Kapsch TrafficCom

White Paper

Intelligent Transport Systems in the EU Taxonomy Regulation.

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Introduction.

Why Intelligent Transport Systems matter for Sustainability.

The EU Taxonomy is an EU-wide common classification system that sets out criteria for defining environmentally sustainable economic activity. It creates transparency for the financial sector and potentially influences public procurement. The EU Taxonomy aims to direct investment towards environmentally sustainable economic activities to meet the goals of the European Green Deal and become net zero by 2050.

Although Intelligent Transport Systems (ITS) such as tolling and traffic management are recognised as environmentally sustainable economic activities, there is a lack of defined technical screening criteria for their operation. Further they also lack an underlying method for the quantification of the associated prevented traffic-related emissions.

In this paper, Kapsch TrafficCom makes the case why road tolling and traffic management should be included in the EU's taxonomy and how their impact could be quantified.

The 'Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment', commonly known as the Taxonomy Regulation, sets out criteria to define 'sustainable economic activity'. To become an 'environmentally sustainable economic activity' this activity must 'align' with the criteria set out in the Taxonomy Regulation.

The importance of road tolling and traffic management is not reflected in the Taxonomy Regulation; hence the Taxonomy Regulation is not in line with EU transport policy or the Green Deal we argue.

> ***`What if not traffic management and tolling can contribute more to reach the targets of the Green Deal in regard to traffic and transport. Consequently, the Taxonomy Regulation should cover traffic management and tolling.´***
>
> Georg Kapsch, CEO of Kapsch TrafficCom

Key point is that the taxonomy is very much product focused and taxonomy 'alignment' is very much about reducing the CO_2 footprint of individual products or services. The taxonomy does not capture changes in user behaviour.

Another key element of 'aligning' with the Taxonomy Regulation is scientific evidence that an activity reduces CO_2 emissions or other adverse impacts without further harming the other objectives of the regulation (e.g. climate adaption, protection of water resources, transition to a circular economy, pollution prevention, protection, and restoration of biodiversity).

In this White Paper, Kapsch TrafficCom presents two calculation methods for CO_2 emission reductions that can be achieved through road maintenance or traffic management. Furthermore, we present two model calculations: one for the Austrian motorway network and one for the city of Vienna.

Road tolling is a socially beneficial activity, it serves changing the composition of the vehicle fleet or mobility patterns by providing incentives. This effect is considered in EU transport policy. The tolls collected are also invested in decarbonisation, through road maintenance. Traffic management and smoothening traffic flow are also recognised as tools to improve the environmental impact of road transport, but scientific evidence is often unrepresentative, difficult to reproduce or applies only to a small sample of vehicles in very specific circumstances.

With this paper, Kapsch TrafficCom would like to contribute to the debate and offer scientific evidence of the CO_2 savings that can be achieved through road tolling and traffic management.

Furthermore we would like to use this opportunity to highlight the central role road operators play in making mobility sustainable. Key mobility related health hazards, such particulate matter and emissions, as well as road safety have to be addressed through traffic management.

The operation of roads has to be recognised as an economic activity with its own technical screening criteria in the Taxonomy Regulation's delegated acts and air quality, particulate matter, air pollutants as well as road safety have to be considered.

The policy case.

Recognising tolling and ITS in the taxonomy.

We believe road tolling and ITS to play a key role in decarbonising road transport as well as preventing pollution and fostering the circular economy.

Road tolling is already playing a key role in legislation to:

1) decarbonising roads & heavy goods transport and
2) EU transport policy contributing to road maintenance.

Furthermore, ITS is key to managing traffic and most notably congestion prevention.

Tolling & decarbonisation.

Decarbonising roads & heavy goods transport.

TFEU Article 191 (2) embeds the ‘polluter pays’ principle in the Treaties[1]. The European Transport Policy White Paper ‘Roadmap to a Single European Transport Area’[2] calls for the application of the ‘user pays’ and ‘polluter pays’ principles in EU transport policy.

The EU's ‘Sustainable and Smart Mobility Strategy‘[3] sets a target of 30 million zero-emission vehicles in the EU by 2030 and almost all road vehicles by 2050. 100 cities should be climate neutral by 2030. The strategy reiterates the importance of the ‘user pays’ and ‘polluter pays’ principles and defines the Eurovignette Directive as a key instrument for implementing the Green Deal on Europe's roads. It also underlines the role of mobility management. Further it highlights the need for investment in sustainable and digital mobility.

In the field of road transport, Directive 1999/62/EC, also known as the ‘Eurovignette Directive’, sets out to implement the ‘user pays’ and ‘polluter pays’ principles for heavy goods vehicles in the EU[4]. The Eurovignette currently provides the legal basis for collecting road charges for infrastructure maintenance and internalising the external cost caused by air pollution and noise. Its latest revision, which is already in force, includes the possibility of charging for interurban congestion and differentiating charges based on emissions to decarbonise road transport.

Road maintenance & decarbonisation of road transport.

Road maintenance itself contributes to decarbonisation by reducing fuel consumption. Its alignment is not only a precondition for the functioning of the EU transport policy and for the financial attractiveness of the technologies needed to achieve the EU's decarbonisation targets.

In addition, road maintenance is intrinsically linked to road tolling through concession contracts that oblige the road operator to maintain roads to certain quality standards.

Finally, for heavy goods vehicles road maintenance is directly and legally linked to tolling through the ‘Eurovignette Directive’ 1999/62/EC, that specifies road infrastructure maintenance as one of the purposes for which truck tolling income is to be used, the other two being CO_2 reduction and the reduction of air pollution and noise pollution, and a congestion charge.

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[1] Consolidated version of the Treaty on the Functioning of the European Union (2012).

[2] COM (2011) 144 ‘Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system’, 28 March 2011

[3] COM (2020) 789 ‘Sustainable and Smart Mobility Strategy – putting European transport on track for the future’

[4] Directive (EU) 1999/62/EC on the charging of heavy goods vehicles for the use of certain infrastructures

ITS & decarbonisation.

ITS decarbonises road transport by improving traffic flow. The European Green Deal explicitly recognises traffic management as one of the key means of reducing congestion[5].

EU transport policy recognises congestion as a cost to society[6] and aims to increase the efficiency of road transport.

Digitalisation is a key instrument to achieve this goal[7]. The European Commission explains in more detail how digitalisation can improve the efficiency of road transport, focusing on making traffic flow more smoothly and reducing congestion.[8]

Providing the missing link.

With this paper, Kapsch TrafficCom would like to present scientific evidence for the decarbonisation effect of road maintenance and traffic management through smoothing traffic by presenting a conservative method to quantify the decarbonisation effect in a model calculation for the Austrian motorway network and the city of Vienna.

The examples are intended to show the application of the formulas and the impact of road maintenance and optimised traffic flow.

The calculation presented below considers both the reduction of emissions due to lower rolling resistance of the road surface and the CO_2 emissions saved by preventing avoidable deceleration and acceleration. Both formulas are based on a publicly available textbook[9] from the Technical University Dresden in Germany that is.

Kapsch TrafficCom considers this approach to be conservative. Varying the formulas with other parameters, e.g. heavier vehicles, different vehicle fleet composition or steeper roads, leads to greater decarbonisation effects.

Rebound effects, such as potential increases in traffic or noise from road maintenance or others are not considered as they strongly depend on the policies surrounding them. The formulas serve the purpose of demonstrating that road maintenance, as well as flowing traffic have decarbonisation effects in themselves.

For instance, traffic lights regulate intersections. The traffic light is merely an instrument of regulation. If a red light is not enforced, the traffic light will not be able to make a positive contribution to either road safety or traffic flow.

The same applies to road tolling or traffic management. Improved road surface or better traffic management can lead to various rebound effects, such as increased traffic, or speed driving and consequently increased air pollution, etc., which can cancel out the CO_2 savings achieved, if unaddressed by traffic policy.

Road tolling as well as traffic management do not operate in a regulatory vacuum, traffic rules such as speed limits or driving restrictions need to be enforced or put in place to make decarbonisation effects sustainable while maintaining road transport.

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[5] European Commission: The 'European Green Deal', COM (2019) 640, pt 2.1.5

[6] European Commission: Sustainable and Smart Mobility Strategy COM (2020) 789, pt 2

[7] European Commission: Sustainable and Smart Mobility Strategy COM (2020) 789, pt 7

[8] European Commission: Proposal for amending Directive 2010/40/EU on the framework for the deployment of Intelligent Transport Systems COM (2021) 813, pt 1

[9] *„Grundlagen der Straßenverkehrstechnik und der Verkehrsplanung – Band 1“* (a general practice for road traffic engineering); ISBN 987-3-410-17271-0

The EU Taxonomy Regulation & tolling and ITS.

Kapsch TrafficCom believes that the EU taxonomy should consider the decarbonisation potential of tolling, ITS and traffic management, and in particular the impact of rejuvenating the vehicle fleet[10], as well as on the traffic flow itself. So far this has not yet happened, but there are signs that it will happen sooner rather than later.

The Taxonomy Regulation[11] already indicates in recital 49 the need for increased investment in decarbonising transport and singles out better traffic management as a specific point of attention. The revised ITS Directive 2023/2661[12] in recital 3 again calls on the European Commission to draft appropriate technical screening criteria to support investment in ITS.

The European Commission has also become active expressing the opinion that road tolling and ITS should be reflected in the taxonomy. As a first step in this direction, the European Commission has highlighted that it believes road tolling, as well as ITS should be regarded under Section 6.15 'Infrastructure enabling low-carbon road transport and public transport' of Annex I of the taxonomy delegated act[13]. The European Commission has also stated that it would consider equipment for road tolling and traffic management as eligible under Section 3.6 'Manufacture of other low carbon technologies' of Annex I of the climate delegated act[14]. Section 6.15 does not include adequate technical screening criteria for road tolling and ITS. Section 3.15 enables the alignment of equipment, but the technical screening criterion may not be suited for public procurement though, as its' 'best in market approach' would create a monopoly and thus make a mockery of the concept of tendering.

The efforts of the European Commission to enable the alignment of ITS and road tolling and the explicit wish of both co-legislators expressed in the recital 49 of the Taxonomy Regulation and recital 3 of the amended ITS Directive (EU) 2023/2661 give us the confidence to present this White Paper and our contribution to the discussion on the scientific evidence for tolling, as well as ITS.

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[10] See the consolidated Directive 1999/62/EC of the European Parliament and of the Council of 17 June 1999 on the charging of heavy goods vehicles for the use of certain infrastructures and in particular its amendment Directive (EU) 2022/362 of the European Parliament and of the Council of 24 February 2022 amending Directives 1999/62/EC, 1999/37/EC and (EU) 2019/520, as regards the charging of vehicles for the use of certain infrastructures, also casually known as 'Eurovignette Directive'

[11] Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088

[12] Directive (EU) 2023/2661 of the European Parliament and of the Council of 22 November 2023 amending Directive 2010/40/EU on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport

[13] European Commission: Commission Notice on the 'interpretation and implementation of certain legal provisions of the EU Taxonomy Climate Delegated Act establishing technical screening criteria for economic activities that contribute substantially to climate change mitigation or climate change adaptation and do no significant harm to other environmental objective' C/2023/267 Question 101

[14] European Commission: Commission Notice on the 'interpretation and implementation of certain legal provisions of the EU Taxonomy Climate Delegated Act establishing technical screening criteria for economic activities that contribute substantially to climate change mitigation or climate change adaptation and do no significant harm to other environmental objective' C/2023/267, Question 44

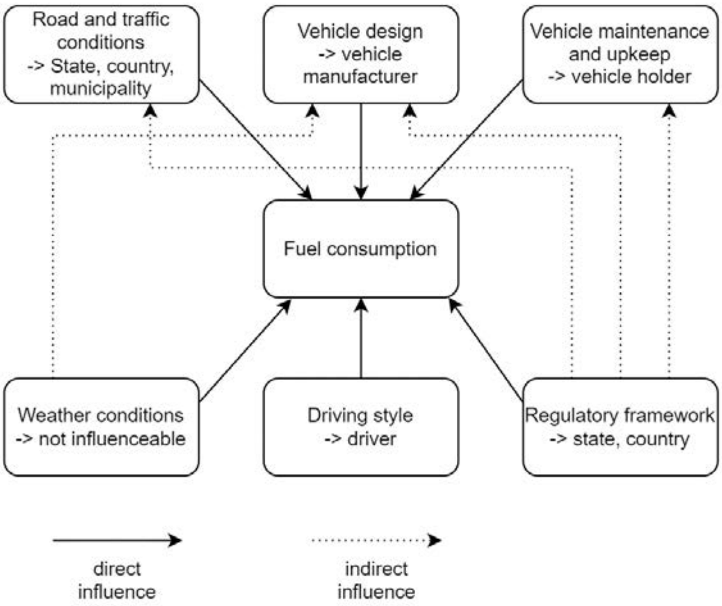
Scientific evidence.

The purpose of the following sections is to outline a scientific, technology-neutral method providing a conservative lower boundary for the reduction of traffic-related greenhouse gas emissions following the introduction of an Intelligent Transport System (a tolling or traffic management solution). The method is based on physical principles and easily obtainable input data.

The method strives for a lower boundary value on emission savings that is conservative, based on data typically available from cities and concessionaires. It is not intended to quantify the full reduction potential of ITS to keep the required input data as simple as possible and to avoid costly simulation or long-term measurement and/or analysis.

In the EU-27, road traffic caused 16.8%[15] of all greenhouse gas emissions in 2020. Globally, traffic causes 25%[16] of air pollution in urban areas. These traffic-related emissions are a directly caused by the fuel consumption of vehicles.

Fuel consumption depends on various physical and non-physical factors that are interdependent:



Road and traffic conditions can be influenced by the operation of tolling and traffic management solutions. Drivers' behaviour can be influenced by setting incentives for optimal road use or managing demand. Legislators can implement intended road and traffic conditions through ITS.

The formulas used by Kapsch TrafficCom are publicly available in '*Grundlagen der Verkehrstechnik und Verkehrsplanung*'[17] and allow the calculation of CO_2 savings per vehicle on a road section achieved through reduced rolling resistance and per reduced number and/or length of vehicle stops.

We apply them with the aim of establishing technology-neutral methods that can be applied across the EU to calculate the decarbonisation effect of road maintenance and smoothing traffic flow. All our assumptions are conservative and broad in order to establish minimum decarbonisation values that we believe can be credibly expected.

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[15] Total greenhouse gas (GHG) emissions of EU-27 in 2020: https://www.umweltbundesamt.de/sites/default/files/medien/5929/bilder/dateien/5_tab_thg-emi-eu-27-kategorien_2024-08-13.pdf; total GHG emissions of EU-27 in 2020 of transport: https://www.eea.europa.eu/en/analysis/indicators/greenhouse-gas-emissions-from-transport; road traffic share on transport emissions: https://www.eea.europa.eu/en/topics/in-depth/road-transport?activeTab=fa515f0c-9ab0-493c-b4cd-58a32dfaae0a; (last visited on 2024-08-19)

[16] https://www.sciencedirect.com/science/article/abs/pii/S0045653521035542 (last visited on 2024-08-19)

[17] Prof. Dr.-Ing. habil. Werner Schnabel; Prof. Dr.-Ing. habil. Dieter Lohse: ‚*Grundlagen der Straßenverkehrstechnik und der Verkehrsplanung – Band 1*', ISBN 987-3-410-17271-0

Quantification of the decarbonisation effect of road maintenance.

The formula below is derived from the textbook "*Grundlagen der Straßenverkehrstechnik und der Verkehrsplanung – Band 1*"[18] by the Technical University Dresden, that offers various formulas for calculating the carbon impact of road traffic and is the core of our method for demonstrating GHG emission savings based on changes in road surface quality.

$$B_{s1} - B_{s2} = \frac{b_e * m * g * (f_1 - f_2)}{\eta_T * \rho_K * 10 * 3600}$$

Analysis of the formula indicates that the rolling resistance coefficients (f_1, f_2) can be isolated and varied independently while all other factors affecting fuel consumption in this formula can be conservatively approximated by constants. We have chosen very conservative approximations for the traffic composition (a small vehicle with low weight and associated car specific constants), driving behaviour (constant speed, therefore no excess fuel consumption due to acceleration), terrain (no inclination of the road) and petrol as the fuel of choice.

This implies that average speed, rolling resistance prior road maintenance (f_1), rolling resistance after road maintenance (f_2), length of the road, traffic volume and a rough traffic composition are sufficient input parameters to calculate a conservative lower boundary for traffic-related emissions saved through well maintained roads.
The rolling resistance coefficients have been taken from scientific literature but can be replaced by actual measurement if deemed necessary.

If desired the engine type can be adapted (e.g. diesel, electric) to reflect more specific traffic compositions. Our aim here is to demonstrate that it is physically possible to prove the fuel saving effects of reducing rolling resistance. This serves as a model and can be adapted to specific contexts at the user's request.

To demonstrate the order of magnitude of the avoided traffic-related greenhouse gas emissions we have quantified the impact of good road maintenance on the Austrian motorway network. Assuming an average speed of 120 km/h, rolling resistance prior road maintenance $(f_1 = 0{,}015)$, rolling resistance after road maintenance $(f_2 = 0{,}005)$ both from scientific literature, length of the road network 2 249 km, traffic volume 38,617 vehicles/day and a traffic mix of more heavy vehicles than motorcycles leads to a conservative lower boundary for traffic-related emissions saved through well maintained roads of 410,977,447 litres of fuel or the equivalent of 974,017 tons of CO_2, expressed in savings of 43,830,745 € (assuming a carbon price of 45 € / ton of CO_2).

This formula does not include the so-called rebound effects, it merely demonstrates the isolated CO_2 savings impact of road maintenance.

The exact calculation can be found in the annex to this document below.

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[18] Prof. Dr.-Ing. habil. Werner Schnabel; Prof. Dr.-Ing. habil. Dieter Lohse: ‚*Grundlagen der Straßenverkehrstechnik und der Verkehrsplanung – Band 1*', ISBN 987-3-410-17271-0

Quantification of the decarbonisation effect of traffic management.

The formula below is derived from the textbook "*Grundlagen der Straßenverkehrstechnik und der Verkehrsplanung – Band 1*"[19] by the Technical University Dresden, that offers various formulas for calculating the carbon impact of road traffic and is the core of our method for demonstrating GHG emission savings based on reducing the number and duration of vehicle stops in traffic. The formula calculates the additional fuel consumption caused by an additional stop and the extended duration of stops due to longer waiting times, thus quantifying the decarbonisation effect of flowing traffic.

$$B_1 - B_2 = (B_{ZV} + t_{h1} * b_l) * n_1 - (B_{ZV} + t_{h2} * b_l) * n_2$$

Analysing the formula implies that average speed, number of stops per vehicle prior introduction of a traffic management system (n_1), number of stops per vehicle after introduction of a traffic management system (n_2), duration of stops per vehicle prior introduction of a traffic management system (t_{h1}), duration of stops per vehicle after introduction of a traffic management system (t_{h2}), traffic volume and a rough traffic composition are sufficient input parameters to calculate a conservative lower boundary for traffic-related emissions saved by smoothed traffic flow.

All other factors affecting fuel consumption in this formula can be conservatively approximated by constants. We have chosen very conservative approximations for the traffic composition (a small vehicle with low weight and associated car specific constants) and petrol as the fuel of choice.

If desired the engine type can also be adapted to diesel as well to reflect more specific traffic compositions. The aim here is to demonstrate that it is physically possible to prove the fuel saving effects of reducing the number and duration of stops. This serves as a model and is open to be adapted to specific contexts, at the user's request.

To demonstrate the order of magnitude of the avoided traffic-related greenhouse gas emissions we have quantified the impact of an effective traffic management system for the city of Vienna. Considering an average speed of 40 km/h, number of stops per vehicle prior introduction of a traffic management system $(n_1 = 12{,}5)$, number of stops per vehicle after introduction of a traffic management system $(n_2 = 9{,}375)$, duration of stops per vehicle prior introduction of a traffic management system $(t_{h1} = 45\ s)$, duration of stops per vehicle after introduction of a traffic management system $(t_{h2} = 35\ s)$, traffic volume of 821,852 vehicle trips / day and a traffic mix of more heavy vehicles than motorcycles leads to a conservative lower boundary for traffic-related emissions saved by improved traffic flow and congestion reduction of 63,838,638 litres of fuel or the equivalent of 151,298 tons of CO_2, expressed in savings of 6,808,391 € (assuming a carbon price of 45 € / ton of CO_2).

This formula does not include the so-called rebound effects, it merely demonstrates the isolated CO_2 savings impact of traffic management.

The exact calculation can be found in the annex to this document below.

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[19] Prof. Dr.-Ing. habil. Werner Schnabel; Prof. Dr.-Ing. habil. Dieter Lohse: ‚*Grundlagen der Straßenverkehrstechnik und der Verkehrsplanung – Band 1*', ISBN 987-3-410-17271-0

Road maintenance: Calculations in detail.

Quantification of the decarbonisation effect of road maintenance.

The following formula is used to calculate the distance-based fuel consumption (B_s) in [l/100 km].

$$B_s = \frac{b_e * P_W}{\eta_T * v * \rho_K * 10}$$

(1-1)[20]

b_e in [g/kWh] is the specific effective consumption, a velocity and fuel type specific value, η_T is the median drive train efficiency rate, a vehicle specific value, v in [km/h] is the driving speed and ρ_K in [kg/l] is the fuel density. P_W in [kW], is the power required at the driving wheels, depending on all resistance to be overcome and the driving speed.

$$P_W = \frac{F_W * v}{3600}$$

The formula reflects that velocity is provided in [km/h] (1-2)

F_W in [N] is the total resistance and the sum of rolling resistance (F_{WR}), gradient resistance (F_{WS}), air resistance (F_{WL}) and acceleration resistance (F_{WB}).

$$F_W = F_{WR} + F_{WS} + F_{WL} + F_{WB}$$

(1-3)

F_{WR} in [N] is the rolling resistance. On a flat road the longitudinal inclination angle $\alpha = 0$ and therefore the rolling resistance is defined by vehicle mass m in [kg] and road quality (i.e. the rolling resistance coefficient f) only.
$g = 9.81 \frac{m}{s^2}$ is the gravitational acceleration.

$$F_{WR} = m * g * \cos\alpha * f$$

(1-4)

F_{WS} in [N] is the gradient resistance. On a flat road, the longitudinal inclination angle $\alpha = 0$ and therefore gradient resistance is zero as well.

$$F_{WS} = m * g * \sin\alpha * f$$

(1-5)

F_{WL} in [N] is the air resistance. It depends on air density ρ_L in [kg/m³], the air resistance coefficient c_W and the front cross-sectional area A in [m²] both vehicle-specific values, as well as the square of driving speed v^2.

$$F_{WL} = \frac{\rho_L}{2} * c_W * A * v^2$$

(1-6)

F_{WB} in [N] is the acceleration resistance. Without acceleration, $a = 0$ and therefore the acceleration resistance is also zero. k_R is the mass factor to consider the rotating parts of the vehicle. It is a vehicle specific value.

$$F_{WB} = m * a * k_R$$

(1-7)

As mentioned above, the rolling resistance (F_{WR}) is one of several factors that make up the sum of all resistances (F_W), which determine the value of P_W and therefore the distance-based fuel consumption B_S. For F_{WR} the quality of the road surface plays an essential role. Here we vary road surfaces to see how a lower resistance road surface affects fuel consumption. For rolling resistance we refer to a set of rolling resistance coefficients that we have taken from the scientific literature.

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[20] All formulas in this chapter are taken from [1]. (1-1) from (5-13) p.542; (1-2) from p.542; (1-3) from p.538; (1-4) to (1-7) from (5-10) p.539.

We have chosen parameters that lead to conservative results only: vehicle mass: 900 kg and all other vehicle-specific parameters in alignment with this mass (median drive train efficiency rate 0.85, air resistance coefficient 0.3, front cross-sectional area 1.8 m, mass factor to consider the rotating parts of the vehicle 1.1), no inclination of the road, no acceleration.

For the use case of comparing fuel consumption on different road surfaces, a car with vehicle mass of 900 kg is a conservative representation of all vehicles on this road, as the possible savings in fuel consumption are the smallest. Therefore, the fuel savings of a small car represent a lower boundary for all vehicles. Motor bikes are outnumbered by trucks (with higher savings potential) on toll roads and are therefore negligible.

A flat road with $\alpha = 0$ is a conservative approximation, as $\sin\alpha + \cos\alpha > 1$ for all realistic slopes. Therefore, the saving potential due to reduced rolling resistance is lower on flat roads than on roads with gradients. Flat roads therefore represent the lower boundary for fuel consumption savings.

Air density varies with temperature and humidity. The value for air density will not be used in the final formula, as it is only used for air resistance. When comparing fuel consumption due to road surface quality, acceleration will not have an impact on the result. Therefore, it is conservative to assume constant driving speed and therefore zero acceleration.

Consider B_{s1} as the fuel consumption of a car with a petrol combustion engine driving at constant speed on a flat road with good road quality, expressed as f_1. The corresponding rolling resistance is expressed as $F_{WR1} = m * g * \cos\alpha * f_1$. Combining formulas (1-1), (1-2) and (1-3) this results in:

$$B_{s1} = \frac{b_e * (F_{WR1} + F_{WL})}{\eta_T * \rho_K * 10 * 3600}$$

(1-8)

Consider B_{s2} as the fuel consumption of a car with a petrol combustion engine driving at a constant speed on a flat road with poorer quality, expressed as f_2. The corresponding rolling resistance is expressed as $F_{WR2} = m * g * \cos\alpha * f_2$.

$$B_{s2} = \frac{b_e * (F_{WR2} + F_{WL})}{\eta_T * \rho_K * 10 * 3600}$$

(1-9)

Fuel consumption avoided by good road quality is therefore quantified by:

$$B_{s1} - B_{s2} = \frac{b_e * (F_{WR1} - F_{WR2})}{\eta_T * \rho_K * 10 * 3600}$$

(1-10)

$$B_{s1} - B_{s2} = \frac{b_e * m * g * \cos\alpha * (f_1 - f_2)}{\eta_T * \rho_K * 10 * 3600}$$

(1-11)

$$B_{s1} - B_{s2} = \frac{b_e * m * g * (f_1 - f_2)}{\eta_T * \rho_K * 10 * 3600}$$

considering a flat road $\cos\alpha = 1$ (1-12)

As explained above, a small car is used as a reference vehicle to calculate the lower boundary for fuel savings due to the reduced rolling resistance coefficient of the road surface (i.e. road quality). This implies that the lower boundary for fuel savings can only be determined based on rolling resistance coefficient of the road, as all other values are either vehicle-specific values of the small reference car or physical constants (such as the density of petrol or the gravitational acceleration).

Our calculation for the Austrian motorway network shows that good road maintenance saves 410,977,447 litres of fuel or the equivalent of 974,017 tons of CO_2, expressed in savings of 43,830,745 €.
The following input parameters were used: $f_1 = 0.005$ (rolling resistance coefficient for improved road quality), $f_2 = 0.015$ (rolling resistance coefficient prior road maintenance), b_e at 120 km/h with a petrol engine, total annual traffic of $31.7*10^9$ km, GHG emission factor for petrol 2.37 kg CO_2/l petrol and carbon pricing in Austria (2024) 45 € / t CO_2.

Details on used variables.

Variable	Unit	Value	Meaning	Additional details
B_s	l / 100 km	Interim result	Distance based fuel consumption	
b_e	g / kWh	At 90 km/h: 394 At 120 km/h: 337	Specific effective consumption	The specific effective consumption is caused by the energy efficiency of the combustion engine and the driving speed. The specific effective consumption values for 90 km/h and 120 km/h are suitable reference values, as drivers will drive at a similar speed on most toll roads.
P_W	kW	Interim result	Required power at the drive wheels	
η_T	-	0.85	Median drive train efficiency rate	This is a car-specific value. As a conservative approach, a reference value for a small car has been chosen. For details see below.
v	km / h	90 km/h 120 km/h	Velocity	The method has been implemented for these driving speeds.
ρ_K	kg / l	0.75	Density of fuel	The method is currently implemented for petrol. Adaptation to reflect diesel or electric power is possible.
F_W	N	Interim result	Total resistance	The total resistance is the sum of rolling resistance, gradient resistance, air resistance and acceleration resistance.
m	kg	900	Vehicle mass	This is a car-specific value. As a conservative approach, a reference value for a small car has been chosen. For details see below.
g	m/s²	9.81	Gravitational acceleration	
α	°	0	Longitudinal inclination angle	As a conservative approach, the value for a flat road has been chosen. For details see below.
f	-	0.005 to 0.4	Rolling resistance coefficient	For details see below.
ρ_L	kg/m³	1.23	Air density	For details see below.
c_W	-	0.3	Air resistance coefficient	This is a car-specific value. As a conservative approach, a reference value for a small car has been chosen. For details see below.
A	m²	1.8	Front cross-sectional area	This is a car-specific value. As a conservative approach, a reference value for a small car has been chosen. For details see below.
a	m/s²	0	Acceleration	As a conservative approach, the value for no acceleration has been chosen. For details see below.
k_R	-	1.1	Mass factor to consider the rotating parts of the vehicle	This is a car-specific value. As a conservative approach, a reference value for a small car has been chosen. For details see below.
F_{WR}	N	Interim result	Rolling resistance	On a flat road, the rolling resistance is defined by vehicle mass and road quality (i.e. rolling resistance coefficient).
F_{WS}	N	0	Gradient resistance	On a flat road, the gradient resistance is zero (sin 0 = 0)
F_{WL}	N	Interim result	Air resistance	The air resistance remains the same for the same car and the same current air density, regardless of road quality.
F_{WB}	N	0	Acceleration resistance	Without acceleration, the acceleration resistance is zero (a=0 => $F_{WB} = 0$)

Table 1 Variables used in the quantification method for use case tolling.

Details on rolling resistance coefficients.

The following rolling resistance coefficients refer to pneumatic car tyres on the specified road surface quality. They are taken from scientific literature. To calculate the lower boundary of emissions reduced by well-maintained road surfaces, either these reference values, or the actual measured rolling resistance of the particular road can be used.

Road surface quality	Rolling resistance coefficient	Source
New firm asphalt, new concrete (better quality)	0.005	[3][21]
Concrete, new asphalt, small new cobbles (better quality)	0.010	[2][22]
Concrete, asphalt	0.011	[3]
Small or large set pavement	0.013	[3]
Concrete, new asphalt, small new cobbles (inferior quality)	0.015	[2]
New firm asphalt, new concrete (inferior quality)	0.015	[3]
Tar or asphalt; rolled new gravel	0.020	[2]
Rolled, firm gravel; wear down, washboard asphalt (better quality)	0.020	[3]
Tarmacadam	0.025	[3]
Tarred, worn, washboard gravel (better quality)	0.030	[3]
Large worn cobbles	0.030	[2]
Rolled, firm gravel; wear down, washboard asphalt (inferior quality)	0.030	[3]
Solid sand; loose worn gravel; medium hard soil (better quality)	0.040	[2]
Tarred, worn, washboard gravel (inferior quality)	0.040	[3]
Very good dirt roads (better quality)	0.040	[3]
Dirt roads (better quality)	0.050	[3]
Unpaved road	0.050	[3]
Very good dirt roads (inferior quality)	0.050	[3]
Solid sand; loose worn gravel; medium hard soil (inferior quality)	0.080	[2]
Field (better quality)	0.100	[3]
Dirt roads (inferior quality)	0.150	[3]
Sand (better quality)	0.150	[3]
Loose sand (better quality)	0.200	[2]
Field (inferior quality)	0.350	[3]
Sand (inferior quality)	0.350	[3]
Loose sand (inferior quality)	0.400	[2]

Table 2 Types of road surface qualities with associated rolling resistance coefficient

Rationale for conservative approach.

Reference vehicle – a small car.

For the use case of comparing fuel consumption on different road surfaces, a car with vehicle mass of 900 kg is a conservative representation of all vehicles on this road, as the possible savings in fuel consumption are the smallest. Therefore, the fuel savings of a small car represent a lower boundary for all vehicles.
Motor bikes are outnumbered by trucks (with higher savings potential) on toll roads and are therefore negligible.

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[21] https://x-engineer.org/rolling-resistance/#coefficient (last visited 2024-08-14)

[22] https://www.researchgate.net/figure/Rolling-resistance-coefficient-for-real-world-roads-13_tbl2_351973711 (last visited 2024-08-14)

The following values for the required variables represent the reference vehicle - a small car:

- Vehicle mass: 900 kg
- Median drive train efficiency rate: 0.85
- Air resistance coefficient: 0.3
- Front cross-sectional area: 1.8 m^2
- Mass factor to consider the rotating parts of the vehicle: 1.1

Note: Besides the vehicle mass, all other values will not be used in the final formula, as they are only used for air resistance and acceleration resistance.

Reference slope of the road - longitudinal inclination angle.

A flat road represented as alpha equals 0, is a conservative approximation, as sin(alpha)+cos(alpha) is greater than 1 for all realistic gradients. Therefore, the savings potential from reduced rolling resistance is lower on flat roads smaller than on roads with gradients. Flat roads therefore represent the lower boundary for fuel consumption savings.

Air density.

Air density varies with temperature and humidity.
Note: The value for air density is not used in the final formula, as it is only used for air resistance.

Acceleration.

When comparing fuel consumption due to road surface quality, acceleration will not have an impact on the result. Therefore, it is conservative to assume constant driving speed and therefore zero acceleration.

Example – nationwide tolling in Austria.

The following table presents all required input parameters to quantify the fuel savings in Austria due to well-maintained roads.

Input parameter	Value	Unit	Source
Rolling resistance coefficient for original road quality (new firm asphalt, new concrete (inferior quality))	0.015	-	[3] [23]
Rolling resistance coefficient for improved road quality (new firm asphalt, new concrete (better quality))	0.005	-	[3]
Fuel savings due to improved road quality per reference car with reference speed of 120 km/h	-0.01296	l/km	[4][24]
GHG emission factor per litre petrol	2.37	kg CO_2	[1][25] p. 531
Carbon pricing (2024)	45	Euro/t	[6][26]
Total annual traffic on Austria's tolled roads	$31.7*10^9$	km	[5][27]

Table 3 Necessary input parameters to calculate the lower boundary of emission savings for nationwide tolling

Results	Value	Unit	Source
Lower boundary of annual fuel savings from improved road quality	-410 977 447	l	[4]
Lower boundary of annual GHG savings from improved road quality	-974 017	t CO_2	[4]
Annual GHG emission cost savings	-43 830 745	Euro	[4]

Table 4 Results of calculation of the lower boundary of emission savings for nationwide tolling

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[23] [3] https://x-engineer.org/rolling-resistance/#coefficient (last visited 2024-08-14)

[24] [4] Sustainable Tolling - Quantification.xlsx (Kapsch implementation of formulas 2024)

[25] [1] Prof. Dr.-Ing. habil. Werner Schnabel; Prof. Dr.-Ing. habil. Dieter Lohse: '*Grundlagen der Straßenverkehrstechnik und der Verkehrsplanung – Band 1*', ISBN 987-3-410-17271-0

[26] [6] https://www.finanz.at/steuern/co2-steuern/ (last visited: 2024-08-14)

[27] [5] https://www.asfinag.at/ueber-uns/zahlen-fakten/ (last visited: 2024-08-14)

Example – road maintenance.

Input parameter	Value	Unit	Source
Rolling resistance coefficient for original road quality (new firm asphalt, new concrete (inferior quality))	0.015	-	[3] [28]
Rolling resistance coefficient for improved road quality (new firm asphalt, new concrete (better quality))	0.005	-	[3]
Fuel savings due to improved road quality per reference car with reference speed of 120 km/h	-0.01296	l/km	[4] [29]
GHG emission factor per litre petrol	2.37	kg CO_2	[1] p. 531
Carbon pricing (2024)	45	Euro/t	[6]
Length of road to be improved	15	km	Example
Expected daily traffic	30 000	vehicle	Example

Table 5 Necessary input parameters to calculate the lower boundary of emission savings for road maintenance

Results	Value	Unit	Source
Lower boundary of annual fuel savings from improved road quality	-2 129 434	l	[4]
Lower boundary of annual GHG savings from improved road quality	-5 047	t CO_2	[4]
Annual GHG emission cost savings	-227 104	Euro	[4]

Table 6 Results of calculation of the lower boundary of emission savings for road maintenance

Road maintenance has an impact on the rolling resistance coefficient and hence contributes to the decarbonisation of road transport. Road maintenance is the legal obligation for most road operators, and the road tolls they collect provide the necessary funding.

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[28] [3] https://x-engineer.org/rolling-resistance/#coefficient (last visited 2024-08-14)

[29] [4] Sustainable Tolling - Quantification.xlsx (Kapsch implementation of formulas 2024)

Optimised traffic: Calculations in detail.

Quantification of the decarbonisation effect of optimised traffic flow.

The following formula is used to calculate the additional fuel consumption (B) in [ml] due to a single stop.

$$B = B_{ZV} + t_h * b_l$$

(2-1)[30]

t_h in [s] is the average duration per stop, b_l in [ml/s] s the consumption during idle mode, a vehicle specific value, B_{ZV} in [ml] is the absolute fuel consumption and detailed below.

$$B_{ZV} = b_{ZV} * m$$

(2-2)

B_{ZV} in [ml] is determined by the product of b_{ZV} in [ml/t], the specific additional fuel consumption and the vehicle mass m in [t]. The specific additional fuel consumption b_{ZV} depends on the fuel type and the driving speed prior the stop.

We have chosen parameters that give only conservative results: vehicle mass: 900 kg and all other vehicle specific parameters in alignment with this mass (consumption during idle mode 0.22 ml/s).

The vehicle mass is set to 900 kg, as for the use case of comparing additional fuel consumption due to stops, a car with vehicle mass of 900 kg is a conservative representation of all vehicles, as the possible savings in fuel consumption are the smallest. Therefore, the fuel savings of a small car represent a lower boundary for all vehicles. Usually, motor bikes are outnumbered by vehicles with higher mass (with higher savings potential) and are therefore negligible.

Consider B_1 as the lower boundary of additional fuel consumption caused by all daily stops of vehicles[31] within a city with traffic management. Where t_{h1} is the average duration per stop and n_1 is the total number of stops.

$$B_1 = (B_{ZV} + t_{h1} * b_l) * n_1$$

(2-3)

Consider B_2 as the lower boundary of additional fuel consumption caused by all daily stops of vehicles within a city without traffic management. Where t_{h2} is the average duration per stop and n_2 is the total number of stops.

$$B_2 = (B_{ZV} + t_{h2} * b_l) * n_2$$

(2-4)

Fuel consumption avoided by traffic management is therefore quantified by:

$$B_1 - B_2 = (B_{ZV} + t_{h1} * b_l) * n_1 - (B_{ZV} + t_{h2} * b_l) * n_2$$

(2-5)

As explained above, a small car is used as a reference vehicle to calculate the lower boundary for the additional fuel consumption caused by stops. This implies that the lower boundary for fuel savings can be determined based on average duration per stop prior and after introduction of a traffic management system, as well as the number of stops prior and after introduction of a traffic management system.

Our calculation for the city of Vienna shows that a full coverage traffic management system saves 23,216,891 litres of fuel or the equivalent of 55,024 tons of CO_2, expressed in savings of 2,476,081 € within one year.
The following input parameters have been used: $n_2 = 10{,}273{,}150$ (number of stops prior introduction of traffic management system), $n_1 = 7{,}704{,}863$ (number of stops after introduction of traffic management system), $b_l = 0.22\ ml/s$ fuel consumption in idle mode with a petrol engine of a small car, $t_{h1} = 35\ s$ average duration of a stop after implementing a traffic management system, $t_{h2} = 45\ s$ average duration of a stop prior implementing a traffic management system, $B_{ZV} = 8.1\ ml$ of additional fuel consumption due to deceleration and acceleration for the stop from a prior average speed $V0 = 40\ km/h$ with a vehicle of mass $m = 900\ kg$, GHG emission factor for petrol 2.37 kg CO_2/l petrol and carbon pricing in Austria (2024) 45 € / t CO_2.

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[30] All formulas in this chapter are taken from [1]. (2-1) from (5-14) p.547; (2-2) from Table (5-4) p.546;

[31] Currently only implemented for petrol combustion engines.

Details on used variables.

Variable	Unit	Value	Meaning	Additional details
B	ml	Interim result	Additional fuel consumption due to a single stop	
B_{ZV}	ml	Interim result	Absolute additional fuel consumption	The absolute additional fuel consumption is caused by the specific additional fuel consumption and the vehicle mass.
t_h	s	Without traffic management: 45 With traffic management: 35	Average duration per stop	This value should be adapted to the actual traffic conditions in the respective city. The chosen values represent typical values.
b_l	ml/s	0.22	Consumption during idle mode	The consumption during the stop. Car-specific values range from 0.7 l/h to 1.0 l/h for vehicles with petrol combustion engine. 0.8 l/h is the average value.[32]
b_{ZV}	ml/t	For V0=30 km/h: 5.1 For V0=40 km/h: 9.0 For V0=50 km/h: 13.1 For V0=60 km/h: 17.6	Specific additional fuel consumption	The specific additional fuel consumption is caused by the fuel type and the driving speed prior the stop. In cities, the speed varies between 30, 40, 50 and 60 km/h. The method is currently implemented for petrol.[33] An adaptation to reflect diesel is possible.
$V0$	km / h	30 km/h 40 km/h 50 km/h 60 km/h	Velocity	The method has been implemented for these driving speeds prior stopping.
m	t	0.9	Vehicle mass	This is a car-specific value. As a conservative approach, a reference value for a small car has been chosen. For details see below.

Table 7 Used variables for quantification method traffic management

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[32] These values are taken from [1] p.546.

[33] These values are taken from [1] p.546.

Rationale for conservative approach – small car.

The vehicle mass is set at 900 kg, as for the use case of comparing additional fuel consumption due to stops, a car with vehicle mass of 900 kg is a conservative representation of all vehicles, as the possible savings in fuel consumption are the smallest. Therefore, the fuel savings of a small car represent a lower boundary for all vehicles. Motor bikes are outnumbered by vehicles with higher mass (with higher savings potential) in cities and are therefore negligible.

Example – traffic management for the city of Vienna.

Input parameter	Value	Unit	Source
Average distance between stops without traffic management	800	m	[7][34]
Typical trip distance for drivers in the city	10	km	[7]
Daily traffic	821 852	trips	[8][35]
Reduction in number of stops with traffic management	25	%	[7]
Average vehicle speed prior stop ($V0$)	40	km/h	[7]
Average duration per stop without traffic management (t_{h2})	45	s	[7]
Average duration per stop with traffic management (t_{h1})	35	s	[7]
GHG emission factor per litre petrol	2.37	kg CO_2	[1] p. 531
Carbon pricing (2024)	45	Euro/t	[6]

Table 8 Necessary input parameters to calculate the lower boundary of emission savings from traffic management in Vienna

Results	Value	Unit	Source
Lower boundary of annual fuel savings from traffic management	-23 216 891	l	[7]
Lower boundary of annual GHG savings fromtraffic management	-55 024	t CO_2	[7]
Annual GHG emissions cost savings	-2 476 081	Euro	[7]

Table 9 Results of calculation of the lower boundary of emission savings from traffic management in Vienna

In conclusion, Kapsch TrafficCom demonstrates that traffic management reduces the number of deceleration-acceleration cycles and/or the length of stops contributes to the decarbonisation of road transport.

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[34] [7] Sustainable Traffic Management - Quantification.xlsx (Kapsch implementation of formulas 2024)

[35] [8] https://www.digital.wienbibliothek.at/wbrup/content/pageview/4999047 (last visited: 2024-08-14)

Conclusion.

We are convinced that road tolling, as well as traffic management are key enablers for decarbonising road transport. They need to be embedded into the Taxonomy Regulation. The Taxonomy Regulation should be consistent with EU transport policy. Hence the implementation of decarbonisation legislation, such as the Eurovignette Directive 1999/62/EC, should be further promoted. The same applies, of course, to the ‘Sustainable and Smart Mobility Strategy’ or the ‘Green Deal’.

Taxonomy alignment intends to set incentives for working towards making economic activity sustainable, it looks mainly at the products themselves, like the aforementioned traffic light, a product can only have an effect if used for the right purpose, in the case of sustainability the right governance.

We urge the European Commission to reward good governance in the field of mobility and to recognise the enabling capacity of mobility management.

We urge the European Commission to recognise the role of road operation for sustainable mobility and set incentives for investment in addressing particulate matter emissions, air pollutants or road safety through adequate technical screening criteria.

We hope that our calculations presented in this White Paper can contribute by providing scientific evidence to recognise that mobility cannot be addressed through improving individual products alone.

It’s the governance of mobility combined with the right digital instruments to enable such governance: road tolling and traffic management.

Kapsch TrafficCom

Kapsch TrafficCom is a globally renowned provider of transportation solutions for sustainable mobility with successful projects in more than 50 countries. Innovative solutions in the application fields of tolling, tolling services, traffic management and demand management contribute to a healthy world without congestion.

With one-stop-shop-solutions, the company covers the entire value chain of customers, from components to design and implementation to the operation of systems.

Kapsch TrafficCom, headquartered in Vienna, has subsidiaries and branches in more than 25 countries and is listed in the Prime Market segment of the Vienna Stock Exchange (ticker symbol: KTCG). In its 2023/24 financial year, about 4,000 employees generated revenues of EUR 539 million.

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