Active Engine-Off Coasting using 48V: Economic reduction of CO_2 emissions

Aktives Segeln mit dem 48 V Mildhybrid: Wirtschaftliche Reduzierung der CO_2 Flottenemissionen

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Kurzfassung

Elektro-und Hybridfahrzeuge tragen zur Reduzierung der weltweiten CO_2-Flottenemissionen bei, können jedoch aufgrund Ihrer moderaten Marktanteile von zirka 7% in 2020/2021 (< 2% in 2014) [1], die Zielerreichung nicht sicherstellen. Ein weiterer Stellhebel für die Reduzierung der CO_2 Emissionen ist die Optimierung der bestehenden Verbrennungsmotorfahrzeuge. Die Realisierung von Hybridfunktionen wie Segeln und Rekuperation ist für die breite Masse der verbrennungsmotorisch angetriebenen Fahrzeuge durch die Verwendung der 48 V-Technologie deutlich besser realisierbar, als es bereits im konventionellen 12 V-Bordnetz mittels eines Energiespeichermoduls möglich ist. Passives Segeln zeigt im realen Fahrbetrieb bereits ein beachtliches Potenzial zur Kraftstoffeinsparung. Da durch die Fahrwiderstände das Fahrzeug in der Ebene verlangsamt wird, ist in theoretischen Bewertungszyklen der Nutzen gering, oder wie im „Neuen Europäischen Bewertungszyklus" (NEFZ) wertlos. Im Gegensatz dazu erlaubt das aktive Segeln mit ausgeschaltetem Verbrennungsmotor im NEFZ eine Einsparung von CO_2 Emissionen, indem die Verzögerung des Fahrzeuges infolge der Fahrwiderstände durch die Nutzung der elektrischen 48V Maschine kompensiert wird.

Dieser Beitrag vergleicht das passive und aktive Segeln mit ausgeschaltetem Verbrennungsmotor und das Boosten bezüglich der Einsparung von CO_2 Emissionen für verschiedene Fahrzeugsegmente (B, D, E) für die Bewertungszyklen NEFZ und WLTP

Abstract

Hybrid and electric vehicles help to achieve global CO_2 , but their benefit is still not sufficient due to their moderate market share of 7% in 2020/21 (2% in 2014) [1]. An additional lever for the emission optimization is the introduction of hybrid functionalities like engine-off coasting and regenerative braking (recuperation) in vehicles with internal combustion engine (ICE). The realization of these applications is much more effective using a 48V power system approach in comparison to the usage of a 12V energy storage module. Passive engine-off coasting, when applied to real world driving shows a promising fuel reduction potential; however, due to the driving resistances the vehicle slows down so that the optimization potential within artificial driving cycles is low, especially within the New European Driving Cycle (NEDC), where it cannot be used at all.

In comparison, active engine-off coasting offers a benefit, with regard to CO_2 emissions, within the NEDC by decreasing the rate of deceleration using the 48V electrical machine for propulsion purposes.

In this paper, passive and active engine off coasting and boosting are evaluated for their CO_2 saving potentials for different vehicle segments (B class, D class and E class) for the WLTP and NEDC driving cycle while considering the dimensions of the major components and electrical load scenarios.

1. Introduction

Hybrid and electric vehicles help to achieve global CO_2 reduction, but their benefit is still not sufficient due to their moderate market share of 7% in 2020/21 (2% in 2014) [1]. Passive engine-off coasting offers CO_2 saving potential within the WLTP and is especially promising in real-world driving cycles. This vehicle functionality can be implemented using 12V as well as 48V power system implementation [2][3]. Nevertheless, when the vehicle powertrain is switched-off, due to the driving resistances like air drag, rolling friction and mechanical friction, the car slows down during the coasting phase. Thus, the saving potential of this vehicle application cannot be utilized within the New European Driving Cycle (NEDC) because the vehicle speed must often be driven at constant speeds with strong decelerations requiring activation of regenerative braking.

Using a 48V power system implementation, a powerful electrical machine with up to 15kW peak power capability is available that can be used to compensate these driving resistances and keep the vehicle at a constant speed, at least for velocities up to 60km/h. The opportunity to use the 48V machine for propulsion purposes to keep a constant vehicle speed (active engine-off coasting) complements the coasting function thereby benefiting the NEDC. In the case of a 48V belt-driven starter generator (BSG), the internal combustion engine (ICE) is not decoupled from the power train thus forcing the BSG to compensate not only the driving resistances, but also the drag torque of the ICE. Because of this additional loss, the benefit of active coasting must be evaluated seriously. The expectation is that the overall efficiency of active engine-off coasting is better than the normal ICE during these low torque demands. The capability of 48V propulsion has to consider the available electrical energy which can be harvested by the regenerative braking (recuperation) application. In addition, the harvested energy can be used to keep the vehicle speed constant and to support the ICE during acceleration of the car (boosting) or during general driving. Here, efficiency improvements of the combustion engine (load point shift of the ICE) should be compared to the usage of the recuperation energy for active engine-off application.

2. Simulation Model

A simulation of 3 different vehicles is used (Figure 1) for the evaluation of the focused vehicle application.

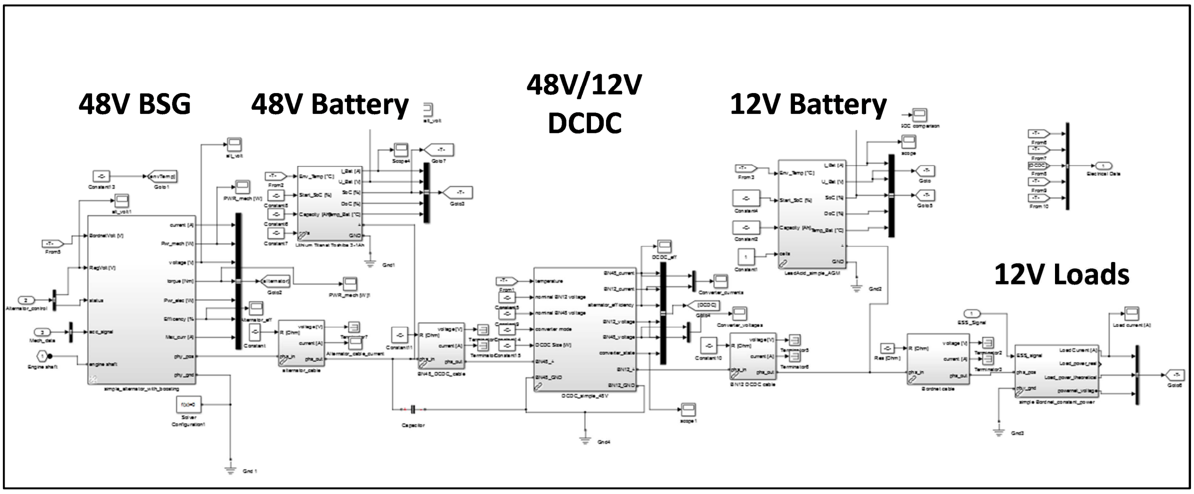

Figure 1: Electrical Subsystem of vehicle simulation model for B, D and E class cars

For a B segment car a generic vehicle 1.2l gasoline model with a mass of 1200kg, 5 gear transmission, 8kW 48V BSG and a 60Ah 12V lead acid battery is used. The D segment car has 1500kg mass, 7 gear transmission, 10kW 48V BSG, 60Ah starter battery and a 1.7l gasoline / 2.0l diesel engine. For the E class segment a 2.0l gasoline and 2.2l diesel engine is evaluated with a car mass of 1800kg, 7 gear transmission and a 15kW 48V BSG. The impact of the different 48V Lithium ion battery capacities is simulated accordingly with capacities of 5Ah, 10Ah, 15Ah and 20Ah. The electrical consumption of the power system itself is defined at 300 W for B segment, 450W for D segment and at 1000W for E segment for normal environmental conditions and 2.5 times higher for cold environment.

The following different operation profiles (function sets 1-7) are simulated and evaluated within the analysis:

- Function set 1: no engine-off coasting, no boosting
- Function set 2: active engine-off coasting, no boosting
- Function set 3: active engine-off coasting, boosting
- Function set 4: no engine-off coasting, boosting
- Function set 5: passive engine-off coasting, no boosting
- Function set 6: passive engine-off coasting, boosting
- Function set 7: active engine-off coasting, passive engine-off coasting

The 48V recuperation is active in all function sets.

As reference a vehicle with Stop/Start function and a standard 12V system was chosen.

Passive and active engine-off coasting as well as boosting requires a sufficient and sustainable electrical energy which can be harvested from the kinetics of the car's braking. The capability of the so called recuperation was determined for 48V systems in [2]. Nevertheless, for the different operation profiles and driving cycles (NEDC and WLTP) its available energy is shown in Figure 2.

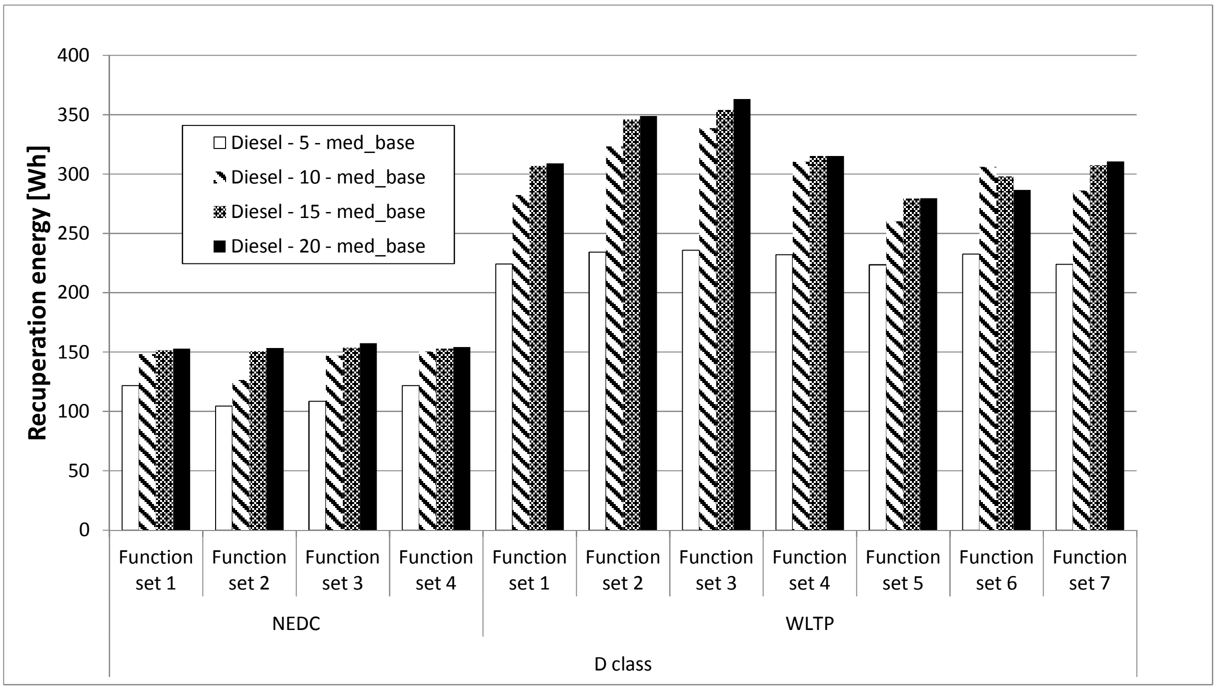

Figure 2: Recuperation energy for all operation profiles exemplary for D class diesel car within the NEDC and WLTP for 48V battery capacity of 5Ah, 10Ah, 15Ah and 20Ah

It can be observed that a 5Ah Lithium Ion battery is too small to achieve the whole potential. A capacity of 10Ah offers a sufficient potential, whereas 15Ah and 20Ah show only slight improvements for this car segment.

If function set 1 and function set 2 are compared using WLTP, there is slightly more recuperation energy possible for function set 2. This is because the active engine-off coasting function consumes electric energy and therefore discharges the 48V battery which enables more energy recuperation later on. (For NEDC, this is not the case). This indicates that all possible recuperation energy is already realized with function set 1 (only recuperation). Obviously the NEDC yields significantly less recuperation energy because of a smaller amount of dynamics with less duration in comparison to the WLTP. However, the average recuperation energy per kilometer for the NEDC and WLTP is almost the same as seen in Figure 3. This is because the longer duration (1800s vs. 1200s) and the higher average speed (46km/h vs. 34km/h) leads to a much longer driving distance (23km vs. 11km) for the WLTP. For that reason the available energy for functions like active engine-off coasting or boosting is nearly the same for both driving cycles.

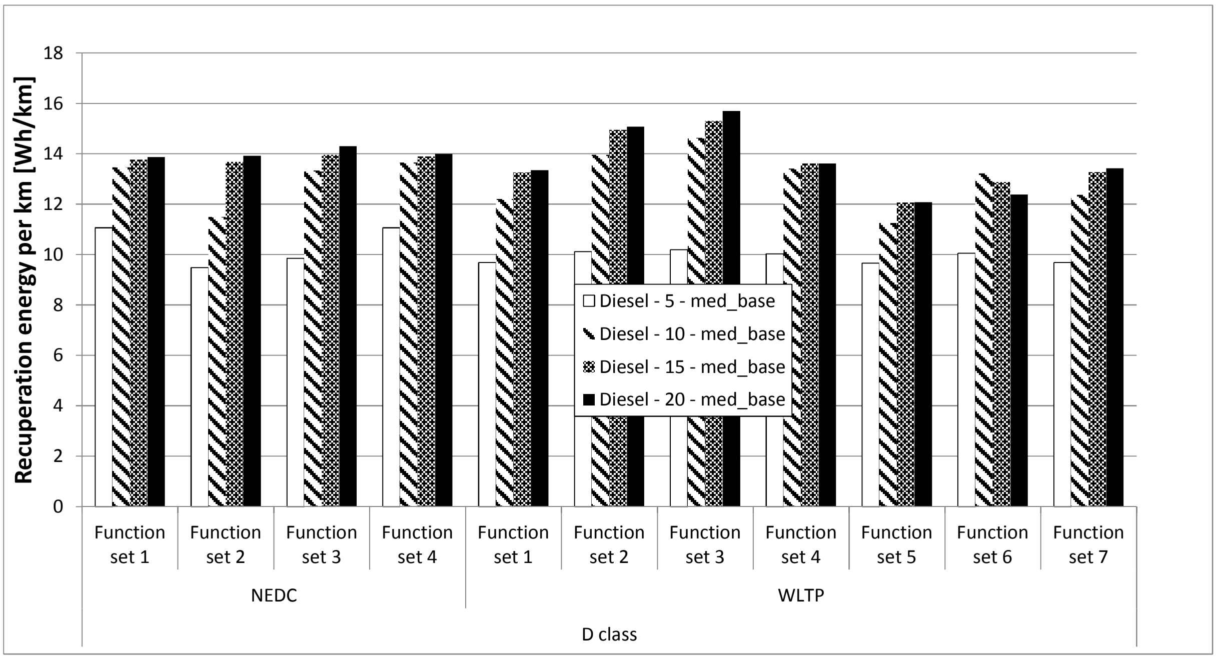

Figure 3: Average recuperation energy per kilometer for all operation profiles exemplary for D class diesel car within the NEDC and WLTP for 48V battery capacity of 5Ah, 10Ah, 15Ah and 20Ah

In the current implementation of passive engine-off coasting the recuperation energy is slightly reduced (function set 5 with WLTP) because the non-optimized algorithm sometimes keeps the vehicle in the passive engine-off coasting a little too long, reducing the braking time slightly.

2. Active Engine-Off Coasting and Boosting

Passive as well as active engine-off coasting have to be integrated beneficially within the operation strategy of the whole vehicle system. The operation strategy used In Figure 4 for active engine-off coasting is shown for a WLTP instance. During phases of constant or slightly decreasing/increasing vehicle speed the belt-driven starter generator is used to compensate driving resistances. If the vehicle is accelerating the BSG is placed in generator mode to supply the power system in a normal manner. During braking, the maximum regenerative capability of the 48V generator is used accordingly.

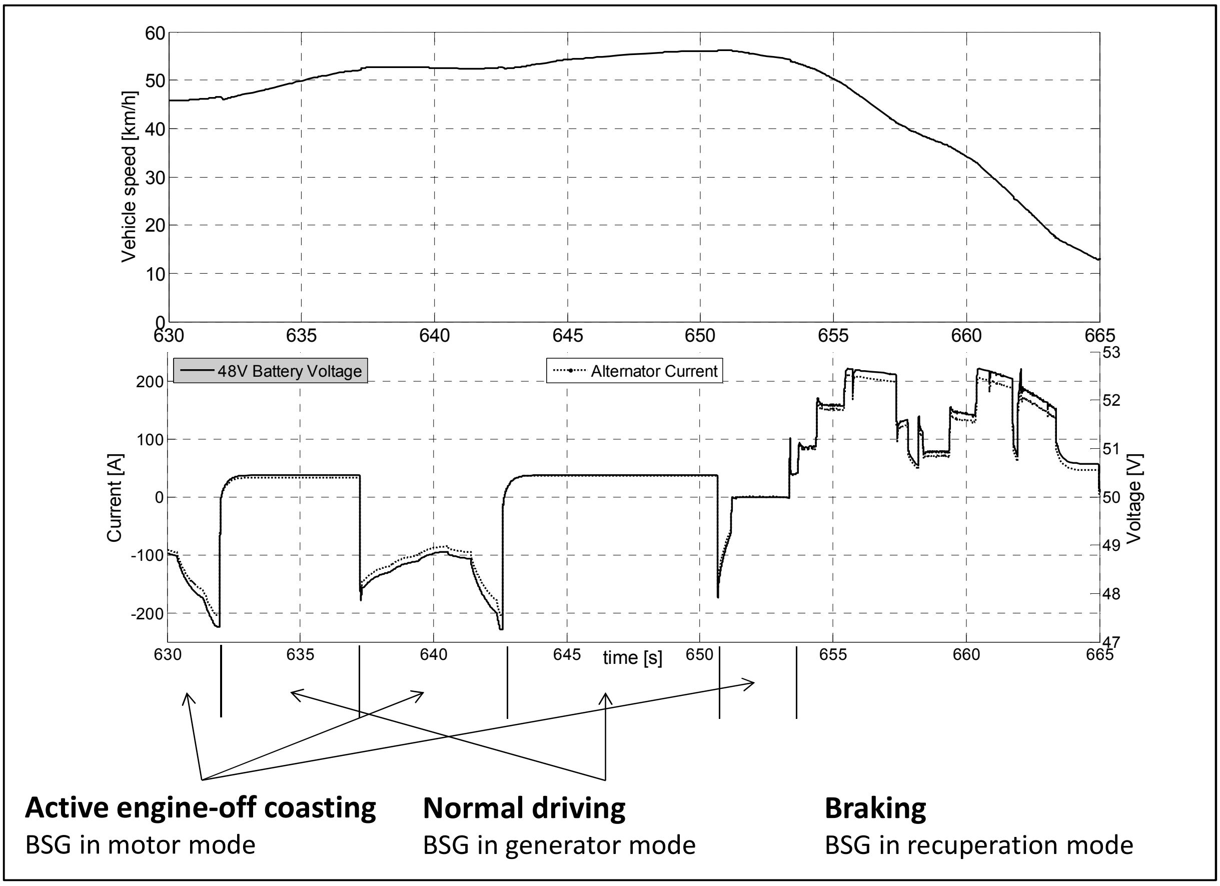

Figure 4: Exemplary operation strategy for active engine-off coasting

For the described function sets different engine-off coasting and boosting time durations are derived out of the system simulations for the D segment car with a diesel engine for the base and winter load scenario (Figure 5.). Coasting phases in the WLTP are longer than in the

NEDC because active engine-off coasting is enabled during phases of constant speed in the NEDC. This consumes a large amount of electrical energy, leading to shorter coasting phases. In addition the WLTP yields a more dynamic characteristic with no significant phases of constant vehicle speed. Therefore, active coasting is mainly used during slight deceleration phases which lead to a reduced electrical energy consumption and longer coasting phases.

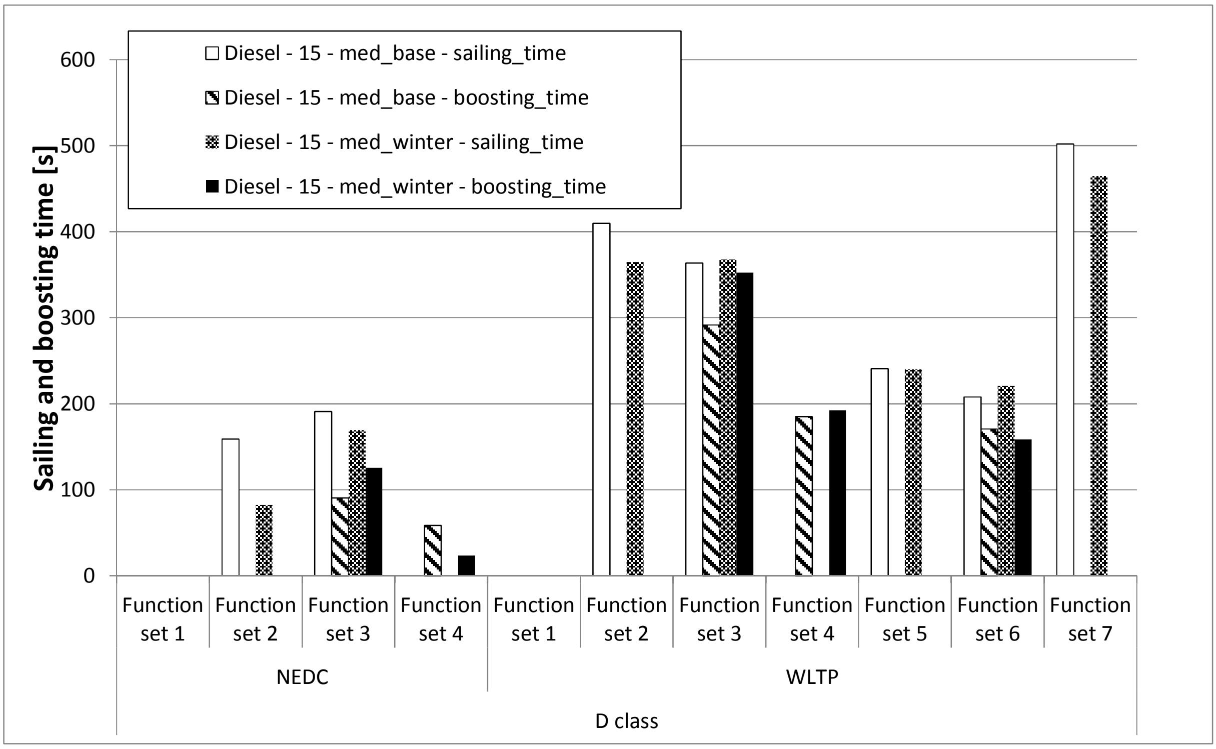

Figure 5: Engine-off and boosting times for the different function sets using the D segment diesel car during base and winter load profiles

The dynamic of the WLTP also yields similar, increased times for the boosting application. Nevertheless, the times are is essentially dependent on the parameters of the operation strategy (e.g. the accelerator pedal thresholds).

3. Results

The results of diesel and gasoline vehicles, which do not deviate in general between normal and cold environmental conditions are illustrated in Figure 6.

The savings during the NEDC for cold environments are slightly higher because the increased electrical load consumes the surplus of available recuperation energy. Under normal environmental conditions this amount of regenerative energy cannot be consumed by the electrical power system.

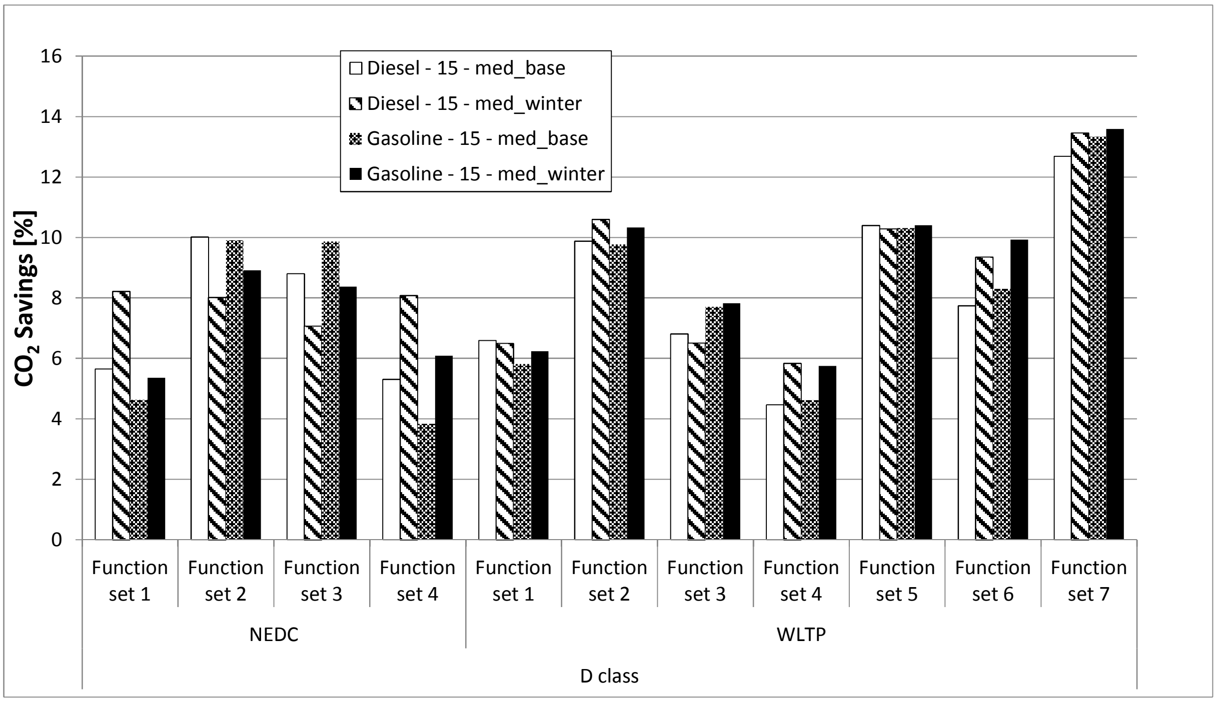

Figure 6: Comparison of saving potential for diesel and gasoline engine and normal and cold environment condition for a D segment car within the NEDC and WLTP

The simulation results for a 15Ah 48V battery of all function sets and vehicle segments are shown in Figure 6. The small car segment used a gasoline engine, while the other cars used a diesel engine.

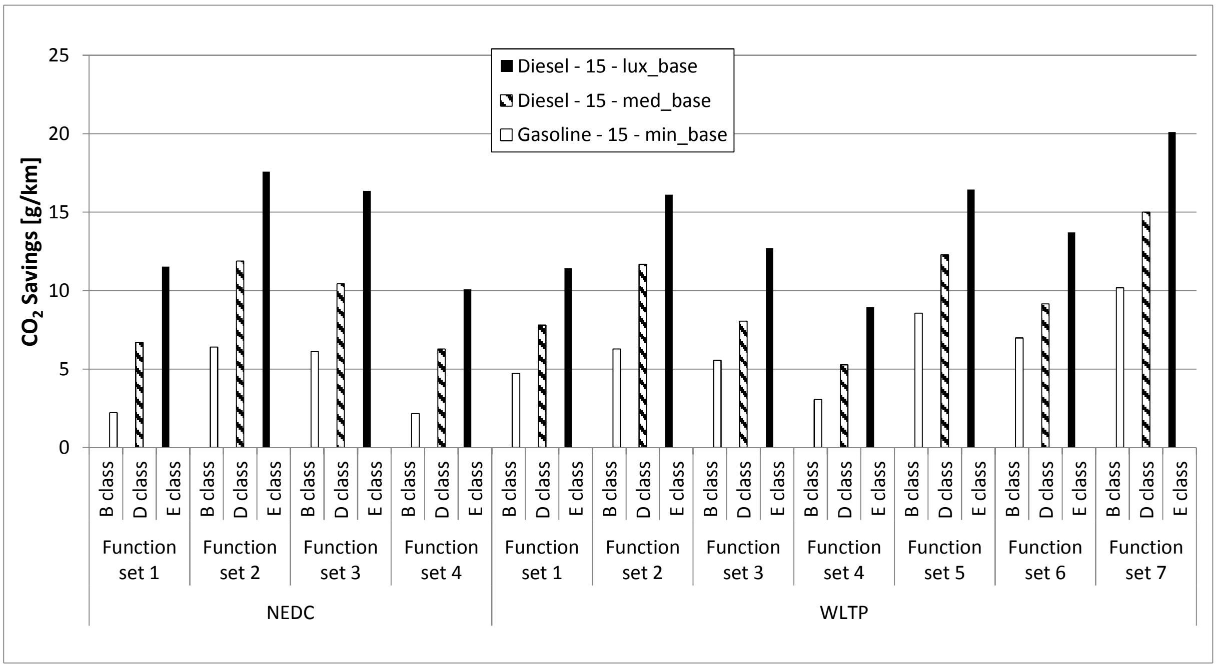

Figure 7: Absolute CO_2 reduction potential of different car segments and ICE types for the NEDC and WLTP with regard to defined operation strategy models

In general the E segment car offers the highest saving potential with up to 20g/km CO_2 savings for function set 7 (active & passive engine-off coasting) which is a reduction of 15% compared with the CO_2 generation of the reference vehicle (Figure 7). Because passive engine-off coasting phases are not possible within the NEDC, the operation function sets 5 to 7 are not evaluated for the NEDC.

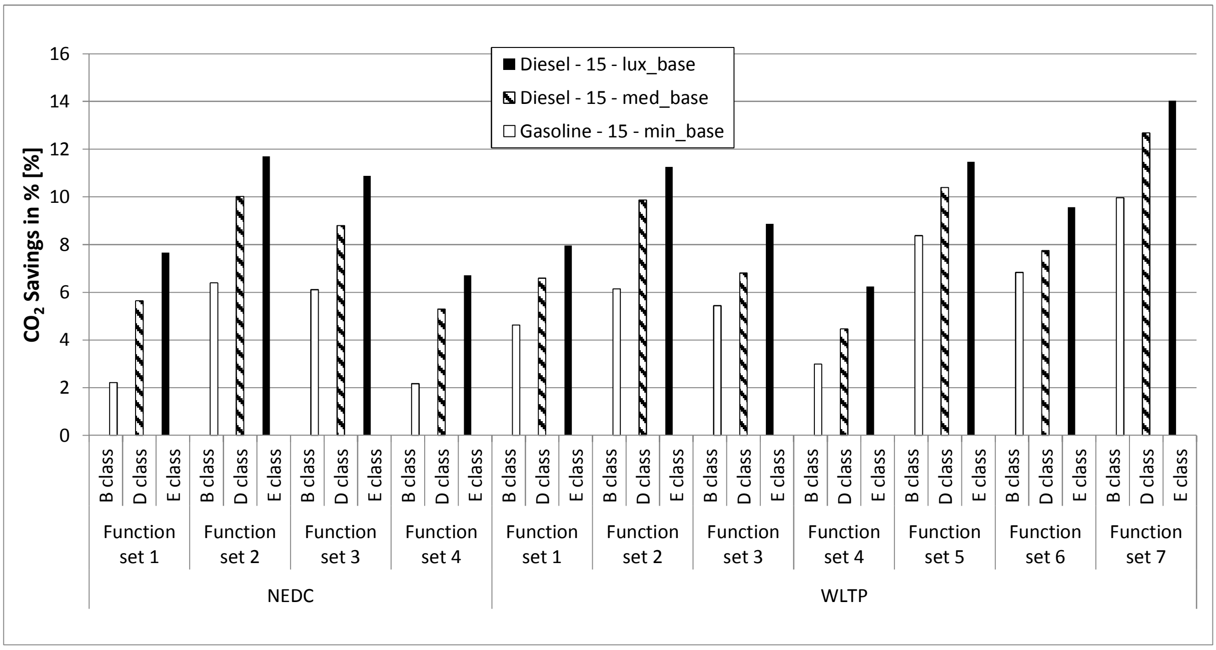

Figure 8: Percentage of CO_2 reduction potential for different car segments and their ICE types for the NEDC and WLTP with regard to defined operation strategy models

The benefit of pure active engine-off coasting is already present within the NEDC. It saves 3% to 4% CO_2 emissions. Additional boosting, by contrast, never shows an improvement of CO_2 savings. In the WLTP the savings from pure active engine-off coasting is not significantly higher for upper car segments. Nevertheless, active coasting shows a higher CO_2 reduction potential than boosting (almost a factor of 2). This leads to the conclusion that switching off the ICE during low torque demands results in better efficiency than ICE boosting. This might change if the boosting capability is utilized in combination with more engine downsizing or other ICE internal measures, which has not been analyzed in this paper.

The benefit of the pure active coasting application is slightly higher within the NEDC than in the WLTP. Additional boosting always reduces the CO_2 savings dramatically, similarly in WLTP and in NEDC. Obviously the combination of active and passive engine-off coasting leads to the highest saving potential for the WLTP (function set 7). Therefore, this combined application is recommended for implementation if a 48V system approach is available, to achieve the maximum reduction potential. Its corresponding operation strategy is illustrated in Figure 9.

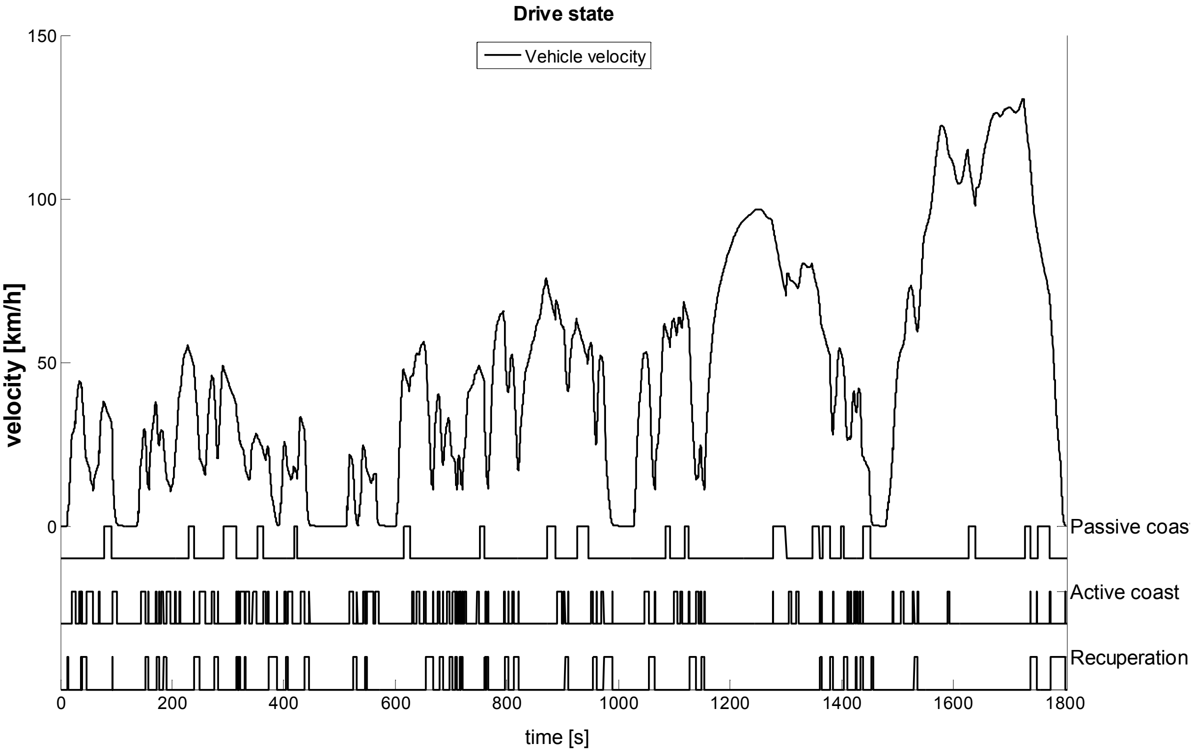

Figure 9: Operation profile of a combination of passive and active engine-off coasting within the WLTP

Further investigation of the data shows that active engine-off coasting is used most frequently during low vehicle speeds while passive engine-off coasting is used mainly during low deceleration phases at high speeds (>40km/h). From an energy savings point of view it would be best to stay in passive engine-off coasting as long as possible since the overall friction is lowest during this vehicle state; hence the vehicle energy efficiency is highest. This also preserves the available electrical energy for cases in which active engine-off coasting has the biggest effect. There are several phases of the operation profile shown in which passive engine-off would be better than active engine-off coasting. However the implemented vehicle state algorithm in the simulation limits the passive engine-off coasting phases to ensure that the vehicle never leaves the allowed ±2km/h band around the vehicle speed profile. During real driving this strict vehicle speed band is not relevant. This leads to the conclusion that the realizable fuel savings are even larger in reality than what is shown in the simulation which means the full CO_2 emission saving potential could be utilized for fleet emission reduction only by Eco innovation.

Implications on driving comfort were not analyzed here, especially audible differences between active engine-off coasting and low torque ICE driving. Frequent changes between these two modes need to be accomplished with modern state-of the art engineering techniques. Passive engine-off coasting of course of course requires an automated clutch or a double clutch gearshift.

4. Conclusion and Outlook

Active engine-off coasting offers a promising CO_2 benefit if a 48V power system approach is implemented to achieve the upcoming targets in 2020/2021. This implementation can be used beneficially especially for the NEDC, which shows no capabilities for passive coasting. It was shown that this application is also valid for different car segments, with the benefit increasing with respect to the car segment. In order to achieve a proper implementation a sufficient battery capacity at 48V must be implemented. To achieve the maximum CO_2 reduction potential, a combination of passive and active coasting should be implemented. The results revealed that the optimization of operation strategy parameters (which must be derived accordingly) in relation to the static vehicle characteristics like weight, air and roll friction and energy consumption is essential to achieve the maximum CO_2 saving potential.

5. References

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