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Low Carbon Route Planning Using Nomadic Devices and ISO-23795-1 Physics of Driving Solutions

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Abstract

With 8,6 billion nomadic devices and vehicles counting 1,5 billion, global markets are dominated by connectivity and road transport products offering world-wide solutions to improve traffic flow and energy-efficiency. Free of charge route planners with app-design for pre-trip and on-trip navigation have user numbers with up-to one billion routing requests per month and are therefore fully funded by advertisers and their cloud-based platforms. Nevertheless, these numbers only reflect the importance of app-store business replacing or complementing in-vehicle systems. The quality of navigation services needs ISO standardization to support energy-efficient route planning, bringing transparency for users and pre-installed nomadic device solutions for mobile telecom operators. In this scientific paper, Deutsche Telekom and Leipzig University of Applied Sciences will demonstrate an ISO-237905-1 implementation of fully transparent physics of driving calculation for finding the optimum low carbon route enabling megatons of potential greenhouse gas savings in road transport by applied ISO standards.

Keywords:

Nomadic Devices, Low Carbon Navigation, Green I.T.S, ISO-23795-1, Emission Trading

Primary keyword and secondary keyword

Nomadic Devices, Low Carbon Navigation,

Low Carbon Route Planning Using Nomadic Devices and ISO-23795-1 Physics of Driving Solutions

Introduction

With 5 gigatons or 17% of annual total carbon emission caused by road transport, low carbon transportation products are urgently needed, and transport policy makers look more than ever for reliable solutions. In the energy sector, significant impact was achieved by market driven emission trading which helped to shift the energy industry from carbon intensive coal to sustainable wind and solar technology. Unfortunately, the emitting sources in road transport, passenger cars and trucks, have small seize but huge volume, and nearly 1,5 billion vehicles are very difficult to adapt to monitoring, reporting and verification principles required in carbon reduction projects.

This was the reason why road transport and building initiatives were highly underrepresented in the United Nations Framework Convention on Climate Change (UNFCCC) emission trading concepts such as Clean Development Mechanism (CDM), or Joint Implementation (JI), even though carbon emissions from road transport remained high. Even worth, in countries dominated by automotive industry such as Germany, carbon emission caused that the overall climate balance sheet was negative relative to the announced policy targets.

In 2021, Germany therefore successfully introduced an important element of carbon emission trading for national fuel distributors, giving them a cap of emission allowance with an increased price per ton of carbon dioxide when exceeding it. With an additional income of several billion Euro in Germany alone, the European Commission adopted the German methodology as regulatory framework for the new emission trading system ETS-2 targeting carbon reduction in road transport. The regulation passed the EU parliament in May 2023 and will be in place already in 2025.

From Newtonian Physics to Carbon Emission Trading – the Art of Fleet Monitoring by Nomadic Devices

As mentioned before, the key challenge of carbon emission trading in transport is to determine the exact amount of CO2 emitted by a single vehicle source. Existing telematic systems are connected to fuel consumption via CAN bus, nevertheless the electronic components bring a variation of results and are therefore often considered unreliable. In this context, automotive researchers developed the principle of deriving energy demand by measuring a relative deviation of Worldwide Harmonized Light Vehicles Test Procedure (WLTP) values, well-known for all registered vehicles worldwide. The mentioned ISO reference standard links the WLTP measurement to the Newtonian forces opposing the movement of a vehicle. It will be shown that this methodology provides measurable quantities of fuel, electricity and required energy, and therefore is a fully transparent and reliable way to setup low carbon navigation and link it to carbon emission trading systems.
The energy equation used for energy analysis can be derived from Newton's three laws of motion as described in the following.

Newton's first law (Newton 1) states that without external forces, all bodies in motion have constant speed or zero speed, yielding a constant momentum. This is described by

$$\boldsymbol{p = m * v = const} \qquad (1)$$

where the symbols have the following meaning:

p is momentum, expressed in kilogram times speed (kg*m/s)

m is mass, expressed in kilogram (kg);

v is speed, expressed in meter per seconds (m/s).

Newton's second law (Newton 2) follows by describing forces that are opposing motion, defining external forces needed to change speed by acceleration as

$$\boldsymbol{F = m * \left(\frac{dv}{dt}\right) = m * a} \qquad \textbf{(2)}$$

where the symbols have the following meaning:

F is force, expressed in kilogram times acceleration (kg*m/s^2)

m is mass, expressed in kilogram (kg);

a is change of speed per second, expressed in meter per seconds square (m/s^2).

Finally, Newton's third law (Newton 3) states that for any closed energy system the exerting internal force F yields an opposing force $(-)F$ with the same magnitude and opposite direction ($actio = reactio$).

Newton's laws are directly linked to most technical equations relevant for transport. For example, energy demand is simply defined as force F times distance Δx travelled. All vehicles in motion with speed v have kinetic energy linked to the momentum by

$$\boldsymbol{E_{kin} = \int m * \left(\frac{dv}{dt}\right) \Delta x = \int m * v \left(\frac{dv}{dt}\right) \Delta t = \frac{p^2}{2m}} \qquad \textbf{(3)}$$

where the additional symbols have the following meaning:

E_{kin} is kinetic energy, expressed in kilogram times speed square (kg*m^2/s^2 = Nm = Joule)

Δx is distance travelled, expressed in meter (m);

Δt is time span travelled, expressed in seconds (s)

For carbon emission analysis, the beauty of Newton's laws lies in their reliable application for analyzing the energy demand of vehicles in traffic, in the easiest case by calculating the mechanical energy needed to keep moving. As in traffic, road conditions are causing an opposing force known as rolling friction, and air conditions a second opposing forces called aerodynamics. Hence, taking into account all three Newton's laws, a simple boundary condition for moving objects results in

$$\boldsymbol{E_{kin} - E_{roll} - E_{aero} > 0} \qquad \textbf{(4)}$$

where the symbols have the following meaning:

E_{kin} is kinetic energy, expressed in Joule (J)

E_{roll} is energy of opposing rolling friction per distance travelled, expressed in Joule (J)

E_{aero} is energy of opposing aerodynamics per distance travelled, expressed in Joule (J)

To ensure constant speed in the regime of opposing forces of rolling friction and aerodynamics means it is necessary to compensate these forces. This finally leads directly to the well-known energy equation for vehicles on roads as can be found in literature References (1) and Reference (2).

$$\boldsymbol{E_{kin} = E_{acc} = E_{roll} + E_{aero} \rightarrow m \sum a\Delta x = \sum(\mu m g + A c_w \rho v v)\Delta x} \qquad \textbf{(5)}$$

where the additional symbols have the following meaning:

m is the numerical value of the total weight of the vehicle, expressed in kilogram (kg).

A' is the numerical value of the cross-sectional area, expressed in meters squared (m^2);

c_w is the numerical value of the drag coefficient, expressed without units;

α is the numerical value of the slope angle, expressed in degree (°);

μ is the numerical value of the friction coefficient, expressed without units.

ρ is the numerical value of air density, expressed in kilograms per meter to the power of three (kg/m^3).

g is the numerical value of acceleration of gravity, expressed in meters per second squared (m/s^2);

Using Newtonian Physics and ISO-23795-1 Standard for Carbon Monitoring in Road Transport

One can easily apply Formula (6) to the real world for analyzing fuel consumption and carbon emissions per vehicle and trip. This is needed for future emission trading of Verified Emission Reduction (VER) certificates in road transport to achieve climate neutrality, announced to be implemented, e.g., by Deutsche Telekom, in 2040, including all logistics suppliers of the entire group.

To achieve this objective, digital freight papers can easily be coupled with B2B apps conforming to ISO-23795-1, installed on nomadic devices operated via iOS or Android, in order to monitor the carbon footprint of the third party, and reduce it, e.g. by improved tour and route planning. This so called Scope 3 Enablement, is supposed to be a multi-billion € market in Europe alone and ISO-23795-1 is the key for setting it up without "green washing" skepticism. It was first presented during the 29th ITS World Congress in Suzhou and enters now into the stage of low carbon navigation, see Reference (3).

Following an example from Reference (2), the methodology for low carbon navigation will be derived for a Private Passenger Car (Golf 7) driving constant speed of 10 km/h with no other opposing forces other than surface friction and aerodynamics. Then, with the following parameters (vehicle, road, physics)

$$M = 1320\,kg, \qquad \mu = 0.015, \qquad g = 9.81\frac{m}{s^2}, \qquad A = 2.5\,m^2,$$

$$\rho = 1.204, \qquad c_w = 0.3, \qquad v = 10\frac{km}{h}, \qquad \Delta x = 1\,m$$

and the definitions of the ISO-23795-1 standard, the application of Equation (6) results in

$$\boldsymbol{F_{roll} = 194\,N,\ \ F_{aero} = F_2 = 90\,N \ \ \rightarrow\ \ E_{kin} = \sum(F_{roll} + F_{aero})\Delta x = 284\,Nm} \qquad \textbf{(6)}$$

This means that an average car driving 10 km/h has opposing energy of 284 Nm to compensate per meter in order to keep his motion constant. If we consider for example 100 km, we have to multiply that value therefore by 100000. To translate it to kWh, the result must be divided by 36000000 resulting in 7,9 kWh. Unfortunately, energy cannot be transferred lossless from engine to wheel. For combustion engines only 25% of the energy provided by the engine can typically be transferred to move the vehicle, thus 7,9 kWh/0,25 = 31,6 kWh are needed from the engine to overcome the forces opposing the movement of the vehicle. As combustion engines are operated with gasoline, kWh must be divided by 8.5 liters per kWh to finally have fuel consumption of 3.7 liters per 100 km for the vehicle under examination. Adding standstill and acceleration energy, one finds a range of 7 to 10 liters per 100 km in urban traffic, reflecting the real fuel consumption.

The example of estimating the energy demand for a medium-size passenger car driving with an average speed of 36 km/h (10m/s) in urban conditions shows how to apply the ISO-23795-1 standard in the Physics of Driving logic for carbon footprint monitoring, reporting and validation (MRV). The above-mentioned ISO standard was developed exactly for MRV purposes using

$$\boldsymbol{\phi = \frac{\eta b \sum(F_1+F_2+F_3+F_4)\Delta x + \eta b F_5 \Delta x}{\Delta s}} \qquad \textbf{(7)}$$

where the additional symbols have the following meaning:

- F_1 is the opposing force of rolling friction, expressed in Newton (N).
- F_2 is the opposing force of aerodynamics, expressed in Newton (N).
- F_3 is the force to exert acceleration or braking, expressed in Newton (N).
- F_4 is the force needed to drive up- and downhill, expressed in Newton (N).
- F_5 idling energy by time translated into energy demands per distance, expressed in Newton (N).
- η is the numerical value of the engine efficiency, expressed in percent (%);
- b is the numerical value of fuel value, expressed in grams per kilowatt hour (g/kWh);
- Δs is the comparative reference distance, expressed usually as extrapolated trip of length 100 km
- ϕ is the energy value per 100 km and different units, for combustion engines expressed in liter per 100 km (l/100km)

Formula (8) is summarizing all influencing forces opposing the movement of the vehicle that have to be compensated by injecting electricity or fuel. The formula also states that energy efficiency and fuel value have to be considered and multiplied for achieving the final result shown in Formula (8). In order to have an overview of all these influencing fuel factors, ISO 23795-1 suggest using the parameters for a well-known vehicle and compare it to the WLTP standard used for bringing new vehicles and engines to market. The WLTP driving cycle has four speed ranges reflecting the street category. These are shown in Figure 1 and are denoted *Low*, *Medium*, *High* and *Extra-High*. The green line in all four sections of the diagram represents the average speed within each section. The street category *Low* typically represents urban traffic with road categories and speed limits around to 30 km/h, whereas *Medium* represents suburbs, *High* rural areas, and *Extra-High* motorways.

According to the corresponding vehicle licenses, every vehicle has well-defined fuel and carbon emissions according to the WLTP reference cycles. The ISO standard then defines that the speed pattern shown in Figure 1 is the reference for determining all forces described above. A real speed profile within one of the speed categories *Low*, *Medium*, *High*, or *Extra-High* will actually exhibit deviations from the corresponding reference speed pattern. The relative deviation of the energy consumption is determined and stored in a database. The engine efficiency and the fuel value including electric parameters are statistical values and might exhibit strong fluctuations on small time interval scales of seconds but proved to be long term stable. Nevertheless, it should be highlighted that it is recommended to keep energy analysis focused on opposing inertial forces or energies based on Formula (8) which reduces the measurement complexity of fuel, electric energy, and carbon emissions to a simple detection of relative deviation of the real speed profile from the WLTP class.

After millions of kilometer have successfully been collected and evaluated in carbon reduction projects in Europe and China, see References (4) and (5), the standardization bodies of Belgium and Germany introduced ISO-23795-1 which passed all ISO approval procedures and has been published June 2022. It will be shown that it perfectly fits to standardized low carbon navigation products, which are currently still untransparent from consumer point of view, and therefore inacceptable for the strict transparency rules for MRV which is required for any carbon reduction funds and climate reduction projects.

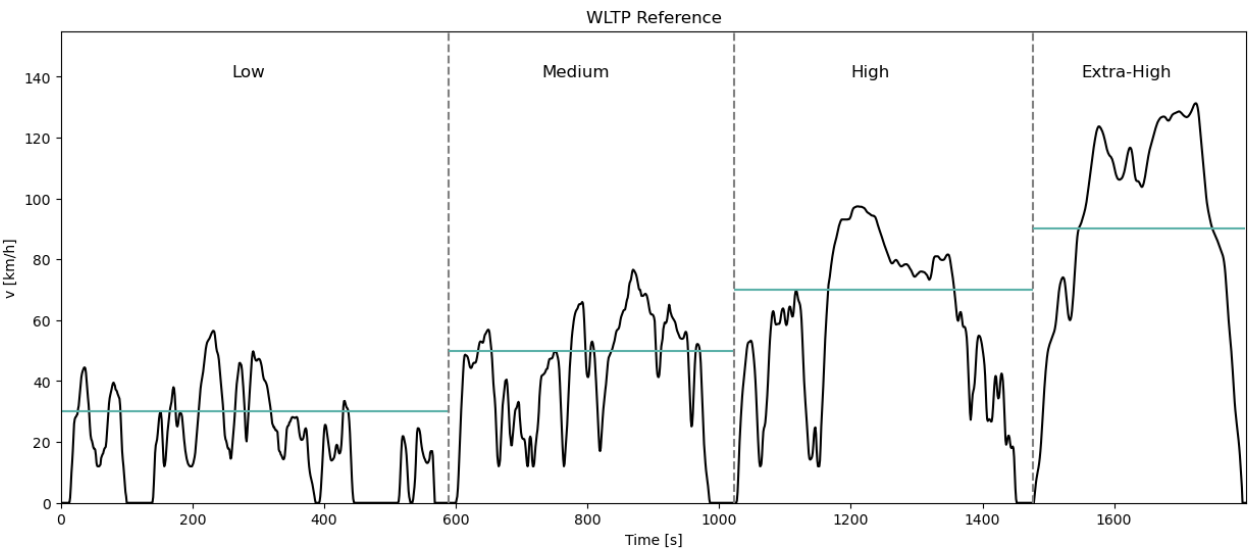

Figure 1 WLTP Cycle Reference

Proposed Methodology for ISO-conform Low Carbon Navigation

Based on Formula (6) and Figure 1 low carbon navigation can be implemented for energy-efficient route selection. An example is shown in Figure 2 which depicts an exemplary graph representing interconnected road segments. The edges represent road segments with associated length and average speed, and the vertices represent the interconnections of the road segments. With the new concepts proposed in this paper, each edge can now be assigned an additional value that describes the expected energy consumption based on ISO 23795-1.

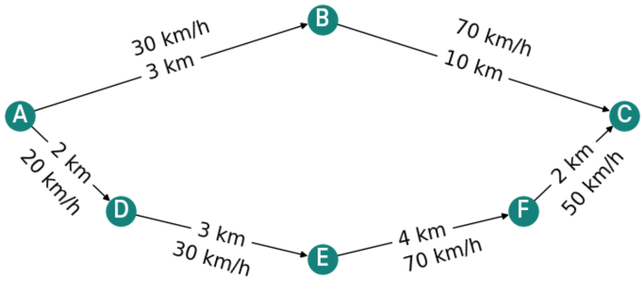

Figure 2 Simulation paths

Assuming for example a road segment of 3 km between A and B where the speed limit is 30 km/h, the edge weight for the route selection can be assigned both with regard to distance and time, as is done and well-known in conventional navigation systems. With the new concept, route selection can be performed based on expected energy consumption in a standardized accurate and efficient way as well.

Table 2 shows that each road segment has assigned an energy value (given in MJ) related to the corresponding WLTP class. Assuming for example 30 km/h as average speed, this corresponds to WLTP Class *Low*. We therefore take into account the related WLTP reference cycle and calculated the energy consumption accordingly. The method does not directly provide real fuel consumption as possible with monitoring for example via CAN bus, but it helps to provide a carbon equivalent value related to the energy consumption. The graph edge value calculated based on WLTP should furthermore also include a WLTP factor for weighing the energy consumption according to the WLTP class since standstill occurs for example much more often in urban traffic regions and sectors then on rural roads with stable driving patterns.

In the ISO standard, guidelines were provided how to handle acceleration and braking, considering the fact that for combustion engines the energy cannot be below 0 according to 3rd law of thermodynamics. Then, according to Formula (8) one finds

$$\boldsymbol{\kappa} = \frac{\sum(F_1+F_2+F_3)\Delta x}{\sum(F_1+F_2)\Delta x} - \mathbf{1} \qquad \textbf{(9)}$$

where the additional symbol has the following meaning

κ is the dimensionless WLTP energy factor >1.

The WLTP factor κ was calculated by comparing inertia forces of rolling friction F_1 and aerodynamics F_2 alone with the total sum of these forces and acceleration (braking) forces F_3. Thus, Formula (9) indicates the additional energy caused by acceleration and braking and reads, e.g., for WLTP LOW as additional 38,7% on top of rolling friction and aerodynamics only. In Table 1, values for all WLTP speed cycles as depicted in Figure 1. In order to assign the factor to individual road segments, a threshold is needed that clearly identifies when each factor should be applied to a specific segment. This threshold is given by the specific speed limit given by the road segment.

Table 1 WLTP factor

Cycle	Low	Medium	High	Extra-High
Speed	$v \leq 30$ km/h	30 km/h < $v \leq 50$ km/h	50 km/h < $v \leq 70$ km/h	70 km/h < v
WLTP factor κ	0,387	0,290	0,121	0,024

Overall, the comparison of carbon and fuel analysis helps as decision point for low carbon navigation as it includes time, distance, and energy as three independent criteria where preferences can easily be chosen. This often was done in the past by navigation systems, unfortunately in a non-standardized manner and not linked to the ISO 23795 calculations published in 2022.

Table 2 Simulation results

Nodes	Edges WLTP simplified			Edges WLTP ISO		
ID_1	Distance/[x]	Time/[Min]	Energy E_1/[MJ]	Energy E_2/[MJ]	Standstill/[s]	Energy E_3/[MJ]
A	Start			Start		
B	3 km	6	0,64	0,88	5s	0,92
C	10 km	9	2,51	2,81	-	2,81
SUM	13 km	15	3,15	3,69	5s	3,75
ID_2	Distance/[km]	Time/[Min]	Energy E_1/[MJ]	Energy E_2/[MJ]	Standstill/[s]	Energy E_3/[MJ]
A	Start			Start		
D	2 km	6	0,39	0,54	2	0,56
E	3 km	6	0,64	0,89	3	0,92
F	4 km	3	1,44	1,61	5	1,66
C	2 km	3	0,38	0,49	-	0,49
SUM	11 km	18 min	2,85 MJ	3,54 MJ	9 s	3,64 MJ

Table 2 shows the results of a simple simulation following the paths of figure 2. The fastest path with ID_1 is represented by the edges of the nodes A, B and C while the optimal path with ID_2 is represented by edges from the nodes A, D, E, F and C. In the first simulation, represented by the column E_1, a simple calculation was made, where neither the WLTP factor nor the standstill consumption were considered. Then, for ISO conform calculation the WLTP factor was used to determine energy E_2 and total energy E_3. The energy savings of the optimal path with ID_2 sum up to 0,11 MJ or 70 gCO_2e according to Reference (8). As mobile navigation Apps have already more than 1 billion users per month, the simple example would have a carbon credit value of 67,2 Mio € per year, which corresponds to the financial size of a typical UNFCCC climate project in other sectors.

Implementation and Exemplary Evaluation

Conventional route planners determine an optimal route between a starting point and a destination using various optimization criteria such as minimum distance or minimum travel time, see Reference (6). With our proposed methodology the route planner shall use estimated energy consumption as metric for route selection. Following the methodology an exemplary implementation was developed using Open Street Map (OSM) and Python. OSM provides the road segment data that is used for creating a corresponding graph as explained above. The WLTP classification of the road segments is done based on the maximum allowed speeds on these road segments provided by OSM. As described above, to each road segment (graph edge) is then assigned a distance, the expected duration based on the speed limit, and the estimated energy consumption based on the WLTP category.

Given an origin point and destination point, the implementation provides three different routes based on a path finding algorithm for graphs with weighted edges. We use here the conventional Dijkstra routing algorithm, see Reference (7). with distance, duration and energy consumption as edge weights.

Figure 3 depicts the fastest route which is found based on the minimum overall travel time whereas the shortest route is found based on the minimum overall distance between the endpoints. The first implementation did not take the WLTP factor into account thus three different routes where found, where one has to understand that a simple Dijkstra algorithm does not consider turn restrictions or similar restrictions in the street network.

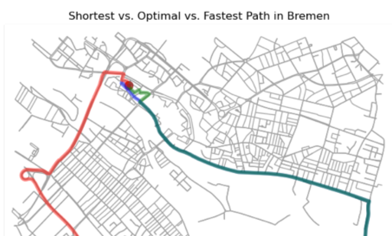

Figure 3 Optimal Path with only ISO and without WLTP or standstill

After the first implementation, the WLTP factor and expected standstill was then implemented to represent a more realistic route calculation. The resulting optimal path is shown in Figure 4 which is the same as in Figure 3, although the overall energy calculation for the estimated consumption is expected to be more accurate for the route in Figure 4. Finally, by analyzing the carbon footprint of more than 5 million kilometer of taxi and logistics fleet data, the presented model for Low Carbon Navigation conforming to ISO-23795-1 is ready for deployment.

In Reference 8, the authors present an overview of Tank-to-Wheel energy demand defined, e.g., for one liter of Diesel as 35,7 Mega-Joule with an equivalent to 2,5 kg CO_2. The energy consumption calculated per WLTP class provides a promising starting point for ISO conform Low Carbon Navigation. It should however be corrected by analyzing real-trips by in terms of big data analytics and AI-ML concepts for model refinement. Figure 5 depicts how this an urban network would look like assuming the speed ranges and WLTP classes as shown in Table 1. This can be easily transferred to a dynamic WLTP road network when using real speed profiles detected from nomadic devices. In Reference (10), more than 300000 trips from logistics and taxi companies were collected and will be evaluated further to define dynamic routing grids for future low carbon navigation APPs. Big data and AI-ML tools are considered as crucial to implement dynamic speed classes conforming to ISO-23795-1.

Figure 4 Optimal Path implemented with WLTP and Standstill

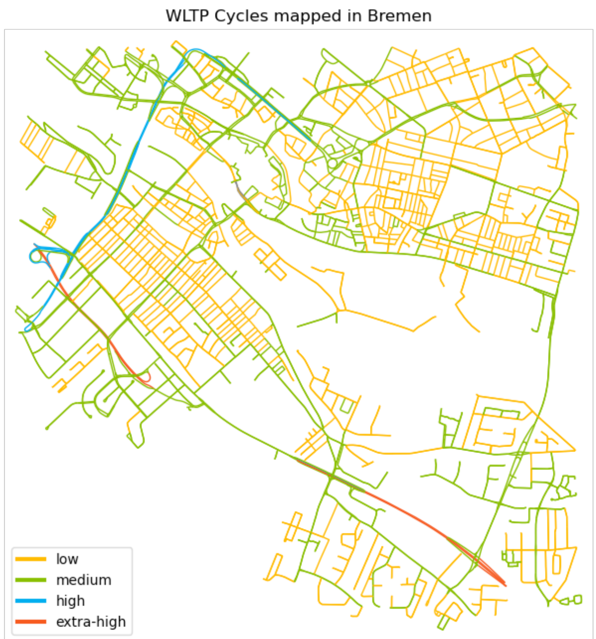

Figure 5 WLPT Cycles mapped in Bremen

Summary

The nomadic device market is approaching 10 billion mobile devices together with 1,5 billion connected vehicles on road. The potential for low carbon navigation solutions is therefore huge. Unfortunately, existing web-based navigation tools for energy-efficient routing do not publish their algorithms and are therefore not suitable for monitoring, reporting and verification tools required in climate protection. Compared to this, the suggested routing tool conforming to ISO-23795-1 enables to quantify the estimated carbon emissions in a fully transparent manner giving reliable values for

a) the carbon optimal route on ISO-23795-1 WLTP basis,
b) the carbon footprint per trip which can be off-set fully transparent,
e.g., by shops, restaurants or hotels together with certified e – couponing to attract customers.

According to Reference (8), the navigation app sector had a revenue of \$16,2 billion in 2022 and is forecasted to grow at a rate of 14,8 percent up to \$36,6 billion in 2028.

By implementing a) and b) within B2B APP solutions in a standardized manner as suggested in this paper, the announced climate neutrality corporate strategy by logistics and telecommunication operators worldwide can be realized in a most efficient and promising way.

The amount of CO_2 savings with low carbon navigation implemented in 10 billion nomadic devices will definitely be as significant as the electrification of automotive engineering and, jointly, they will boost road transport towards sustainability, urgently needed for future generations. Figure 6 summarizes the scientific approach and provides an overview of aspects discussed here.

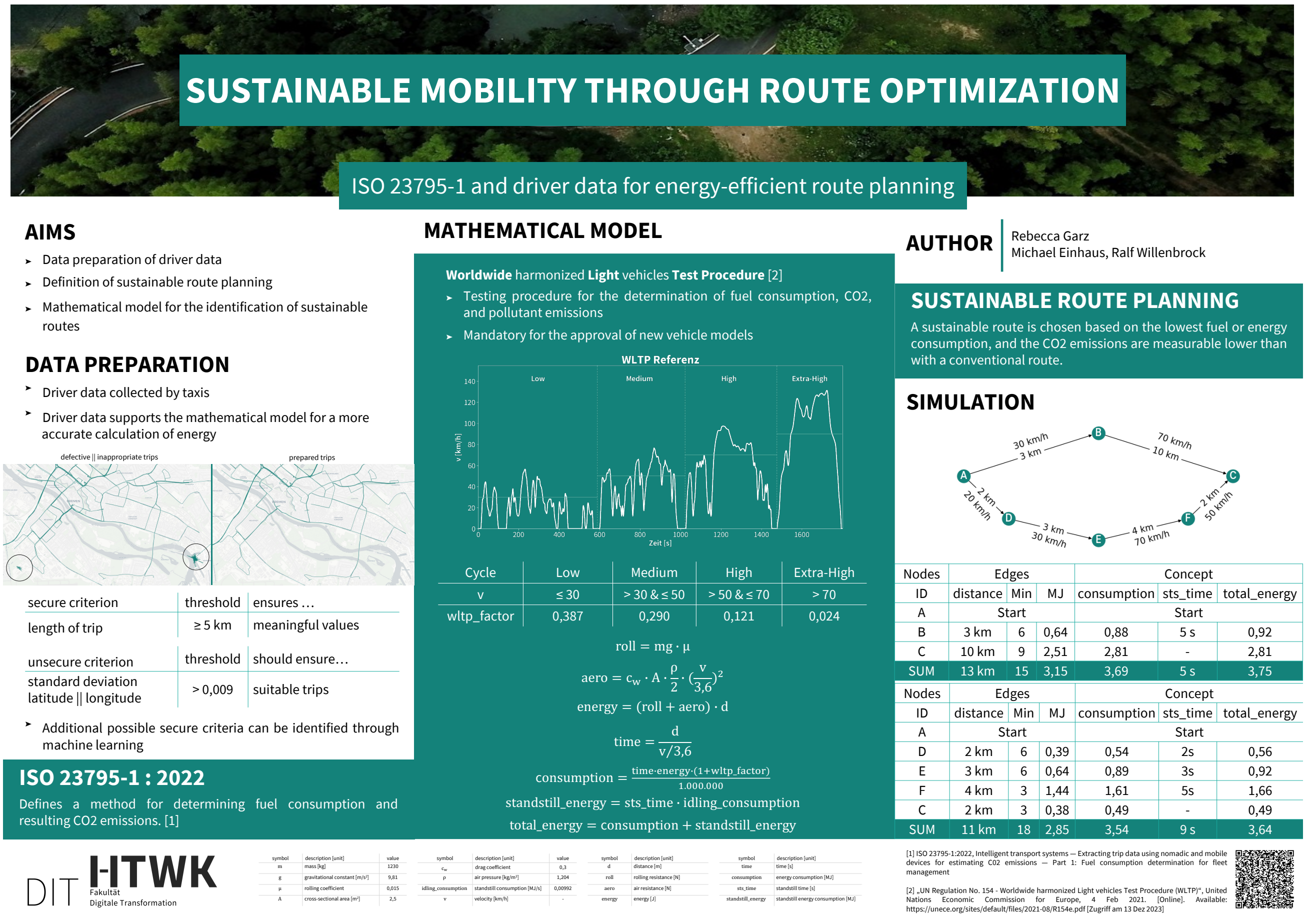

Figure 6 Overview of Low Carbon Navigation methodology

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