

Sample calculation of societal life cycle costs of for a diesel vehicle

Definition of the functional unit:

This sheet calculates the Life Cycle Costs for a mid sized passenger "Toyota Camry like" car with the following characteristics:

1. Automatic Transmission

2. Lifetime of the vehicle LTV := 15yr

3. Kilometers traveled per year: KTY := 20000 $\frac{\text{km}}{\text{yr}}$

Vehicle kilometers traveled: VKT := LTV · KTY VKT = 300000 km

Value of Baht: valB := 40 $\frac{\text{Baht}}{\text{Dollar}}$ * all results are presented in USDollar

1. Calculation of the vehicle first costs (relative to the baseline gasoline vehicle):

In Thailand cars are deemed as luxury goods and therefore the excise tax for vehicles are relatively high.

Retail price of the baseline gasoline vehicle: retailprice_gasoline := 1300000 Baht

Excise tax for a gasoline vehicle (2001-2500cc): etax_gasoline := 0.35

Excise tax for a diesel vehicle (2001-2500cc): etax_diesel := 0.35

The Definition of the excise tax factor is: $\text{etax}(x) := \frac{x}{1 - 1.1 \cdot x}$ etax(etax_gasoline) = 0.569

Reference: The Customs Department

Value added tax in Thailand: VAT := 0.07

First costs of a gasoline car without tax:

$\text{fc_notax_gasoline} := \frac{\text{retailprice_gasoline}}{(1 + \text{VAT}) \cdot (1 + \text{etax}(\text{etax_gasoline}))}$ fc_notax_gasoline = 774297 Baht

The vehicle price of the baseline gasoline vehicle without tax is about one half of the price with tax. In reality the tax are much higher than the stated 35%. The reason for that is is the definition of the excise tax factor.

1.1 Calculation of the first costs of a diesel vehicle without tax:

Additional costs for a diesel vehicle (no tax): $\text{add_diesel} := 1750\text{Dollar}$ Source: [18]

Then the price of a diesel vehicle without tax is:

$$\text{fc_notax_diesel} := \text{fc_notax_gasoline} + \text{add_diesel} \cdot \text{valB} \quad \text{fc_notax_diesel} = 844297\text{Baht}$$

1.2 Calculation of the first costs of a diesel vehicle with tax:

The difference or relative first costs of a diesel vehicle with tax is:

$$\text{d_fc_tax_diesel} := \frac{\text{fc_notax_diesel} \cdot (1 + \text{VAT}) \cdot (1 + \text{etax}(\text{etax_diesel})) - \text{retailprice_gasoline}}{\text{valB}}$$

$$\text{d_fc_tax_diesel} = 2938\text{Dollar}$$

With tax a diesel vehicle is $\text{d_fc_tax_diesel} = 2938$ US\$ more expensive than a gasoline vehicle.

2. Calculation of the vehicle operation costs (relative to the baseline gasoline vehicle):**2.1 Calculation of relative operation costs (fuel costs) with tax**

First the fuel prices have to be calculated based on the same unit (Dollar/GJ)

$$\text{Gasoline higher heating value:} \quad \text{hvgasoline} := 35 \frac{\text{MJ}}{\text{liter}}$$

$$\text{Diesel higher heating value:} \quad \text{hvdiesel} := 38.11 \frac{\text{MJ}}{\text{liter}}$$

$$\text{Fuel price of gasoline (07.2005)} \quad \text{fp_gasoline} := 26.94 \frac{\text{Baht}}{\text{liter}} \cdot \frac{1}{\text{valB}} \cdot \frac{1}{\text{hvgasoline}}$$

$$\text{fp_gasoline} = 19.243 \frac{\text{Dollar}}{\text{GJ}}$$

$$\text{Fuel price of diesel (07.2005)} \quad \text{fp_diesel} := 24.19 \frac{\text{Baht}}{\text{liter}} \cdot \frac{1}{\text{valB}} \cdot \frac{1}{\text{hvdiesel}}$$

$$\text{fp_diesel} = 15.869 \frac{\text{Dollar}}{\text{GJ}}$$

Fuel economy - energy consumption

There are many ways to state the fuel economy or fuel consumption of a vehicle technology. In the US the fuel economy is expressed in miles per gallon in some European countries the fuel consumption is given in liters per 100km and other countries it is given in km per liters. The problem of these definitions is that the energy content in the volume depends on the fuel. For the comparison of different vehicle technologies is necessary to state the energy consumption of the different vehicle technologies. Since the SI unit of energy is Joule, the unit of the energy consumption will be MJ/km. For the convenience of the reader the energy consumption is also stated in the unit of miles per USgallon gasoline equivalent.

$$\text{Energy content of gallon gasoline equivalent: } \text{ggeq} := 35 \frac{\text{MJ}}{\text{liter}} \cdot \text{gal} \quad \text{ggeq} = 132.489 \text{ MJ}$$

Energy consumption of the baseline gasoline vehicle:

$$\text{eco_gasoline} := 2.386 \frac{\text{MJ}}{\text{km}} \quad \frac{1}{\text{eco_gasoline}} = 34.5 \frac{\text{mile}}{\text{ggeq}} \quad \text{Source [15]}$$

Energy consumption of a diesel vehicle:

$$\text{eco_diesel} := 1.844 \frac{\text{MJ}}{\text{km}} \quad \frac{1}{\text{eco_diesel}} = 44.64 \frac{\text{mile}}{\text{ggeq}} \quad \text{Source [15]}$$

Annual Operational Costs:

$$\begin{aligned} \text{lfc_gasoline} &:= \text{fp_gasoline} \cdot \text{eco_gasoline} \cdot \text{KTY} & \text{lfc_gasoline} &= 918 \frac{\text{Dollar}}{\text{yr}} \\ \text{lfc_diesel} &:= \text{fp_diesel} \cdot \text{eco_diesel} \cdot \text{KTY} & \text{lfc_diesel} &= 585 \frac{\text{Dollar}}{\text{yr}} \end{aligned}$$

Discounted Present Value (DPV): The present worth of costs occurring in future years using a real discount rate to incorporate the time value of money. DPV is calculated based on the following equation:

$$\text{DPV} = \text{Recurring Annual Costs} = A \left\{ \frac{1 - (1 + i)^{-n}}{i} \right\}$$

Where:

- A = Annual cost
- i = Real discount rate
- n = Number of years

Real discount rate $\text{dr_i} := 2 \cdot \%$

$$\text{DPV} := \frac{\frac{\text{LTV}}{\text{yr}}}{\text{dr_i} \cdot (1 + \text{dr_i})^{\text{yr}} - 1}$$

$$\text{lfc_gasoline_DPV} := \text{lfc_gasoline} \cdot \text{yr} \cdot \text{DPV} \quad \text{lfc_gasoline_DPV} = 11799$$

$$\text{lfc_diesel_DPV} := \text{lfc_diesel} \cdot \text{yr} \cdot \text{DPV} \quad \text{lfc_diesel_DPV} = 7520$$

Relative fuel costs of a diesel vehicle:

$$d_lfc_diesel := lfc_diesel_DPV - lfc_gasoline_DPV$$

$$d_lfc_diesel = -4279 \text{ Dollar}$$

With the consideration of tax the life cycle fuel costs for a diesel vehicle are significant lower the fuel cost for the baseline gasoline vehicle. The main reason for the low Diesel fuel costs is that in Thailand the tax for diesel fuel are lower compared to gasoline.

2.2 Calculation of relative operation costs (fuel costs) without tax

The fuel prices have to be calculated based on the same unit (Dollar/GJ)

$$\text{Fuel price of gasoline without tax: (07.2005)} \quad fp_notax_gasoline := \left(26.94 \cdot \frac{\text{Baht}}{\text{liter}} - 7.18 \cdot \frac{\text{Baht}}{\text{liter}} \right) \cdot \frac{1}{\text{valB}} \cdot \frac{1}{\text{hvgasoline}}$$

$$fp_notax_gasoline = 14.11 \frac{\text{Dollar}}{\text{GJ}}$$

$$\text{Fuel price of diesel without tax: (07.2005)} \quad fp_notax_diesel := \left(24.19 \cdot \frac{\text{Baht}}{\text{liter}} - 3.55 \cdot \frac{\text{Baht}}{\text{liter}} \right) \cdot \frac{1}{\text{valB}} \cdot \frac{1}{\text{hvdiesel}}$$

$$fp_notax_diesel = 13.54 \frac{\text{Dollar}}{\text{GJ}}$$

Annual Operational Costs without tax:

$$lfc_notax_gasoline := fp_notax_gasoline \cdot eco_gasoline \cdot KTY \quad lfc_notax_gasoline = 674 \frac{\text{Dollar}}{\text{yr}}$$

$$lfc_notax_diesel := fp_notax_diesel \cdot eco_diesel \cdot KTY \quad lfc_notax_diesel = 499 \frac{\text{Dollar}}{\text{yr}}$$

Life cycle fuel cost of a gasoline vehicle without tax:

$$lfc_notax_gasoline_DPV := lfc_notax_gasoline \cdot yr \cdot DPV$$

$$lfc_notax_gasoline_DPV = 8654 \text{ Dollar}$$

Life cycle fuel cost of a diesel vehicle without tax:

$$lfc_notax_diesel_DPV := lfc_notax_diesel \cdot yr \cdot DPV$$

$$lfc_notax_diesel_DPV = 6416 \text{ Dollar}$$

Relative fuel costs of a diesel vehicle:

$$d_lfc_notax_diesel := lfc_notax_diesel_DPV - lfc_notax_gasoline_DPV$$

$$d_lfc_notax_diesel = -2238 \text{ Dollar}$$

The result of the calculation of the life cycle fuel costs without tax shows, that the fuel costs of a diesel vehicle are lower than the fuel cost of the baseline gasoline vehicle. The reasons for the lower fuel cost is the higher efficiency of the Diesel vehicle.

3. Calculation of the air pollution damage costs (relative to the baseline gasoline vehicle)

As mentioned above it is assumed that the production of the diesel vehicle and the production of the diesel fuel do not cause significant higher pollution damage cost compare to the baseline gasoline vehicle. But the air pollution caused by tailpipe emissions from a diesel or gasoline vehicles are quite different. Therefore the tailpipe emissions have to be studied in detail.

Tailpipe emissions form the baseline vehicle:
Volatile Organic Compounds

| | | |
|-----------------------------------------|----------------------------------------------------------------------|----------------------------------------|
| $VOC_gasoline := 0.125 \frac{g}{mile}$ | Source [14]: including evaporative VOC (0.063 g/mile) | $VOC_gasoline = 0.078 \frac{g}{km}$ |
| $NOx_gasoline := 0.036 \frac{g}{mile}$ | Source [14]: | $NOx_gasoline = 0.022 \frac{g}{km}$ |
| $CO_gasoline := 0.667 \frac{g}{mile}$ | Source [14]: | $CO_gasoline = 0.414 \frac{g}{km}$ |
| $PM_gasoline := 0.031 \frac{g}{mile}$ | Source [14]: including particle from tires and brakes (0.021 g/mile) | $PM_gasoline = 0.019 \frac{g}{km}$ |
| $GHG_gasoline := 262 \frac{g}{mile}$ | Source [14]: including fuel production | $GHG_gasoline = 162.799 \frac{g}{km}$ |

Source:

[14] Wang, M.Q., GREET —transportation fuel-cycle model: Center for Transportation Research, Argonne National Laboratory

[12] Tom Beer et al., (May 2004), Life-Cycle Emissions Analysis of Fuels for Light Vehicles AUSTRALIAN GREENHOUSE OFFICE

Tailpipe emissions form the diesel vehicle:

| | | |
|---------------------------------------|--------------|------------------------------------|
| $VOC_diesel := 0.049 \frac{g}{mile}$ | Source [14]: | $VOC_diesel = 0.03 \frac{g}{km}$ |
| $NOx_diesel := 0.330 \frac{g}{mile}$ | Source [14]: | $NOx_diesel = 0.205 \frac{g}{km}$ |

ANNEX A 8

| | | |
|---------------------------------------|----------------------------------------------------------------------|---------------------------------------|
| $CO_{diesel} := 0.239 \frac{g}{mile}$ | Source [14]: | $CO_{diesel} = 0.149 \frac{g}{km}$ |
| $PM_{diesel} := 0.046 \frac{g}{mile}$ | Source [14]: including particle from tires and brakes (0.021 g/mile) | $PM_{diesel} = 0.029 \frac{g}{km}$ |
| $GHG_{diesel} := 229 \frac{g}{mile}$ | Source [14]: including fuel production | $GHG_{diesel} = 142.294 \frac{g}{km}$ |

Tailpipe emissions from a diesel vehicle (relative to the baseline gasoline vehicle)

| | |
|-----------------------------------------------------------|----------------------------|
| $d_{VOC_{diesel}} := \frac{VOC_{diesel}}{VOC_{gasoline}}$ | $d_{VOC_{diesel}} = 39\%$ |
| $d_{NOx_{diesel}} := \frac{NOx_{diesel}}{NOx_{gasoline}}$ | $d_{NOx_{diesel}} = 917\%$ |
| $d_{CO_{diesel}} := \frac{CO_{diesel}}{CO_{gasoline}}$ | $d_{CO_{diesel}} = 36\%$ |
| $d_{PM_{diesel}} := \frac{PM_{diesel}}{PM_{gasoline}}$ | $d_{PM_{diesel}} = 148\%$ |
| $d_{GHG_{diesel}} := \frac{GHG_{diesel}}{GHG_{gasoline}}$ | $d_{GHG_{diesel}} = 87\%$ |

Pollution Damage costs of each pollutant in USDollar/kg:

In this example the values for France converted for Thailand (benefit transfer method).

| |
|--------------------------------------|
| $costVOC := 0.56 \frac{Dollar}{kg}$ |
| $costNOx := 2.3 \frac{Dollar}{kg}$ |
| $costCO := 0 \frac{Dollar}{kg}$ |
| $costPM := 21 \frac{Dollar}{kg}$ |
| $costGHG := 0.008 \frac{Dollar}{kg}$ |

It should be noted that the valuation of the pollution is quite subjective. Therefore it will be necessary to compare different valuations in a life cycle cost assessment.

Calculation of the air pollution damage costs of a gasoline vehicle:

$$pdc_{gasoline} := \left[\begin{array}{l} (VOC_{gasoline} \cdot costVOC \dots) \dots \\ + NOx_{gasoline} \cdot costNOx \dots \\ + CO_{gasoline} \cdot costCO \dots \\ (+ PM_{gasoline} \cdot costPM \dots) \\ + GHG_{gasoline} \cdot costGHG \end{array} \right] \cdot KTY_{yr} \cdot DPV$$

$$pdc_{gasoline} = 463 \text{ Dollar}$$

Calculation of the air pollution damage costs of a diesel vehicle (relative to the baseline gasoline vehicle):

$$d_pdc_diesel := \left[\begin{array}{l} (VOC_diesel \cdot costVOC \dots) \dots \\ + NOx_diesel \cdot costNOx \dots \\ + CO_diesel \cdot costCO \dots \\ + PM_diesel \cdot costPM \\ + GHG_diesel \cdot costGHG \end{array} \right] \cdot (KTY\ yr \cdot DPV) - pdc_gasoline$$

$$d_pdc_diesel = 109\ \text{Dollar}$$

The pollution damage costs of a Diesel vehicle are higher than the costs of the baseline gasoline vehicle. In general the pollution cost difference is small compared to the fuel cost benefit of the Diesel vehicle.

4. Results of the calculation

4.1 Societal Life Cycle Costs

(Sum of all costs without tax relative to the baseline gasoline vehicle)

Additional vehicle first costs without tax: $add_diesel = 1750\ \text{Dollar}$

Additional operation costs without tax: $d_lfc_notax_diesel = -2238\ \text{Dollar}$

Additional pollution damage costs: $d_pdc_diesel = 109\ \text{Dollar}$

Sum of all relative costs:

$$sum_all_notax_diesel := add_diesel + d_lfc_notax_diesel + d_pdc_diesel$$

$$sum_all_notax_diesel = -379\ \text{Dollar}$$

As a result of this calculation the societal life cycle costs of a diesel vehicle are lower compared to the baseline gasoline vehicle. The pollution costs of a Diesel vehicle are higher but the lower fuel costs compensate the environmental damage and higher first costs.

4.2 Consumer Life Cycle Costs

Sum of all costs without external costs with tax (relative to the baseline vehicle):

Additional vehicle first costs with tax: $d_fc_tax_diesel = 2938\ \text{Dollar}$

Additional operation costs with tax: $d_lfc_diesel = -4279\ \text{Dollar}$

$$sum_noex_diesel := d_fc_tax_diesel + d_lfc_diesel$$

$$sum_noex_diesel = -1341\ \text{Dollar}$$

The result of the consumer life cycle costs is negative, which means that for the consumer a diesel vehicle has lower costs than a gasoline vehicle. This is because of the low Diesel fuel prices. In Thailand the tax for Diesel fuel are lower than the tax for gasoline.

4.3. Tax

Sum of all tax (relative to the baseline vehicle):

$$d_tax_diesel := d_fc_tax_diesel - add_diesel + d_lfc_diesel - d_lfc_notax_diesel$$

$$d_tax_diesel = -853 \text{ Dollar}$$

The government tax income of a Diesel vehicle is lower compared to the baseline gasoline vehicle. In other words the Diesel vehicle is subsidized.

5. Analysis of the results

Under these assumptions the Diesel vehicle would be the preferable option because the societal life cycle costs are lower compared to the baseline gasoline vehicle. For the consumer the life cycle costs of a Diesel vehicle are lower as well. Even without subsidy the consumer would prefer the Diesel vehicle option. Despite unnecessary subsidy for the Diesel vehicle, in this case it would not be required to change the tax structure because market forces support the option with the lowest societal life cycle costs.