wet grip and possibly aquaplaning". These parameters are important for road safety. Therefore, focusing the improvement of future tires only on rolling resistance could considerably affect road safety. However, the EU tire labelling system includes rolling resistance and wet grip, so it is expected that this dual labelling will not lead to a deterioration of wet grip "because customers are likely to rank safety as a more important attribute than fuel efficiency when purchasing a tyre" ([EPEC, 2008], p. 66). "This increased challenge for tyre producers to optimise not just rolling resistance and wet grip but also to ensure tyre noise does not exceed the standards set is reflected in the higher tyre production costs estimated for dual labelling" ([EPEC, 2008], p. 63). Hence, no adverse effects of the labelling for low rolling resistance tires on road safety are estimated.
- **Vehicle operation costs:** Purchasing low rolling resistance tires requires higher investment costs for the vehicle owners. Improving rolling resistance of all tires of a vehicle by one RRC label class (e.g. from label C to label B) means additional investment costs of about 200 € for a semi-trailer truck and less than 50 € for a rigid truck. On the other hand, this improvement of rolling resistance reduces fuel consumption by about 1-4 % and consequently fuel costs. In this way, a semi-trailer truck in long-haul transport can save about 2 000 € fuel costs per year and even a rigid truck in urban delivery saves about 300 € per year [ifeu, / TU Graz, 2015]. In consequence, investment in current low rolling resistance tires has a payback within few months and leads to a considerable reduction of vehicle operation costs. Even higher fuel cost savings are possible by changing to tires of the best available RRC label class. For semi-trailer trucks first "label A" tires for all vehicle axles are on the market since end of 2014 [M.Kern, 2014].

3.3 Definition of MRV assessment boundaries

First step of the MRV process is the definition of assessment boundaries, i.e. which emission sources and emissions and which time frames are considered in the analysis of GHG impacts. These definitions are basically driven by the identified direct and indirect GHG impacts and their expected relevance for the total GHG impacts of the measures. However, adjustments of assessment boundaries can be required depending on data availability for calculation parameters.

An important part of the definition of MRV assessment boundaries is also the decision if there are relevant non-GHG impacts to be included in the MRV process.

European tire regulations concern passenger cars, vans, trucks and buses. However, the present MRV blueprint addresses only those measures within European tire regulations concerning heavy-duty road freight transport. Therefore, also MRV assessment boundaries refer only to impacts of the measure on freight transport.

System boundaries

The European tire labelling and phase-out regulations cover road transport activities in all 28 member states of the European Union (EU 28). Assuming that only vehicles registered in EU are equipped with tires sold in EU (original equipment of new vehicles and regular tire replacement), the measure affects the whole road transport activities in the EU territory. Transboundary road transport on EU external borders can be assumed to have very low relevance due to the large geographical area of EU and the high border share of seacoast with no transboundary road traffic. Therefore, system boundaries were defined as road transport activities in the EU territory.

Emission sources

As GHG impact chains in section 3.1 show, European tire labelling and phase-out regulations for heavy-duty truck tires affect primarily GHG emissions of heavy-duty truck transport during vehicle use. Other transport modes (rail, inland navigation) could be indirectly affected due to modal-shift effects resulting from possibly reduced road freight transport prices. However, these indirect GHG impacts are expected to be rather low and could only be estimated with considerable additional efforts but high uncertainties. They should therefore be omitted in the calculation of GHG impacts, at least in the MRV initial phase. Accordingly, emission sources considered in the MRV of the measure were restricted to heavy-duty trucks with a gross vehicle weight (GVW) from 3.5 to 60 tons.

Different future developments of transport demand and overall energy efficiency are expected for different vehicle sizes and operation fields (e.g. long-haul, urban delivery) in Europe (see [AEA, / Ricardo, 2011]. Furthermore, also rolling resistance and its contribution to total energy demand differ significantly for different vehicle segments (see section 2.2.2). For its consideration in the impact assessment, heavy-duty trucks have been differentiated into three vehicle segments with different typical operation fields:

1. Small: Rigid trucks with 3.5 to 12 t gross vehicle weight (GVW), typical for urban delivery.
2. Medium: Rigid trucks with 12 to 40 t GVW and articulated trucks or tractor-trailer combinations with up to 28 t GVW; main application in urban and regional delivery.
3. Large: Articulated trucks or tractor / trailer combinations with 28 to 60 t GVW, which are primarily used in long-haul freight transport, but also in regional delivery.

Covered GHG emissions

GHG emission factors can be differently defined. Main decisions for the GHG emissions covered by applied emission factors are:

- Greenhouse gases: CO_2 vs. CO_2 equivalents (incl. CH_4 and N_2O)
- Emission origins: Direct emissions in vehicle use ("tank-to-wheel") and upstream emissions to provide the fuel (well-to-tank). Upstream emissions from vehicle (or vehicle parts) production.

In this MRV blueprint, considered GHG emissions cover well-to-wheel CO_2 equivalent emissions of CO_2, CH_4 and N_2O including both fuel consumption in the vehicles and upstream processes. No GHG emissions from other life cycle stages of tires are considered as these are very low compared to GHG emissions during use phase (see section 3.1.1).

Time interval and Reporting period

GHG emissions savings of the measure are calculated for each reporting period (usually one year). These calculations are repeated in defined intervals (e.g. annually or every 5 years). A first assessment of general effectiveness of the measure should be prepared in the year 2020 or 2021, when the second stage limit value comes into force (see section 2.2.1). Total reporting period should continue up to the year 2030 or later in order to assess long-term GHG impacts of the measure.

Assessment of non-GHG impacts

There are several potential non-GHG impacts of the measure, identified in section 3.2. These are primarily co-benefits for other environmental fields, but also for road safety and vehicle operation costs. The measure addresses directly improvements of road safety and external noise. These should therefore also be included in the MRV process. Additionally, changes of vehicle operation costs should be included as cost savings are an important driver for the dissemination of low rolling resistance tires.

4 Measurement of GHG impacts

The main impacts of the European tire labelling and phase-out regulations and of potential further analogous implementations as a NAMA in other regions are direct impacts on GHG emissions via fuel savings as identified in section 3. This MRV blueprint focusses on measuring these impacts for HDVs with a gross vehicle weight (GVW) above 3.5 tons.

4.1 Overview of the methodological approach for the measurement of GHG impacts

GHG emissions savings of the European tire labelling and phase-out regulations for heavy-duty trucks are assessed by comparing the development of real GHG emissions with the measure to a hypothetical baseline development without measure. The measure aims at improving rolling resistance coefficients of vehicle tires and, thus, reducing the rolling resistance of the vehicles. In this way, only that share of fuel consumption and GHG emissions is affected that is caused by rolling resistance (see Figure 2 in section 2.2.2), but no other factors influencing fuel efficiency such as aerodynamic drag, acceleration or auxiliary equipment. Therefore, absolute GHG impacts of the measure can be measured by focusing the analysis only on the shares of GHG emissions that are directly caused by rolling resistance.

To assess the overall relevance of the measure impacts, a complementary comparison of absolute GHG savings to total GHG emissions of heavy-duty truck transport is recommended. Calculation methodology includes therefore the following steps:

1. **Calculating real GHG emissions of heavy-duty truck transport per reporting year**
   - Calculating **real rolling-resistance related GHG emissions**, i.e. partial GHG emissions that are directly related to rolling resistance of the vehicle.
   - Calculating **real total GHG emissions** of heavy-duty truck transport in Europe.
   - Deriving the share of rolling resistance on total GHG emissions.
2. **Measurement of absolute GHG impacts per reporting year**
   - Calculating baseline rolling-resistance related GHG emissions assuming no introduction of the European tire regulations.
   - Calculating absolute GHG impacts by comparing real rolling resistance related GHG emissions to baseline rolling resistance related GHG emissions.
3. **Assessment of overall GHG impacts for heavy-duty truck transport per reporting year**
   - Calculating baseline total GHG emissions of heavy-duty truck transport in Europe.
   - Calculating of percentage change of total GHG emissions of heavy-duty truck transport in Europe by comparing **real** and **baseline** total GHG emissions.

The following sections provide concrete guidance for each of the above calculation steps in the MRV process and the required calculation parameters. Currently available data sources for the real development of calculation parameters, estimated ex-ante baseline developments without the measure and default values for calculation parameters, which cannot be monitored regularly with reasonable effort, are determined in section 4.5 Section 4.6 shows a calculation example for the measurement of GHG impacts. An analysis of main uncertainties of the measurement of GHG impacts is done in section 4.7.

4.2 Calculating real GHG emissions of heavy-duty truck transport

4.2.1 Real GHG emissions from rolling resistance

In the first calculation step, real GHG emissions resulting directly from rolling resistance are calculated. This is the most important calculation for assessing GHG impacts in the MRV.

Rolling resistance is directly correlated with the rolling resistance coefficients (RRC) of the tires and with the vehicle mass. Furthermore, powertrain efficiency and operation conditions such as road gradient, surface and conditions or tire pressure are of importance for the rolling resistance (see section 2.2.2). Accordingly, real rolling resistance related fuel consumption per transport activity (VKT) can be calculated with the following bottom-up equation:

$$FC_{RR,spec.} = RRCreal \times C_{RRC} \times m \times g / \eta_{pt} /1000 \qquad (1)$$

Where:

$FC_{RR,spec}$	Real specific fuel consumption per VKT from rolling resistance (in MJ/vkm)
RRCreal	Real Rolling resistance coefficient (in kg/t)
C_{RRC}	RRC correction factor (dimensionless)
m	vehicle weight (=empty weight + vehicle load) (in tons)
g	gravity acceleration (9,81 m/s²)
η_{pt}	average powertrain efficiency of the vehicle (in %)

Rolling resistance related GHG emissions are calculated by multiplying the VKT of the heavy-duty vehicles with this specific fuel consumption and the fuel specific GHG conversion factor.

$$GHG_{RR} = VKT \times FC_{RR,spec.} \times GHG_{fuel.spec.} /10^6 \qquad (2)$$

Where:

GHG_{RR}	Real GHG emissions resulting from rolling resistance (in 10^6 tons)
VKT	Transport activity (in 10^6 vkm per year)
$FC_{RR,spec}$	Real specific fuel consumption per VKT from rolling resistance (in MJ/vkm)
$GHG_{fuel,spec.}$	GHG conversion factor for the used fuel (in g CO_2e/MJ)

Figure 4 gives an overview of the model approach. Calculations have to be done individually for each of the defined heavy-duty vehicle segments.

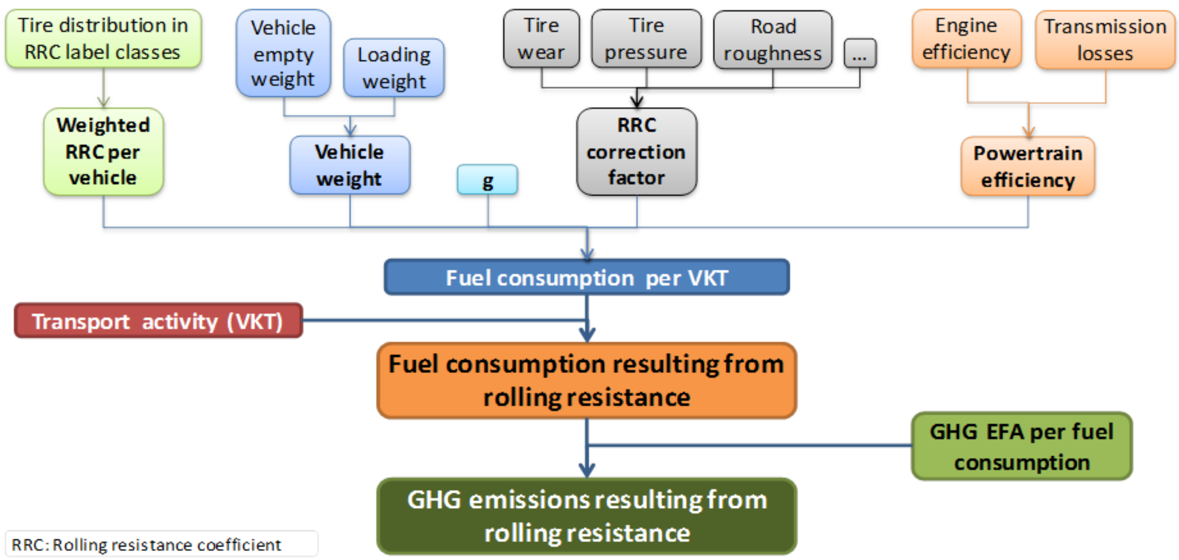


Figure 4: Bottom-up model approach for calculating fuel consumption and GHG emissions related to rolling resistance

Table 5 gives further characterizations of the calculation parameters. Data sources for monitoring the real development of calculation parameters as well as additional assumptions for those calculation parameters, which cannot be monitored with reasonable effort, are determined in section 4.5. The most important calculation parameter for the measurement of GHG impacts is the rolling resistance coefficient (RRC). This is the main parameter influenced by the measure and therefore highly relevant for comparing real emissions to baseline developments. Accordingly, knowing the real RRC developments is essential for the MRV process. All other calculation parameters are identical for real developments and baseline developments.

Table 5: Calculation parameters for real rolling resistance GHG emissions

Calculation parameter	Description	Unit	Influenced from measure	Data sources in section
RRCreal	Real medium Rolling resistance coefficient per vehicle segment and year	kg/t	Yes	4.5.1
C_{RRC}	RRC correction factor	-	No	4.5.2
m	Vehicle mass (=empty weight + vehicle load) per vehicle segment and year	metric tons	No	4.5.2
g	Gravity acceleration: 9.81 m/s^2	m/s^2	No	-
η_{ttw}	Medium powertrain efficiency per vehicle segment and year	%	No	4.5.2
VKT	Annual VKT per vehicle segment	10^6 vkm	(No)*	4.5.3
$GHG_{fuel,spec}$	GHG conversion factor for diesel fuel in Europe per year	g CO_2e / MJ	No	4.5.3

* There could be slight indirect impacts of the measure also on VKT due to rebound effects. However, these effects are not included in the MRV boundaries as they are expected to be small and could only be analysed with high additional effort (see section 3.3).

4.2.2 Real total GHG emissions of heavy-duty truck transport

Total GHG emissions of heavy-duty truck transport are calculated complementary to the specific calculations for the partial GHG emissions resulting from rolling resistance. This calculation step is not needed to assess absolute GHG emission savings from the measure. However, it enables an additional assessment of the relevance of measure-specific GHG impacts on total GHG emissions of heavy-duty truck transport in Europe.

Total GHG emissions are calculated based on statistical data of transport activities and, specific fuel consumption factors from comprehensive data bases and fuel specific GHG conversion factors with the following equation:

$$GHGtotal = VKT \times FCtotal_{,spec.} \times GHG_{fuel.spec.} / 10^6 \qquad (3)$$

Where:

GHG_{total} GHG emissions per year (in 10^6 tons)
VKT Transport activity in veh.km per year (in 10^6 veh.km)
$FCtotal_{,spec}$ Total specific fuel consumption per VKT under real driving conditions (in MJ/vkm)
$GHG_{fuel,spec.}$ GHG conversion factor for the used fuel (in g CO_2e/MJ)

Table 5 gives further characterizations of the calculation parameters. Data sources for the parameters are determined in section 4.5.

Table 6: Calculation parameters for total GHG emissions of heavy-duty truck traffic

Calculation parameter	Description	Unit	Influenced from measure	Data sources in section
VKT	Annual VKT per vehicle segment	10^6 vkm	(No)*	4.5.3
$FC_{total,spec}$	Specific fuel consumption per VKT per vehicle segment and year	MJ/vkm	Yes**	4.5.3
$GHG_{fuel,spec}$	GHG conversion factor for diesel fuel in Europe per year	g CO_2e / MJ	No	4.5.3

* There could be slight indirect impacts of the measure also on VKT due to rebound effects. However, these effects are not included in the MRV boundaries as they are expected to be small and could only be analysed with high additional effort (see section 3.3).
** As rolling resistance contributes considerably to specific fuel consumption of a vehicle, also real total fuel consumption factors for the whole vehicle, provided in according data bases are influenced by the measure.

4.2.3 Share of rolling resistance on total GHG emissions

A helpful additional indicator for the effectiveness of European tire regulations is the estimate of the share of rolling resistance related GHG emissions on total GHG emissions of heavy-duty trucks. State-of-the-art heavy-duty trucks have a contribution of rolling resistance to total fuel consumption and GHG emissions in the range of about 20-35 % depending on vehicle size and operation field (see section 2.2.2). Decreasing shares of rolling resistance in future reporting years indicate that the improvement of rolling resistance contributed above average to total reduction of GHG emissions from heavy-duty truck transport.

The share of rolling resistance on total GHG emissions of heavy-duty trucks is calculated with the following equation:

GHGshare= GHGRR / GHGtotal (4)

Where:

GHGshare Share of rolling resistance on real total GHG emissions per year (in 10^6 tons)
GHG_{RR} Real GHG emissions resulting from rolling resistance (in 10^6 tons, section 4.2.1)
GHGtotal Real total GHG emissions (in 10^6 tons, section 4.2.2)

Calculations are fully based on the results of previous calculations and no additional calculation parameters are required.

4.3 Measuring absolute GHG impacts per reporting year

4.3.1 Baseline GHG emissions from rolling resistance

The MRV boundaries for European tire labelling and phase-out regulations include only direct effects of the measure on the development of rolling resistance coefficients. Potential indirect GHG impacts, e.g. from rebound effects, are not considered in the MRV (see section 3.3).

Therefore, the methodological approach for baseline GHG emissions from rolling resistance is identical to the calculation of real rolling resistance related GHG emissions. Baseline rolling resistance GHG emissions are calculated with equations **(1)** and **(2)** from section 4.2.1

Differences between real and baseline GHG emissions calculations apply only for the rolling resistance coefficients (RRC) of the tires. For calculating baseline GHG emissions from rolling resistance, hypothetical baseline medium Rolling resistance coefficients per vehicle segment and year are required (seeTable 7). These baseline RRC developments reflect hypothetical average improvements without the EU tire labelling and phase-out regulations.

Baseline developments are estimated ex-ante before starting the continuous MRV process, but adjustments can become necessary in future in certain cases. All other calculation parameters for baseline GHG emissions from rolling resistance are identical to calculation parameters for real GHG emissions from rolling resistance (see Table 5 in section 4.2.1).

Estimated baseline RRC developments for this MRV are explained in section 4.5.1, where data sources for all calculation parameters of real and baseline calculations are presented.

Table 7: Calculation parameters for baseline rolling resistance GHG emissions

Calculation parameter	Description	Unit	Influenced from measure	Data sources in section
RRCbaseline	Baseline medium Rolling resistance coefficient per vehicle segment and year	kg/t	Yes	4.5.1
All other calculation parameters are identical to the calculation of real rolling resistance GHG emissions (see Table 5 in section 4.2.1).				

4.3.2 Absolute GHG impacts

The absolute GHG emission savings for the whole assessed heavy-duty truck traffic due to the European tire labelling and phase-out regulations are calculated as difference of real and baseline rolling resistance related GHG emissions:

$$GHGsaving_{absolute} = GHG_{RR,baseline} - GHG_{RR,real} \quad (5)$$

Where:

$GHGsaving_{absolute}$	Absolute GHG emissions saving per year (in 10^6 tons)
$GHG_{RR,baseline}$	GHG emissions per year (in 10^6 tons, section 4.3.1)
$GHG_{RR,real}$	GHG emissions per year (in 10^6 tons, section 4.2.1)

A positive calculation result means that the measure has yield GHG emission savings of this amount.

Calculations are fully based on the results of previous calculations.

4.4 Assessing overall relevance for GHG emissions from heavy-duty truck transport

To assess the overall relevance of the measure impacts, a complementary comparison of absolute GHG savings to total GHG emissions of heavy-duty truck transport is recommended. This is done by comparing absolute GHG emissions savings with hypothetical baseline total GHG emissions for the whole heavy-duty truck transport without European tire regulations.

Baseline total GHG emissions of heavy-duty transport

As a first step, hypothetical baseline total GHG emissions are are calculated by adding absolute GHG emissions savings to the total real GHG emissions:

$$GHGtotal,_{baseline} = GHGtotal,_{real} + GHGsaving_{absolute} \quad (6)$$

Where:

$GHG_{total,baseline}$	Baseline total GHG emissions (in 10^6 tons)
$GHG_{total,real}$	Real total GHG emissions (in 10^6 tons, section 4.2.2)
$GHGsaving_{absolute}$	Absolute GHG saving (in 10^6 tons, section 4.3.2)

Calculations are fully based on the results of previous calculations.

Percentage change of total GHG emissions of heavy-duty truck transport in Europe

The percentage change of GHG emissions of the heavy-duty transport sector as a result of European tire labelling and phase-out regulations is calculated with the quotient of real total GHG emissions to baseline total GHG emissions:

$$GHGsaving_{share} = GHGsaving,_{absolute} / GHGtotal,_{baseline} \quad (7)$$

Where:

$GHGsaving,_{share}$	Saved percentage share of total GHG emissions (in %)
$GHGsaving,_{absolute}$	Absolute GHG emissions saving per year (in 10^6 tons, section 4.3.2)
$GHGtotal,_{baseline}$	Real total GHG emissions (in 10^6 tons, equation 6)

Calculations are fully based on the results of previous calculations.

4.5 Data sources of calculation parameters

This chapter gives an overview of all required calculation parameters for the measurement of GHG impacts identified in sections 4.2 and 4.3 and proposes suitable data sources for each parameter. According to the GHG assessment boundaries (section 3.3), all parameters are differentiated by vehicle segments.

- Section 4.5.1 provides data sources for real developments of rolling resistance coefficients and ex-ante estimates for baseline RRC developments without the measure. Knowing the real RRC developments as well as a comprehensive estimate of baseline RRC developments are essential for the MRV process as rolling resistance coefficients are the main parameter influenced by the measure.
- Section 4.5.2 provides additional parameters for calculating the partial specific fuel consumption resulting from rolling resistance are the vehicle weight, RRC correction factors and powertrain efficiency. These parameters are not influenced from the measure and, therefore, identical in real and baseline calculations.
- Section 4.5.3 provides data sources for the real developments of general parameters for the heavy-duty transport sector in Europe, including transport activities (VKT), specific fuel consumption per vehicle segment and GHG conversion factors. These parameters are required for the calculation of rolling resistance related GHG emissions as well as for total GHG emissions.

Table 8 summarizes for all calculation parameters and their data sources.

Table 8: Overview of calculation parameters and data sources

Calculation parameter	Description	Unit	Data sources
RRCreal	Real medium Rolling resistance coefficient per vehicle segment and year	kg/t	Market offer of truck tires (see section **Fehler! Verweisquelle konnte nicht gefunden werden.**)
RRCbaseline	Baseline medium Rolling resistance coefficient per vehicle segment and year	kg/t	Estimates in section **Fehler! Verweisquelle konnte nicht gefunden werden.**
C_{RRC}	RRC correction factor	-	[Bode, / Bode, 2013], [IFEU, 2015]
m	Vehicle mass (=empty weight + vehicle load) per vehicle segment and year	metric tons	HBEFA 3.1 [INFRAS, 2010], TRACCS [Emisia, 2013]

Calculation parameter	Description	Unit	Data sources
g	Gravity acceleration: 9.81 m/s²	m/s²	- (physical constant)
η_{ttw}	Medium powertrain efficiency per vehicle segment and year	%	[IFEU, 2015]
VKT	Annual VKT per vehicle segment	10^6 vkm	TRACCS [Emisia, 2013], EU Transport in figures [EU, 2013]
$FC_{total,spec}$	Specific fuel consumption per VKT per vehicle segment and year	MJ/vkm	TRACCS [Emisia, 2013], HBEFA [INFRAS, 2010]
Biofuel share	Share of biofuels on diesel fuel in Europe. (required for calculating weighted GHG conversion factors)	%	EU transport in figures - statistical pocketbook [EU, 2013]
$GHG_{fuel,spec}$	GHG conversion factor for diesel fuel in Europe per year	g CO_2e/MJ	EN 16258 [COM, 2013]

4.5.1 Real and baseline rolling resistance coefficients

The most important calculation parameter for the measurement of GHG impacts is the weighted average rolling resistance coefficient (RRC) by vehicle segment for a reporting period.

- Real developments are required, resulting from the effects of the measure.
- Hypothetical baseline developments estimate expected developments without measure.

RRCs are dimensionless coefficients but are typically expressed in the unit kg/t or N/kN (i.e. ‰). Typical RRCs of tires vary strongly for particular vehicle segments and application fields and even for different axles of a vehicle (see section 2.2.2). For calculations on a high level of accuracy, differentiated data for individual vehicle segments are recommended.

Rolling resistance coefficients in the base year and real future developments

There are no regularly updated and differentiated statistics on RRCs of sold truck tires (tire class C3) in the EU [ETRMA, 2014]. The only regularly available information is the market offer of truck tires from selected tire shops (e.g. [Reifenleader, 2015]). Though RRC distribution of the tire offer probably is not representative for that of tire sales, its analysis gives at least an approximate overview of the present RRC distribution of truck tires in the absence of better statistical sources.

Available information enables filtering the offered truck tires by size and axle (steer, drive, trailer) and shows the number of products in each RRC label class. In this way, it enables to estimate the RRC distribution for offered truck tires and derive weighted average RRCs differentiated by vehicle segment for each monitoring year.

Tires on different axles can contribute diverging shares to total rolling resistance of the vehicle, depending on the average RRC per axle and on the weight distribution in the vehicles (see section 2.2.2). For the calculation of weighted average RRCs, approximate distribution parameters can be used from Table 9 for a start, if no additional information is available.

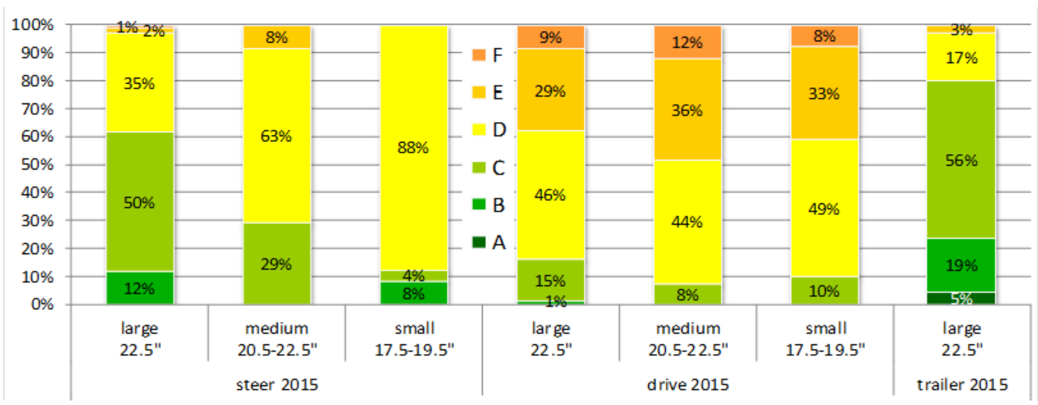
Table 9: Distribution parameters for the calculation of weighted rolling resistance coefficients

Vehicle segment	Steer	Drive	Trailer
Semi-trailer trucks and truck trailers	17%	33%	50%
Rigid trucks	50%	50%	-

Figure 5 shows exemplary data on RRC distribution and resulting weighted average RRCs of C3 truck tires differentiated by tire size and axle for the year 2015 from one online tire shop [Reifenleader, 2015]. Table 10 shows weighted average RRCs derived on this basis. According to additional analyses in [IFEU, 2015] did not change considerably in the last years. Therefore, these average RRC values might also be used for earlier base years than 2010.

Table 10: Estimates of weighted average rolling resistance coefficients in the year 2015

	Large	Medium	Small
RRC in kg/t	6.3	7.1	7.1



Average RRC kg/t)	6.1	6.6	6.6	7.1	7.3	7.2	5.7

Figure 5: Exemplary distributions of truck tires in EU tire label RRC classes in the market offer of one online tire shop and derived weighted average [Reifenleader, 2015]

Baseline developments of rolling resistance coefficients

For calculating baseline GHG emissions from rolling resistance, hypothetical baseline medium rolling resistance coefficients per vehicle segment and year are required. These baseline RRC developments reflect hypothetical average improvements without the EU tire labelling and phase-out regulations.

Future baseline developments of rolling resistance coefficients were estimated ex-ante based on the current situation. Analyses of RRC data from 2007 to 2015 in [IFEU, 2015] show no relevant improvement of average RRC values so far (despite implementation of the obligatory labelling in 2012). On this basis, no future improvements of rolling resistance coefficients in the baseline development are assumed for the years up to 2030 for all vehicle segments due to the following reasons.

- In many operation fields (except long-haul transport) fuel costs have only low relevance for the total costs of vehicle operation [ifeu, / TU Graz, 2015]. Therefore, other criteria have higher importance in buying decisions (e.g. purchase price, durability, see e.g. [COM, 2008a]) and there are no market drivers for the development of tires with reduced rolling resistance.
- In long-haul transport, vehicle owners are generally more interested in technologies to reduce specific fuel consumption of their truck. However, vehicle owners are rather sceptical of manufacturer's promises on efficiency gains [NACFE, 2013]. Without official tire labels they have no reliable information on actual rolling resistance and focus on other, more comprehensible criteria in their buying decisions.

These assumptions therefore represent a conservative estimate of the baseline developments of rolling resistance coefficients of truck tires in Europe, i.e. no improvement of fuel efficiency of heavy-duty trucks coming from reduced rolling resistance.

Baseline assumptions of future RRC developments should remain unchanged in all future reporting years if there are no additional insights on how RRC values would have developed without the European tire labelling and phase-out regulations. Additional insights might come from comparison with other markets outside Europe without existing or planned tire regulations, without other policy measures inducing rolling resistance improvements and uninfluenced by the developments in Europe (though in a globalized market the European tire labelling might also influence developments on other regions worldwide).

4.5.2 Parameters for rolling resistance related fuel consumption

Vehicle weight

The total vehicle weight of a heavy-duty truck is the sum of the vehicle empty weight and the weight of the loading. Both parameters can change in future depending on additional measures in the transport sector (e.g. light weighting, increase of vehicle load factors) and their development should therefore be monitored.

- Empty weights for each are provided for all vehicle segments from the European emission factor database HBEFA 3.1 [INFRAS, 2010].
- Average loading weights were calculated for the base year 2010 as quotient of the ton.km and veh.km values per vehicle segment provided in TRACCS [Emisia, 2013]1.

If data of these projects are updated regularly in future, they should also be used for regular updates of the average loading weights. Otherwise, values from the last year should be continued to use.

[1] In this European research project, an extensive set of historical transport data (vehicle stock, VKT, ton.km, fuel consumption factors etc.) has been collected for all European Member States, based on European as well as national statistics, other databases and models (e.g. Copert, HBEFA/TREMOD, TREMOVE). The TRACCS data base provides therefore a detailed up-to-date and comprehensive data base for the transport sector (up to 2010) and is also used in several European processes.

RRC correction factor

The rolling resistance coefficient (RRC) does not only depend on the construction properties of the tires but is also influenced by other factors such as abrasive wear, tire pressure, track alignment, deformation through load, ambient temperature, road roughness and water on the road [Bode, / Bode, 2013]. E.g. RRC of a tire with a half worn profile on a flat road is almost 30 % lower compared to the RRC of the new tire. Most other factors increase the RRC, but vary considerably depending on the actual conditions during a trip. Therefore, no general correction factor exists. For the MRV process it is recommended to assume as a start that RRC increasing factors in sum offset the average RRC reduction from abrasive wear. In this way, a RRC correction factor of 1.0 can be used in all calculations and all monitoring years unless better data becomes available.

Powertrain energy efficiency

Powertrain energy efficiency includes conversion efficiency of the engine and power losses in gearbox and axles. It depends on vehicle characteristics and varies depending on the driving situation (engine map characteristics). Medium powertrain energy efficiency values for recent 12 t and 40 t heavy-duty trucks EURO V and EURO VI are available from [ifeu, / TU Graz, 2015]. Large trucks have a higher efficiency than smaller trucks, recent EURO VI models have a higher efficiency than older EURO V models. This information was also used to estimate powertrain efficiency for older vehicles (Euro 0-IV) as well as future developments of powertrain efficiency of new vehicles. Based on powertrain efficiency estimates per vehicle segment and age, medium powertrain efficiency of the vehicle fleet in each scenario year was calculated considering average ag e distributions per vehicle segment and year provided in the European model TREMOVE [TML, 2010].

Table 11 shows estimated average powertrain efficiency values by vehicle segment for 2010-2030. These values can be used as defaults in the MRV process. Nevertheless, this data should be replaced from more exact sources if these become available.

Table 11: Estimated development of powertrain efficiency values for heavy-duty trucks in Europe

Vehicle segment	2010	2020	2030
Rigid 3.5-7.5t GVW	35%	36.5%	37.5%
Rigid >7.5t GVW, truck-trailer <= 28t GVW	37.5%	39%	40%
Truck-trailer >28-60t GVW	39%	41%	42%

4.5.3 Parameters for general developments in heavy-duty transport

For the calculation of real GHG emissions from rolling resistance, regular information on the annual transport activities in heavy-duty truck transport and specific GHG conversion factors for the diesel fuel are required. For real total GHG emissions, additionally real developments of specific fuel consumption factors for the whole vehicle need to be known.

Transport activities and specific fuel efficiency

Main data sources for transport activities and specific fuel efficiency are:

TRACCS [Emisia, 2013]: In this project, an extensive set of transport data including vehicle stock, transport activities (VKT, ton.km) and specific fuel efficiency (MJ/vkm) has been collected for all European Member States, based on European and national statistics, other databases and models (e.g. Copert, HBEFA/TREMOD, TREMOVE). The TRACCS data base provides a detailed up-to-date and comprehensive data base for the transport sector (up to 2010) and is also used in several European processes. If data of this project were updated regularly in the future, they would represent a best-practice data base on both transport activities and fuel consumption for the whole road freight transport sector in Europe.

EU transport in figures - statistical pocketbook [Emisia, 2013]: This yearly publication includes regular information on the development of freight transport volumes (ton.km) in Europe. This data source can be used for estimating relative developments (percentage increase) of VKT based on data for the last available year in the detailed TRACCS data base.

HBEFA [INFRAS, 2010]: The European emission factor database HBEFA provides annual fuel consumption factors for all road vehicle categories, differentiated by vehicle segments (and further criteria). Though all fuel consumption factors are specific for particular countries, they are widely comparable to the fuel efficiency factors in TRACCS. HBEFA values can therefore be applied in future monitoring years if no updates of the TRACCS data base are available.

Well-to-wheel GHG conversion factors

Well-to-wheel GHG conversion factors depend on the carbon content of the fuel and on the upstream pathways to provide the fuel. Heavy-duty transport in Europe is still almost completely pending on diesel fuel, however with increasing shares of biofuels on total fuel. Average GHG conversion factors for each reporting year have therefore to be calculated by weighting the percentage fossil and bio shares on total fuel. Data sources for these calculations are:

EU transport in figures - statistical pocketbook [EU, 2013]: This statistical database provides annual information on the share of biofuels on total fuel consumption in road transport in Europe.

European standard EN 16258 “Methodology for calculation and declaration of energy consumption and GHG emissions of transport services (freight and passengers)”: This standard provides well-to-wheel GHG conversion factors for fossil fuels and a methodology to calculate GHG conversion factors for different shares of biofuel on total fuel.

4.6 Calculation example for the measurement of GHG impacts

This section shows a calculation example for the GHG assessment methodology. Exemplary calculations are based on the ex-ante assessment in [IFEU, 2015] including only the large vehicle segment (articulated trucks or tractor / trailer combinations with 28 to 60 t GVW) and refer to the year 2020. Table 12 shows the input parameters for all calculations. Table 13 shows the calculation steps and the results. Baseline calculation results are highlighted in red colour. Calculated GHG impacts for the reporting year are highlighted in green colour.

Table 12: Exemplary calculation parameters for the year 2020 for the large vehicle segment

Calculation parameter	Value 2020	Unit
RRCreal	5.75	kg/t
RRCbaseline	6.30	kg/t
C_{RRC}	1.0	-
m	25.1	metric tons
g	9.81	m/s^2
η_{ttw}	41%	%
VKT	124'363	10^6 vkm
$FC_{total,spec}$	11.04	MJ/vkm
$GHG_{fuel,spec}$	87.2	g CO_2e/MJ

Table 13: Exemplary assessment of GHG impacts for the year 2020 for the large vehicle segment

Equation		Calculation	Result	Unit
1	$FC_{RR,spec}$ *real*	5.75 x 1.0 x 25.1 x 9.81 / 0.41 / 1000	3.45	MJ/vkm
	$FC_{RR,spec}$ ***baseline***	6.30 x 1.0 x 25.1 x 9.81 / 0.41 / 1000	3.78	MJ/vkm
2	GHG_{RR} *real*	124'363 x 3.453 x 87.2 / 10^6	37.4	10^6 tons
	GHG_{RR} ***baseline***	124'363 x 3.784 x 87.2 / 10^6	41.0	10^6 tons
3	*GHGtotal real*	124'363 x 11.04 x 87.2 / 10^6	119.7	10^6 tons
4	*GHGshare real*	0.037 / 0.120	31.3	%
5	***$GHGsaving_{absolute}$***	0.041 - 0.037	**3.6**	**10^6 tons**
6	*$GHGtotal_{,baseline}$*	0.120 + 0.004	123.3	10^6 tons
7	***$GHGsaving_{share}$***	0.004 / 0.124	**2.9**	**%**

4.7 Assessment of uncertainties

Uncertainties of calculated GHG impacts result primarily from the following reasons

- Accuracy of calculation parameters
- Differentiation level of calculation methodology and therewith possible accuracy of results
- Appropriateness of baseline assumptions

Main uncertainties in this MRV come from **uncertain accuracy of calculation parameters**. This concerns primarily information on real distribution of rolling resistance coefficients

(RRCs). Currently, average RRCs are estimated based on information on the market offer of truck tires from selected tire shops. However, RRC distributions of the tire offer probably are not representative for that of tire sales and give therefore only an approximate overview of the distribution of truck tires in a reporting year and its development over time. Accordingly, the most important step to reduce uncertainties in the MRV would be to establish a regularly updated data base for representative RRC data from truck tires in Europe (e.g. obligation of tire manufacturers to provide annual sales data to the European Commission or regular field monitoring of the tire equipment of trucks on European roads).

Further uncertainties result from uncertainties of other rolling resistance specific calculation parameters, i.e. development of powertrain efficiency and RRC correction factors, but are rather low compared to RRC distribution as powertrain efficiency improves only slightly over the years and RRC correction factors can be assumed to remain widely stable over the years.

Uncertainties of calculation parameters might also result from future data availability for transport activities and overall fuel efficiency of heavy-duty vehicles. Basic data for the year 2010 adopted from TRACCS project provide a high level of detail and can be seen today's best data base for road freight transport in Europe. If this data base is updated regularly in future, uncertainties of these parameters remain low. However, uncertainties of calculation parameters will increase if future developments need to be estimated from overall development of transport demand without information on individual vehicle segments (see section 4.5.3).

The defined **differentiation level of the methodology** depends on data availability of appropriate calculation parameters in the required level of detail and also on the possible periodic efforts for data collection and measurement of GHG impacts. Calculation methodology as defined in this MRV blueprint enables a high level of accuracy considering differences of effects from European tire regulations on the rolling resistance development for individual heavy-duty vehicle segments as well as general differences in developments of transport activities and fuel efficiency per vehicle segment. On principle, differentiation level of calculation methodology could be further refined, e.g. with a more detailed differentiation of vehicle segments and additional differentiation of transport activities per vehicle segment by road categories or operation fields (long-haul, urban delivery…). However, this would increase calculation efforts considerably and requires a high level of detail of most calculation parameters, which is not regularly available so far.

Uncertainties due to **possible inappropriateness of baseline assumptions** concern mainly the development of rolling resistance coefficients, as only this parameter differs in baseline calculations to the monitoring of real emissions developments. In this MRV, no improvements of rolling resistance are assumed for the baseline development as available RRC information for past years do not show significant improvements and no relevant incentives to develop low rolling resistance tires are expected without the implementation of European tire labelling and phase-out regulations (see section 4.5.1). This baseline estimate could be too conservative at least for the long-haul sector because vehicle operators in this segment are generally interested in fuel saving truck technologies. They might include rolling resistance criteria in their tire buying decision also without manufacturer-independent information if they can be convinced of fuel saving effects of tires in another way – and therefore induce RRC improvements over time also without the European measure. However, there is no evidence (e.g. from other regions in the world) that such effects should be assumed in the baseline development.

5 Indicators for non-GHG impacts of the measure

The measure has several potential non-GHG impacts, identified in section 3.2 Within the assessment boundaries (section 3.3), following non-GHG impacts should be monitored in the MRV process:

- Road safety
- External rolling noise
- Vehicle operation costs

Road safety and external rolling noise

Road safety and external rolling noise are directly addressed in European tire labelling and phase-out regulations. The European tire label includes labels for the wet grip as indicator for road safety and labels for external rolling noise (see section 2.2.1). The development of truck tire shares in different label classes can be a suitable indicator for a fast overview of improvements of these parameters. Indeed, developments indicate general improvements of these parameters, but do not represent only impacts attributable to the measure as long as they are not compared to a baseline development.

There are no regularly updated statistics on according label distributions of sold truck tires (tire class C3) in the EU, but estimates are possible based on information on the market offer of truck tires from selected tire shops (e.g. [Reifenleader, 2015]). Though label class distributions of the tire offer probably are not representative for that of tire sales, its analysis gives an approximate overview of the distribution of truck tires in a reporting year and its development over time.

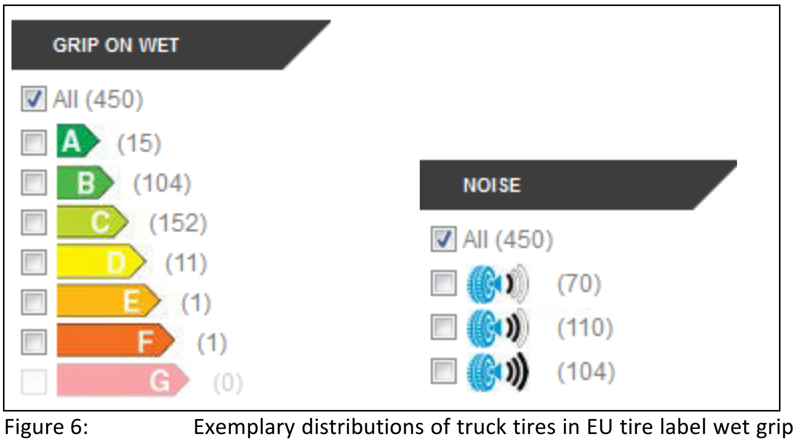


Figure 6: Exemplary distributions of truck tires in EU tire label wet grip classes (left) and noise levels (right) in the market offer of one online tire shop [Reifenleader, 2015]

Vehicle operation costs

Changes of vehicle operation costs result on the one hand from increased investment costs for low rolling resistance tires compared to conventional tires, but on the other hand from reduced fuel costs resulting from fuel savings. Accordingly, a full cost impact assessment should consider both cost parameters. However analyses in [ifeu, / TU Graz, 2015] show that additional investment costs only amount to 10-20 % of fuel cost savings and investment in low rolling resistance tires has a payback within few months (see also section 3.2).

Annual cost savings resulting from the measure can therefore be roughly estimated by

1. Recalculating fuel savings per year from absolute GHG savings
2. Multiplying fuel savings per year with average fuel prices.
3. Reduction factor of results (e.g. 20%) for additional investment costs.

As the measure affects heavy-duty transport in whole Europe, cost savings can be in the range of several million Euros per year.

$$\boldsymbol{COSTsaving} = \frac{\boldsymbol{GHGsaving_{absolute}}}{\boldsymbol{GHG_{fuel.spec.}\ x\ 35.74\ x\ 10^6}}\ \boldsymbol{x\ fuel\ price\ x\ 80\%} \quad (8)$$

Where:

$COSTsaving_{,share}$	Cost saving per year (in 10^6 Euro)
$GHGsaving_{absolute}$	Absolute GHG saving (in 10^6 tons, section 4.3.2)
$GHG_{fuel,spec.}$	GHG conversion factor for the used fuel (in g CO_2e/MJ)
35.74	Conversion factor for fuel consumption (35.74 MJ/litre diesel)
fuel price	Fuel price (in Euro/litre Diesel)
80%	Reduction factor for additional investment costs

6 Monitoring of measure implementation progress and data sources

6.1 Monitoring of measure implementation progress

The European tire labelling and phase-out regulations have been decided in the year 2009. Relevant implementation steps are (see section 2.2.1):

- 2012: Implementation of the tire labelling, including RRC label classes.
- 2016: Coming into effect of the first stage RRC limit value.
- 2020: Coming into effect of the second stage RRC limit value.

All implementation steps are mandatory regulations and need therefore no special monitoring of implementation progress.

If the European measure is translated into a NAMA, type of measure can change. In this case, an additional monitoring of selected parameters can help to control the implementation progress, e.g.:

- Measure: Self-commitments of tire manufacturers for stepwise reduction of rolling resistance coefficients of truck tires
- Monitoring parameter: Obligatory annual information from tire manufacturers about percentage share of produced/sold tires meeting different limit values.

If appropriate monitoring parameters are defined, they cannot only indicate the progress of the measure implementation but also be used in the measurement of GHG impacts.

6.2 Updating data sources and calculation approach

The measurement of GHG impacts needs to be updated regularly for each reporting period. If data sources remain unchanged in all reporting periods, this requires only collecting data for the new reporting year from existing data sources and repeating all calculations with updated parameters. However, from one reporting period to the next, availability or quality of existing data sources can change or better data sources may become available. In these cases, changes of data sources and, in some cases, adaptations of the methodological approach may be advantageous or necessary. The following steps should be followed if changes are made:

- The motivations for the changes are documented.
- Possible limitations of consistency are discussed.
- Calculations for past periods are repeated with the new methodology and / or calculations for the current period are simultaneously performed using the previous methodology if possible. Deviations of the results are discussed.

7 Reporting

An essential part of MRV is the regular reporting of measurement results and the discussion of the achievement of measure objectives. The MRV report should be prepared for each reporting period.

The first MRV report for European tire labelling and phase-out regulations should include the following information that can be broadly adopted from this MRV blueprint:

- Background and objectives of the measure: All basic information on the general background why the measure has been started and the main objectives of the measure.
- MRV assessment boundaries, including system boundaries, emission sources and covered GHG emissions (CO_2 equivalents, well-to-wheel). Also the inclusion of non-GHG impacts in the assessment boundaries is documented. The documentation of MRV assessment boundaries includes also information on the reasons for their definition. In case that limited data availability has been a crucial factor for defining assessment boundaries that are not fully compatible to measure all relevant impacts of the measure, consequences for the interpretation of measurement results should be discussed.
- Methodological explanation of the measurement of GHG and non-GHG impacts, including methodological steps, main equations and calculation parameters.
- Documentation of data sources and baseline assumptions for all calculation parameters.
- Calculations for the base year and measurement results for the first reporting year, including discussion of this first short-term outcome of the measure.

Regular updates of the MRV report do not require extensive explanations on the measure, its objectives, boundaries, methodology and data sources, unless there have been substantial changes to the previous reporting period (e.g. introduction of additional limit values for years after 2020). Nevertheless, update reports should give a short summary on all topics and refer to the first monitoring report for detailed information.

Furthermore, the MRV update report should address the following topics:

- Adjustments of assessment boundaries and measurement methodology: Starting the MRV process, availability of basic data in high quality can be still limited, requiring simplifications of assessment boundaries and/or measurement methodology. E.g., for the European tire labelling and phase-out regulations no information on rolling resistance coefficients of actual tire sales is available but only on tire market offer. And no quantification of potential rebound effects including modal shift from rail and water transport is possible by now. Therefore, improving basic data availability is a continuous task in the MRV process in order to improve coverage of relevant impacts in the assessment boundaries and accuracy of calculated measure impacts. All changes of boundaries or methodological aspects due to availability of additional data sources have to be documented in the updated MRV reports and discussed for their consequences of the interpretation of measurement results.

- Discussion of long-term measure impacts: A strong increase of measure-related GHG impacts is expected for later years after implementation of the measure in the ex-ante assessment [IFEU, 2015]. The discussion of long-term measure impacts should analyze, if these expectations have been satisfied and what are main reasons for differences of real impacts to the ex-ante assessment. In case of changed assessment methodology and boundaries, also consistency of the time series has to be discussed and, where done, adjusted recalculations for former years have to be documented.

8 Verification

In this specific case, no verification is/was carried out. However, the data use is available and accessible (see data sources cited) and allows a transparent verification process. The spreadsheet model used is can be send to interested countries (or verifiers) on request. Calculations by TREMOD can be explained by IFEU on site.

9 Applicability of the MRV blueprint for related NAMAS

The European tire labelling and phase-out regulations could be a basis for implementing comparable measures in other countries within the NAMA framework. Therefore, also the applicability of the MRV blueprint for the European measure on comparable NAMAs in other regions has been assessed.

Applicability of this exemplary European MRV blueprint to NAMAs in other regions depends first on the comparability of the measures. If other measures also focus on improving rolling resistance by establishing limit values for rolling resistance coefficients and/or introducing a tire labelling, most parts of the GHG assessment methodology can be adopted from this MRV blueprint. In this case, calculation parameters are the same as in Europe (see Table 8).

Main differences of the measurement of GHG impacts can concern available data sources and therewith level of detail in the calculations, but also definition of assessment boundaries and baseline assumptions:

- Level of detail in the calculations: In the exemplary European MRV blueprint, all calculations are done separately for individual vehicle segments. Furthermore, differences of rolling resistance coefficients RRCs on different axles of the vehicles are considered in the derivation of average RRCs per vehicle segment. Adopting this MRV blueprint to NAMAs for other regions with reduced data availability might require simplified calculations, e.g. using one average RRC for the whole vehicle fleet. However, regular availability of data for the real development of RRCs is essential in any case for assessing GHG impacts of the NAMA.
- Assessment boundaries: This MRV blueprint covers whole heavy-duty truck transport including all trucks with a gross vehicle weight (GVW) > 3.5 tons on all roads on the territory of the European Union. Adopting this MRV blueprint to other regions might require a change of assessment boundaries, e.g. only including truck transport on highways and only semi-trailer trucks, depending on the regular availability of statistics on transport activities. Also amendments of assessment boundaries to further vehicle segments are possible if these are relevant for GHG impacts of the NAMA.
- Baseline assumptions: In Europe, there are still no relevant interactions of tire regulations with other GHG mitigation measures in the freight transport sector. However, interaction with further measures can be relevant in other regions. E.g. fuel efficiency standards for heavy-duty trucks (as introduced e.g. in China) can lead to RRC improvements also without a tire-specific measure and need therefore to be considered in the derivation of baseline developments.

Besides the assessment of GHG impacts, also the estimate of fuel cost savings as non-GHG impact can be adopted from this exemplary European MRV blueprint to NAMAs in other regions. Moreover, if NAMAs include requirements on wet grip and rolling noise and regularly available information on the real development of these parameters, also indicators for these non-GHG impacts can be adopted from the exemplary European MRV blueprint.

References

AEA / Ricardo (2011): Reduction and Testing of Greenhouse Gas (GHG) Emissions from Heavy Duty Vehicles – Lot 1 : Strategy. Nikolas Hill, Stephen Finnegan, John Norris, Charlotte Brannigan, David Wynn, Hannah Baker, Ian Skinner (AEA, Ricardo).

Bode, O. / Bode, M. (2013): FAT 255: Untersuchung des Rollwiderstands von Nutzfahr zeugreifen auf echten Fahrbahnen. FAT, Berlin.

COM (2008): IMPACT ASSESSMENT - Tyre labelling.

COM (2013): EU Energy, Transport and GHG Emissions Trends to 2050 - Reference Scenario 2013. European Commission; DG ENER, DG CLIMA and DG MOVE.

Continental (1999): Life Cycle Assessment of a Tire. S. Krömer, E. Kreipe, D. Reichenbach,R. Stark, Hannover.

EC (2009a): REGULATION (EC) No 661/2009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 July 2009 concerning type-approval requirements for the general safety of motor vehicles, their trailers and systems, components and separate technical units intended therefor.

EC (2009b): REGULATION (EC) No 1222/2009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 November 2009 on the labelling of tyres with respect to fuel efficiency and other essential parameters. EUROPEAN PARLIAMENT AND COUNCIL.

EC (2011): COMMISSION REGULATION (EU) No 1235/2011 of 29 November 2011 amending Regulation (EC) No 1222/2009 of the European Parliament and of the Council with regard to the wet grip grading of tyres, the measurement of rolling resistance and the verification proced. pp. 17–23.

EC (2014): Strategy for reducing Heavy-Duty Vehicles' fuel consumption and CO_2 emissions. European Commission, Brüssel. *http://ec.europa.eu/clima/policies/transport/vehicles/heavy/documentation_en.htm*.

EMEP-EEA (2013): EMEP/EEA air pollutant emission inventory guidebook 2013 - Technical guidance to prepare national emission inventories. European Environmental Agency.

Emisia (2013): Transport data collection supporting the quantitative analysis of measures relating to transport and climate change Project acronym : TRACCS. Papadimitriou, G Ntziachristos, L Notter, B Keller, M Fridell, E Winnes, H Styhre, L Commission.

EP (2009a): REGULATION (EC) No 1222/2009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 November 2009 on the labelling of tyres with respect to fuel efficiency and other essential parameters. EUROPEAN PARLIAMENT AND COUNCIL.

EP (2009b): REGULATION (EC) No 661/2009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 July 2009 concerning type-approval requirements for the general safety of motor vehicles, their trailers and systems, components and separate technical units intended therefor.

EPEC (2008): Impact Assessment Study on Possible Energy Labelling of Tyres. Nick Bozeat, European Policy Evaluation Consortium (EPEC), commissioned by the European Commission DG TREN, Brussels.

ETRMA (2014): Market data for C3 tires. European Tyre & Rubber Manufacturers' Association, Brussels, Personal communication,11 Nov 2014.

EU (2013): EU transport in figures - statistical pocektbook 2013.

GIZ (2014): Navigating Transport NAMAs - A practical handbook on Nationally Appropriate Mitigation Actions (NAMAs) in the transport sector.

IFEU (2013): Erfassung von Emissionen des Verkehrs in Deutschland im PRTR Erarbeitung methodischer Grundlagen Quellen für den Bereich Verkehr im nationalen Schadstofffreisetzungs- und -verbringungsregister PRTR.

IFEU (2015): GHG Impact Assessment for Energy Labelling of Heavy-Duty Truck Tires and a Related Phase-Out Scheme in the European Union. H. Keller, F. Dünnebeil, commissioned by Deutsche Gesellschaft für Internationale Zusammenarbeit (giz) GmbH.

ifeu / TU Graz (2015): Zukünftige Maßnahmen zur Kraftstoffeinsparung und Treibhausgasminderung bei schweren Nutzfahrzeugen. Institut für Energie- und Umweltforschung Heidelberg (ifeu) und Institut für Verbrennungskraftmaschinen und Thermodynamik, Technische Universität Graz. Im Auftag des Umweltbundesamtes. Forschungskennzahl 3711 96 105. Dessau-Roßlau, April 2015.

INFRAS (2010): Handbuch Emissionsfaktoren des Straßenverkehrs (HBEFA), Version 3.1. Dokumentation in Vorbereitung, Bern. *www.hbefa.net*.

M.Kern (2014): Dreigestrichenes A. In: *Lastauto Omnibus*. Vol. 12, pp. 26–27.

NACFE (2013): Barriers to the Increased Adoption of Fuel Efficiency Technologies in the North American On-Road Freight Sector. Mike Roeth, Dave Kircher, Joel Smith, Rob Swim. *http://www.theicct.org/hdv-technology-market-barriers-north-america*.

Reifenleader (2015): Reifenleader Online shop.

TML (2010): TREMOVE v3.3.2 (2010). Leuven. *http://www.tmleuven.be/contact/home.htm*.