Energy Demand in Test Cycles

Test Cycles

Test cycles consist of standardised speed and elevation profiles, used to

1. Compare pollutant emissions

2. Compare fuel economy

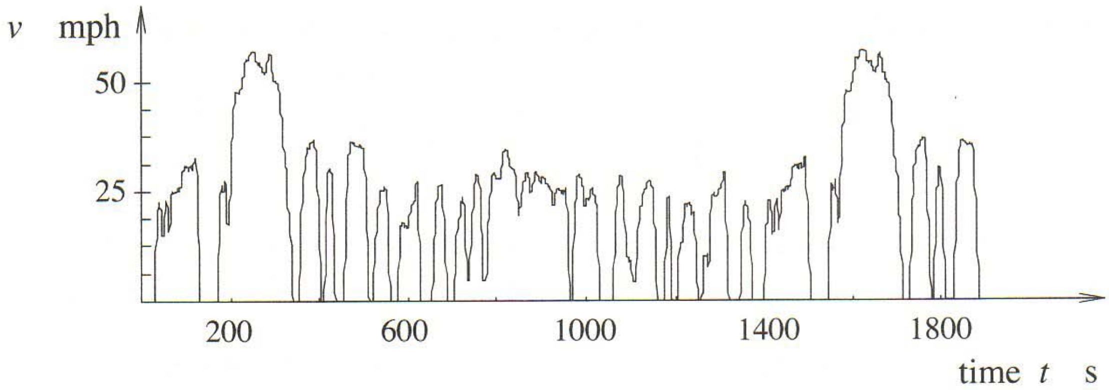
Commonly used cycles

USA

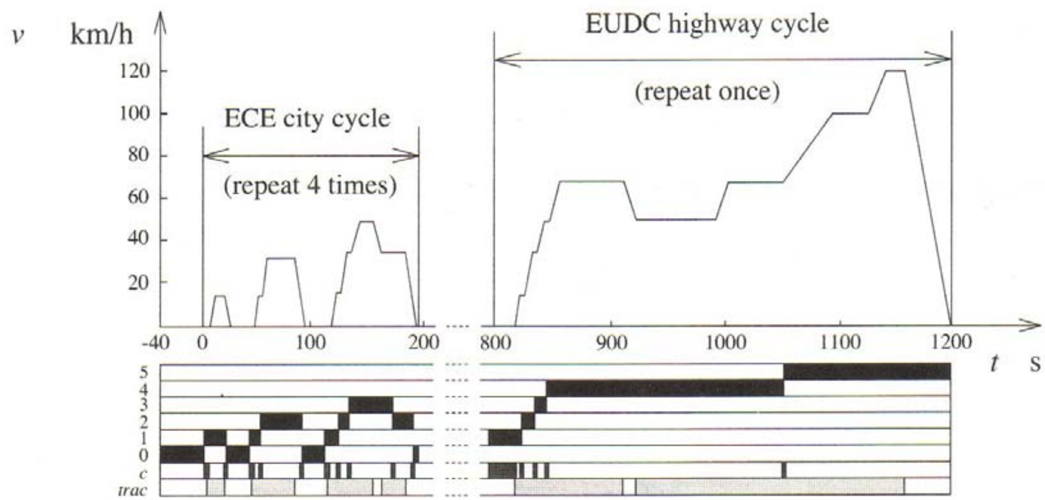
1. FUDS - federal urban driving cycle
2. FHDS -federal highway driving cycle
3. FTP-75 - federal test procedure

EU

1. ECE - urban
2. EUDC - highway
3. MVEG-95 4 ECE + 2 EUDC



US test cycle FTP–75 (Federal Test Procedure), length: 11.12 miles (17.8 km), duration: 1890 s, average speed: 21 mph (9.43 m/s).



European test cycle MVEG–95, gears 1–5, "c": clutch disengaged, "trac": traction time intervals. Total length: 11.4 km, duration: 1200 s, average speed: urban 5.12 m/s, extra-urban 18.14 m/s, overall 9.5 m/s. The cycle includes a total of 13 gear shifts.

Mechanical Energy

Mean tractive force

$$\overline{F}_{tract} = \frac{1}{x_{total}} \int_{t \in tract} F(t) \cdot v(t) dt$$

In practice, v(t) is sampled

$$v_i = v(t_i), \qquad t_i = i \cdot h, \qquad i = 0,1,2,\ldots n$$

$$velocity: \; v(t) = \overline{v}_i = \frac{v_i + v_{i-1}}{2}$$

$$acceleration: \; a(t) = \overline{a}_i = \frac{v_i - v_{i-1}}{h}$$

$$\overline{F}_{tract} \approx \frac{h}{x_{total}} \sum_{i \in tract} F_{tract,i} \overline{v}_i$$

Energy Demand Case 1 No Recuperation

Mean tractive force

$$\overline{F}_{tract} = \overline{F}_{tract,m} + \overline{F}_{tract,a} + \overline{F}_{tract,r}$$

$$(F_g = 0, F_d = 0)$$

Inertia resistance

$$\overline{F}_{tract,m} \approx \frac{1}{x_{total}} m_v \sum_{i \in tract} \overline{a}_i \overline{v}_i h$$

Aerodynamic drag

$$\overline{F}_{tract,a} \approx \frac{1}{x_{total}} \frac{1}{2} \rho_a A_f c_d \sum_{i \in tract} \overline{v}_i^3 h$$

Rolling friction

$$\overline{F}_{tract,a} \approx \frac{1}{x_{total}} m_v g c_r \sum_{i \in tract} \overline{v}_i h$$

For MVEG-95, ECE, and EUDC cycles, respectively

$$\frac{1}{x_{total}} \sum_{i \in tract} \overline{a}_i \overline{v}_i h = \{0.101 \quad 0.126 \quad 0.086\}$$

$$\frac{1}{x_{total}} \sum_{i \in tract} \overline{v}_i^3 h = \{319 \quad 82.9 \quad 455\}$$

$$\frac{1}{x_{total}} \sum_{i \in tract} \overline{v}_i h == \{0.856 \quad 0.81 \quad 0.88\}$$

Energy Consumed

$$\overline{E} = \overline{F}_{tract} x_{total} = m_v \sum_{i \in tract} \overline{a}_i \overline{v}_i h + \frac{1}{2} \rho_a A_f c_d \sum_{i \in tract} \overline{v}_i^3 h + m_v g c_r \sum_{i \in tract} \overline{v}_i h$$

For MVEG – 95 cycle

$$\overline{E} = x_{total} \left(0.101 m_v + 319 \frac{1}{2} \rho_a A_f c_d + 0.856 m_v g c_r \right)$$

$$Let\ x_{total} = 100km = 100000m$$

$$\overline{E} = x_{total} \left(0.101 m_v + 319 \frac{1}{2} \rho_a A_f c_d + 0.856 m_v g c_r \right)$$

$i.e$

$$\overline{E} = 10100 m_v + 15950000 \rho_a A_f c_d + 838800 m_v c_r \,(J)$$

or

$$\overline{E} = 10.1 m_v + 15950 \rho_a A_f c_d + 838.8 m_v c_r \,(kJ)$$

Energy Demand Case 2 Full Recuperation

Full recuperation: energy spent in accelerating vehicle is completely recuperated during the braking.

Mean tractive force

$$\bar{F}_{tract} = \bar{F}_{tract,a} + \bar{F}_{tract,r}$$

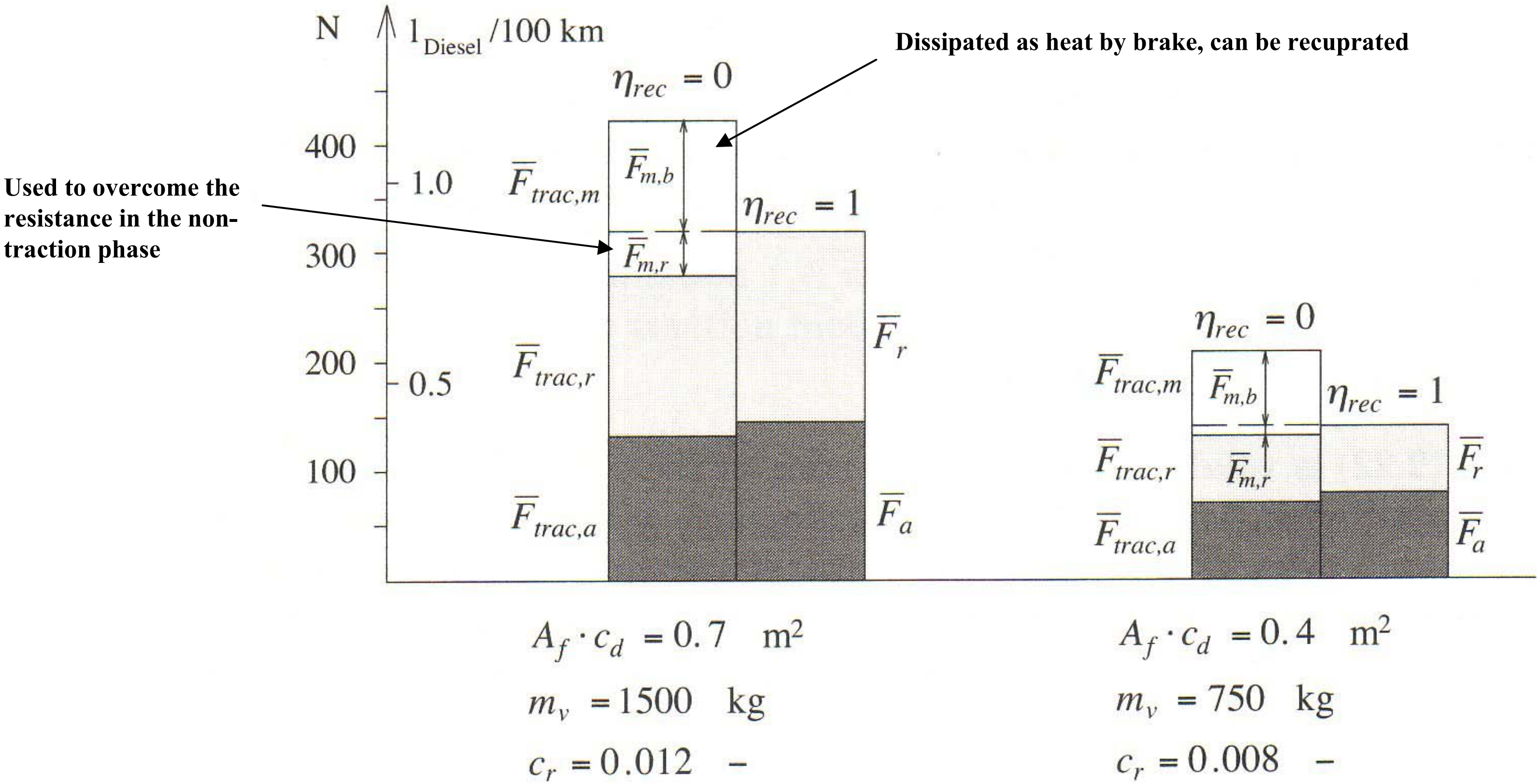
For MVEG-95, ECE, and EUDC cycles, respectively

$$\frac{1}{x_{total}} \sum_{i \in tract} \bar{v}_i h = \{1 \quad 1 \quad 1\}$$

$$\frac{1}{x_{total}} \sum_{i \in tract} \bar{v}_i^3 h = \{363 \quad 100 \quad 515\}$$

$$Let \ x_{total} = 100000m$$

$$\bar{E} = x_{total}\left(363\frac{1}{2}\rho_a A_f c_d + m_v g c_r\right) = 18150\rho_a A_f c_d + 980 m_v c_r \,(kJ)$$



Comparison of the energy demand in the MVEG–95 cycle for a full-size car (left) and a light-weight car (right). A mean force of 1 N is equivalent to 27.78 Wh mechanical energy per 100 km. The lower heating value for Diesel fuel is approximately 10 kWh/l.

Vehicle kinetic energy partially is going to breaking recuperation

Energy demand of Different Vehicles

MVEG-95 cycle

There is a big difference between small average power and maximum power required for acceleration (0 to 100km/h within 10 seconds – satisfactory drivability)
SUV – sport utility vehicle

Numerical values of the average and peak tractive powers for different vehicle classes.

	SUV	full-size	compact	light-weight
$A_f \cdot c_d$	$1.2\,\mathrm{m}^2$	$0.7\,\mathrm{m}^2$	$0.6\,\mathrm{m}^2$	$0.4\,\mathrm{m}^2$
c_r	0.017	0.013	0.012	0.008
m_v	2000 kg	1500 kg	1000 kg	750 kg
$\bar{P}_{MVEG-95}$	11.3 kW	7.1 kW	5.0 kW	3.2 kW
P_{max}	155 kW	115 kW	77 kW	57 kW

Sensitivity of energy demand to parameters

$$S_p = \lim_{\Delta p \to 0} \frac{\frac{\Delta E}{E}}{\frac{\Delta p}{p}} = \frac{p}{E}\frac{\partial E}{\partial p}$$

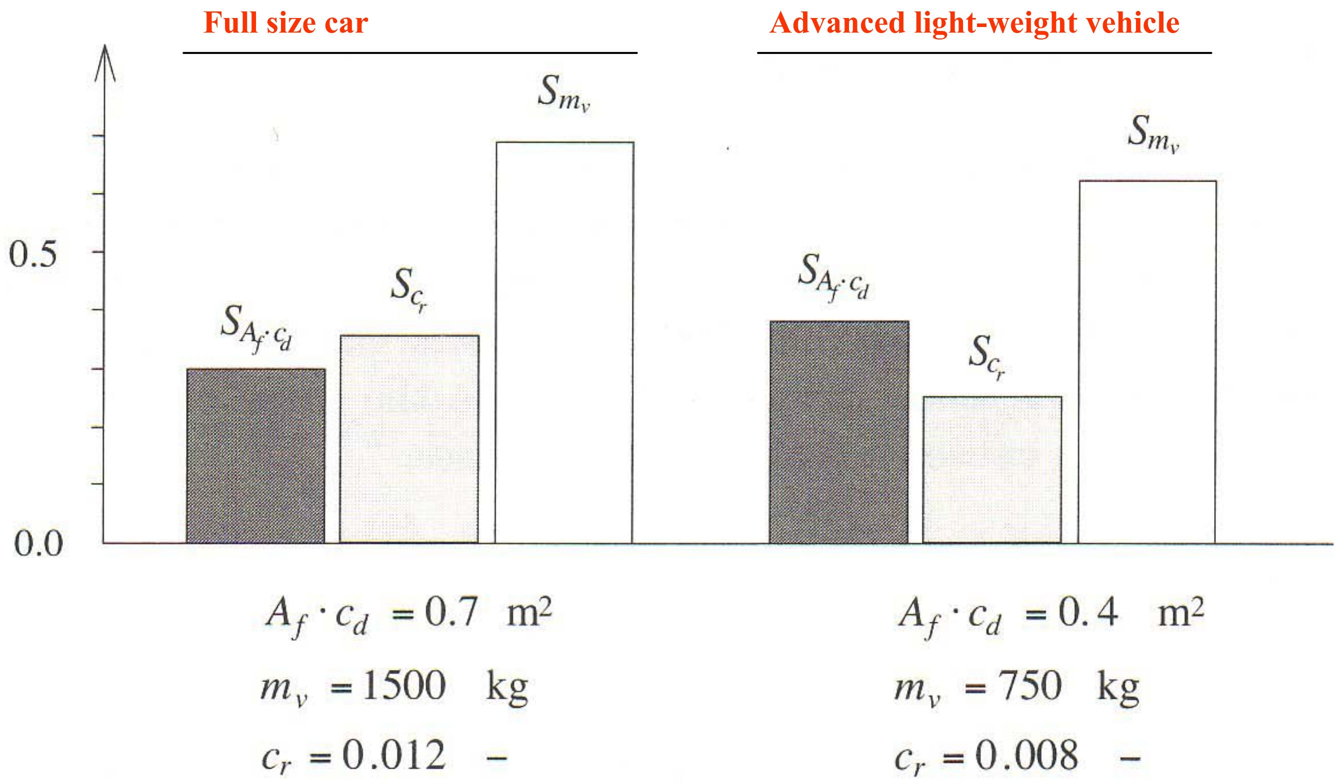
For MVEG – 95

$$\overline{E} = 10.1 m_v + 15950 \rho_a A_f c_d + 838.8 m_v c_r \ (kJ)$$

$$\frac{\partial \overline{E}}{\partial m_v} = 10.1 + 838.8 c_r, \qquad S_{m_v} = \frac{m_v(10.1 + 838.8 c_r)}{10.1 m_v + 15950 \rho_a A_f c_d + 838.8 m_v c_r}$$

$$\frac{\partial \overline{E}}{\partial (A_f c_d)} = 15950 \rho_a, \qquad S_{(A_f c_d)} = \frac{15950 \rho_a A_f c_d}{10.1 m_v + 15950 \rho_a A_f c_d + 838.8 m_v c_r}$$

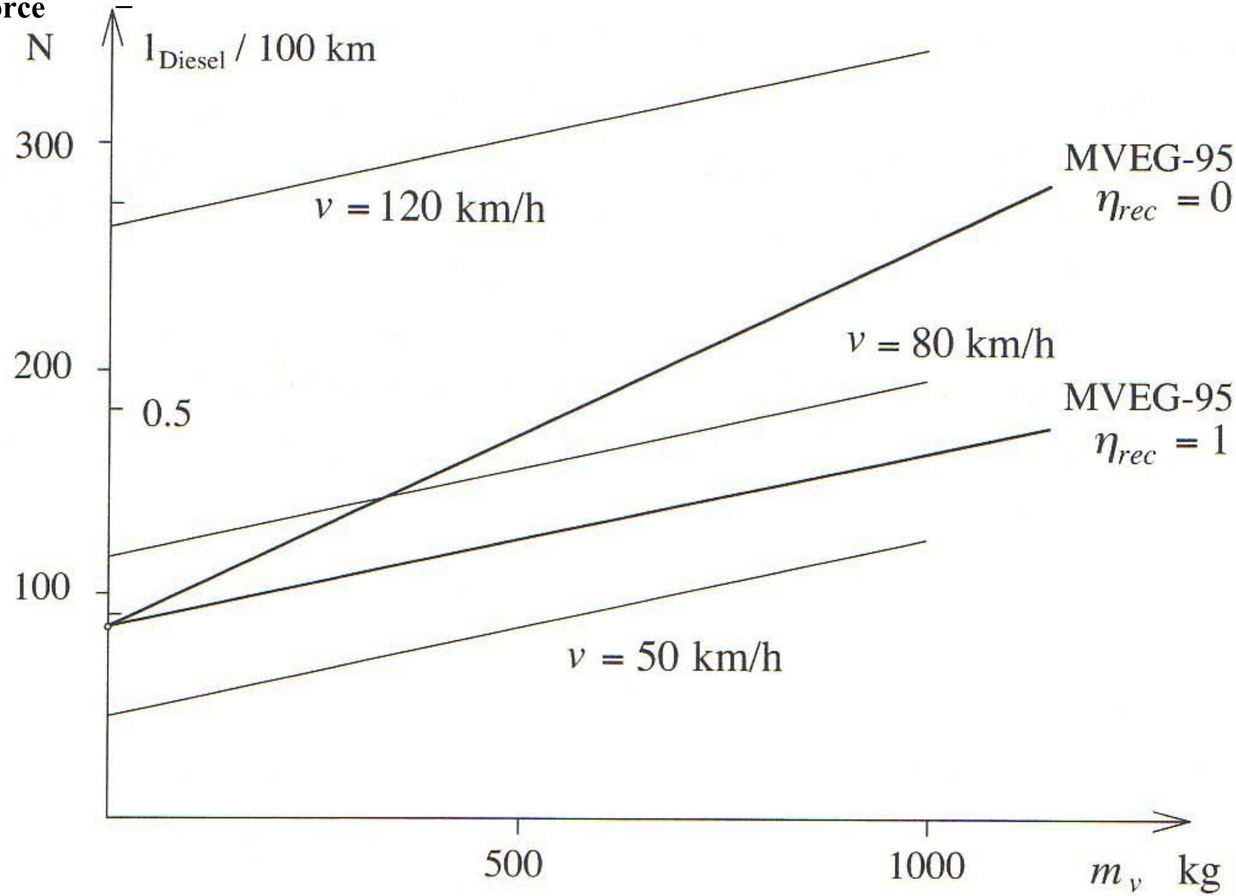
$$\frac{\partial \overline{E}}{\partial c_r} = 838.8 m_v, \qquad S_{c_r} = \frac{838.8 m_v c_r}{10.1 m_v + 15950 \rho_a A_f c_d + 838.8 m_v c_r}$$



Sensitivities (2.32) of the mechanical energy consumption in the MVEG–95 cycle with respect to the three main vehicle parameters. Two cases: full-size car (left); advanced light-weight vehicle (right).

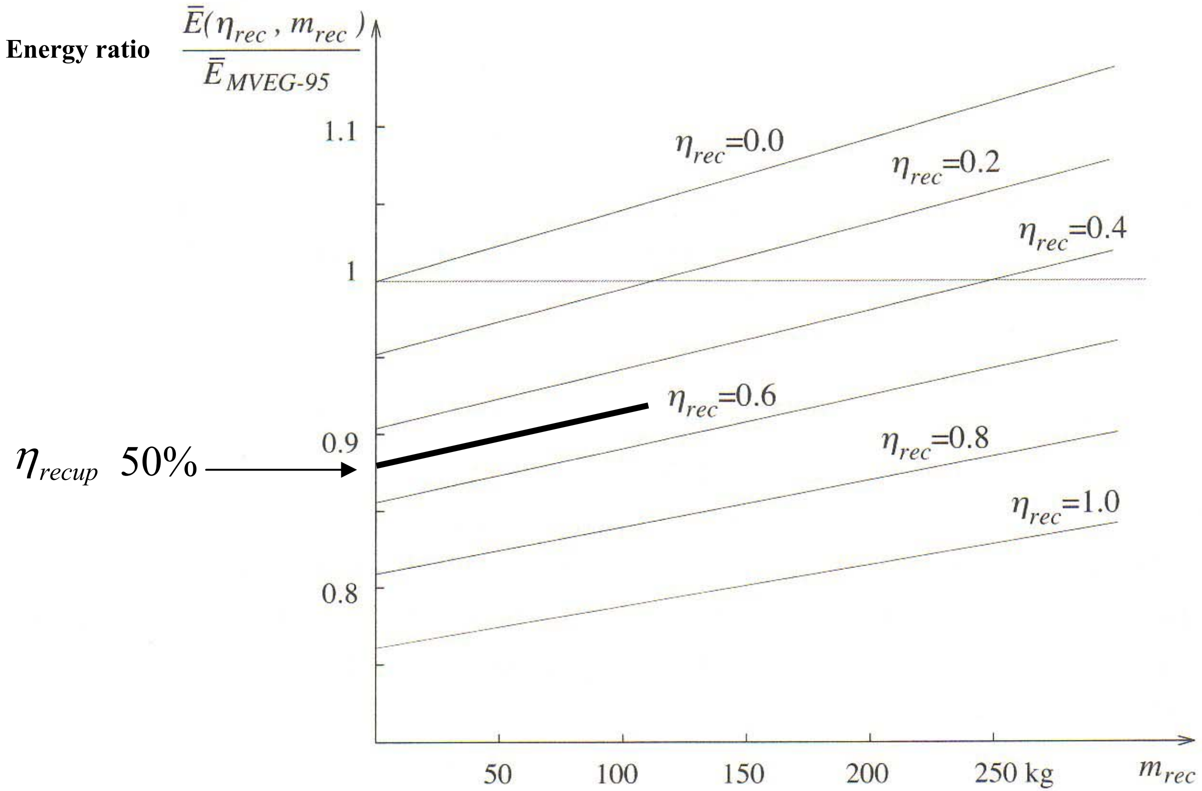
- S_{m_v} is the biggest, to reduce vehicle mass is most effective to save energy
- Advanced light vehicle cannot reduce the energy consumption effectively.

Mean traction force



the mean force on the vehicle mass for the MVEG–95 and three values of speed. The example is valid for an advanced vehicle with the parameters $\{A_f \cdot c_d, c_r\} = \{0.4\,\mathrm{m}^2, 0.008\}$.

- Realistic recuperation efficiency η_{recup} around 50%
- Recuperation device will increase the mass of vehicle (m_{rec}).



Energy demand in the MVEG–95 cycle of a vehicle equipped with a recuperation device with mass m_{rec} and efficiency η_{rec}, normalized by the energy $\bar{E}_{MVEG-95}$ consumed by a vehicle without recuperation device. The example is valid for a vehicle with the parameters $\{A_f \cdot c_d, c_r, m_v\} = \{0.7\,\text{m}^2, 0.012, 1500\,\text{kg}\}$.