Compilation of emission factors for biofuels into a GAINS script

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Problem background

- The current version of the GAINS model does not include impact on air pollutants from different levels of biofuel use in the transport sector
- New studies shows that the use of biofuel has an impact on emissions of air pollutants
- If the GAINS model were able to describe emission of air pollutants as a function of biofuel use, co-benefits between air pollution and greenhouse gases might be better reflected in the model

Problem definition

Biofuels in GAINS, transport sector: only CO2 emissions are affected by varying biofuel shares. This is implemented by modifying (decreasing proportionally) activity data on fuel consumption:

GAINS, Emissions, CO2, detailed results: Gasoline, gas, and diesel fuel consumed in the transport sector includes only fossil (Mineral) fuel share (GSL_M, GAS_M, MD_M).

Task: to link energy share of E100 (hereinafter X) in a car fleet using E5 and E85 to available NOx emission factors for E5 and E85, get a new equation for NOx emissions and introduce it into the model script.

Background information

IVL report B1962
http://www3.ivl.se/rapporter/pdf/B1962.pdf

Emission factors* for ethanol fuelled and gasoline fuelled passenger cars (year 2020, in g/km, weighted emission factors considering implemented Euro standards)

*Emission factors for NOx are taken from:

Graham L.A., Belisle S.L, Baas C.-L., Emissions from light duty gasoline vehicles operating on low blend ethanol gasoline and E85. Atmospheric Environment 42, 4498 (2008).

"The reason is that the study comprises a compilation of a relatively large number of tests"

Assumptions, simplifications, boundary conditions: specific case

- GSL for passenger cars = E5 + E85

Both E5 and E85 are mixtures of pure gasoline (E0) and pure ethanol (E100)

- 85% (by volume) of E100 in E85
- Part of the script to modify:
  TRA_RD_LD4C (passenger cars) + GSL + NOx
- EF(E85) / EF(E5) (in g/km or t/PJ) = 0,5804 for NOx, for each Euro class
- Same energy efficiency (PJ/km) for E5 and E85 as for E0 (← same activity data, mileage, number of vehicles)

Assumptions, simplifications, boundary conditions: general case

Applicability for other fuels, sub-sectors, pollutants:

- Fuel = low blended fuel (LF) + high blended fuel (HF)

Both LF and HF are mixtures of pure fossil fuel (F0) and pure biofuel (F100)

- Part of the script to modify:
  specific transport sub-sector + specific fuel + specific pollutant
- Ratio EF(HF) / EF(LF) is a known constant for each Euro class
- Same energy efficiency (PJ/km) for HF and LF as for F0 (← same activity data, mileage, number of vehicles)

Getting emission calculation equation

Step 1: From energy share of pure biofuel to volume share of pure biofuel

General case

$$v\%(HF) = \frac{CV(LF) * en\%(HF)}{CV(LF) + (CV(LF) - CV(HF)) * en\%(HF)}$$

en% - energy share

v% - volume share

CV – calorific value

Specific case

$$v\%(E100) = \frac{32{,}76 * X}{21{,}24 + 11{,}52 * X}$$

X – energy share of E100 (GAINS input data)

Getting emission calculation equation

Step 2: From volume share of pure biofuel to volume share of high blended fuel

General case

$$v\%(HF) = \frac{v\%(F100) - w(LF)}{(w(HF) - w(LF))}$$

w- volume % of pure biofuel F100 in a low-blended or high-blended fuel

Specific case

$$v\%(E85) = \frac{v\%(E100) - 0{,}05}{0{,}8}$$

Getting emission calculation equation

Step 3: From volume share of high blended fuel to energy share of high blended fuel

General case

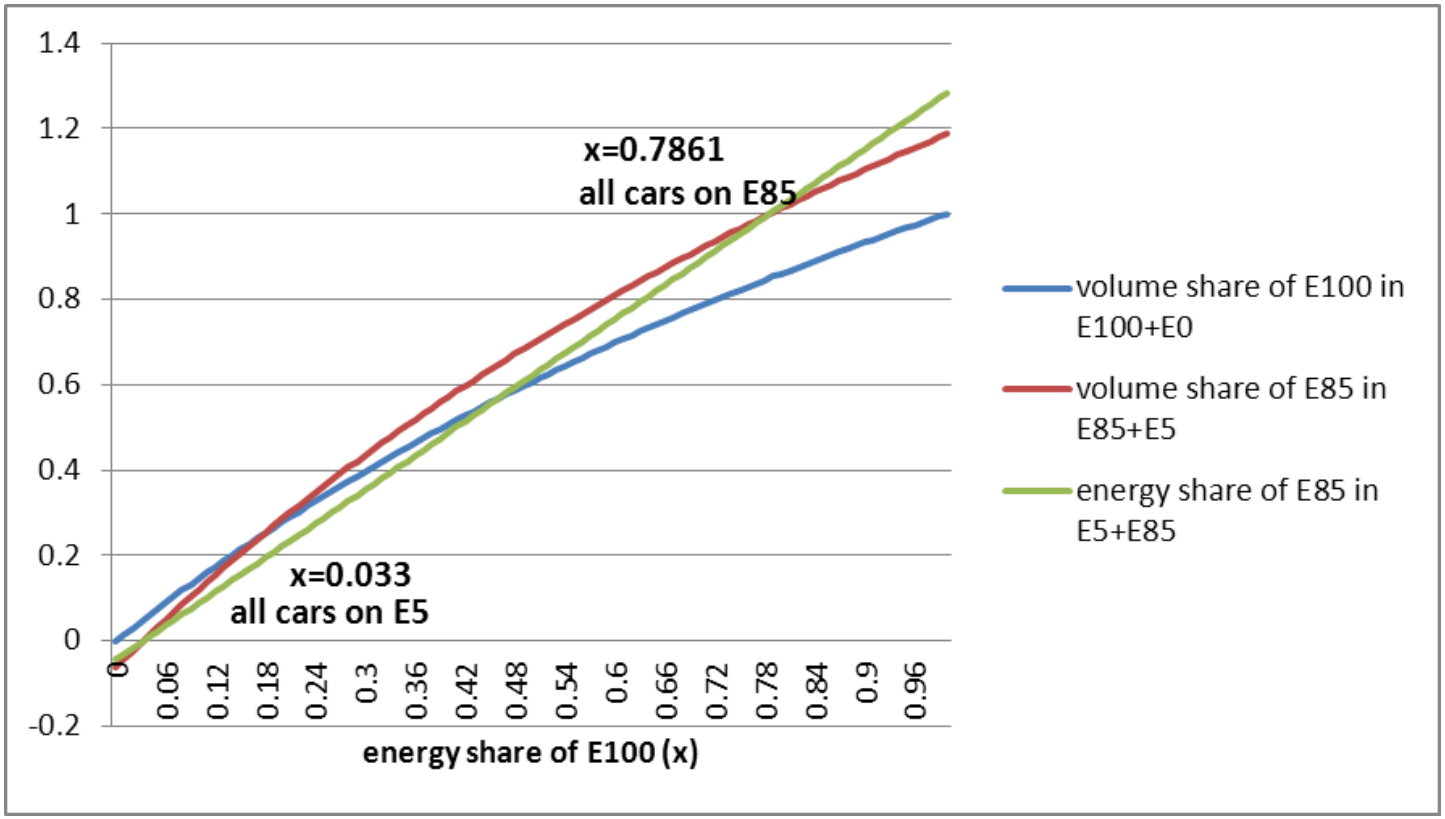
$$en\%(HF) = \frac{CV(HF) * v\%(HF)}{CV(HF) + (CV(HF) - CV(LF)) * v\%(HF)}$$

Specific case

$$en\%(E85) = \frac{32{,}18 * v\%(E85)}{32{,}18 + 9{,}21 * v\%(E85)}$$

Visualisation of steps 1-3

Volume share of E100, volume share of E85 and energy share of E85 depending on energy share of E100 (X)



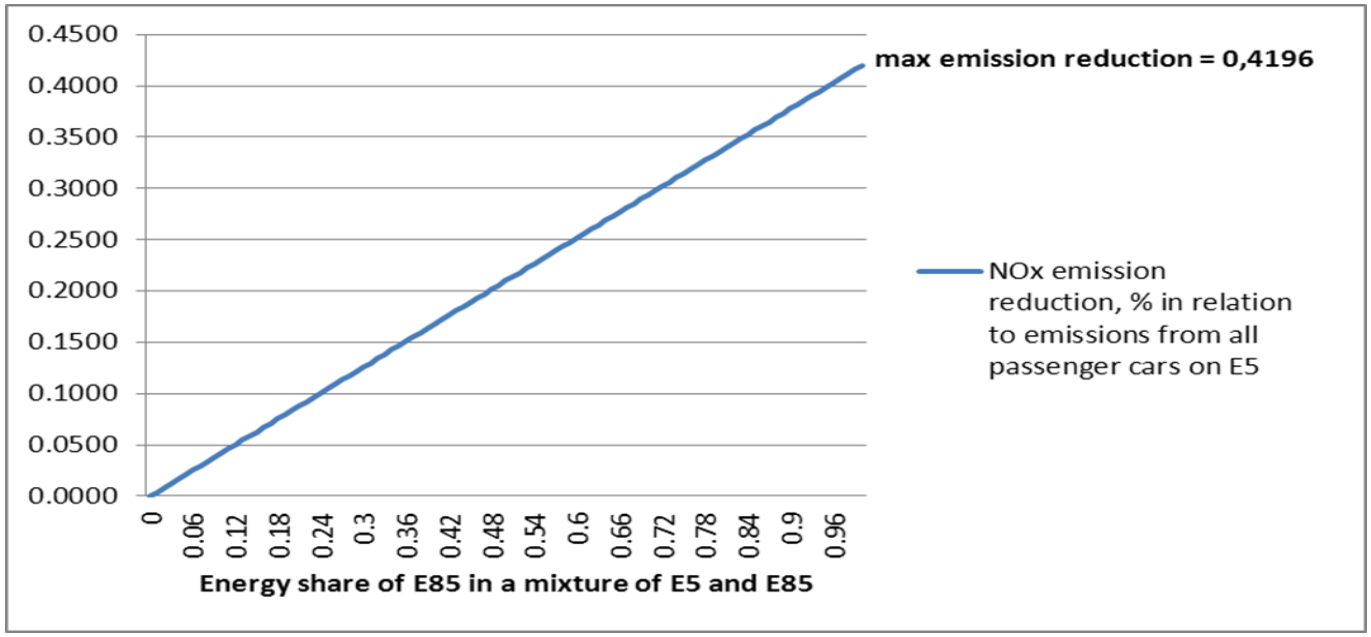
Getting emission calculation equation

Step 4: Emission reduction (in % to the "all LF" case) as a function of energy share of high blended fuel

General case

$$\%\_of\_emission\_reduction) = (1 - \frac{EF(HF)}{EF(LF)}) * en\%(HF)$$

Specific case



$$\%\_of\_emission\_reduction = 0{,}4196 * en\%(E85)$$

Getting emission calculation equation

Step 5: Emissions as emissions from "all low blended fuel" case multiplied by (1 - emission reduction)

General case

$$Em = A * EF(LF) * (1 - \%\_of\_emission\_reduction)$$

Specific case

$$Em = A * EF(E5) * (1 - \%\_of\_emission\_reduction)$$

Em – emissions

A – activity data

Final emission calculation equation

General case

$$Em = A * EF(LF) * (1 - (a * X + b) * (1 - \frac{EF(HF)}{EF(LF)}))$$

$$a = \frac{CV(F0)^2 - CV(F0) * (CV(F0) - CV(F100)) * (w(HF) + w(LF)) + (CV(F0) - CV(F100))^2 * w(HF) * w(LF)}{(w(HF) - w(LF)) * CV(F0) * CV(F100)}$$

$$b = \frac{w(LF) * (CV(F0) - w(HF) * (CV(F0) - CV(F100))}{(w(HF) - w(LF)) * CV(F0)}$$

Specific case

$$Em = A * EF(E5) * (1 - (1{,}3279 * X + 0{,}0438) * 0{,}4196)$$

fuel-specific

pollutant-specific

Euro standards for cars on biofuels

$$Em = \sum_i A * EF(E5)_{NOC} * (1 - (1{,}3279 * X + 0{,}0438) * (1 - \frac{EF(E85)_{Euroi}}{EF(E5)_{Euroi}})) * (1 - RE_{Euroi}) .* impl.rate_{Euroi}$$

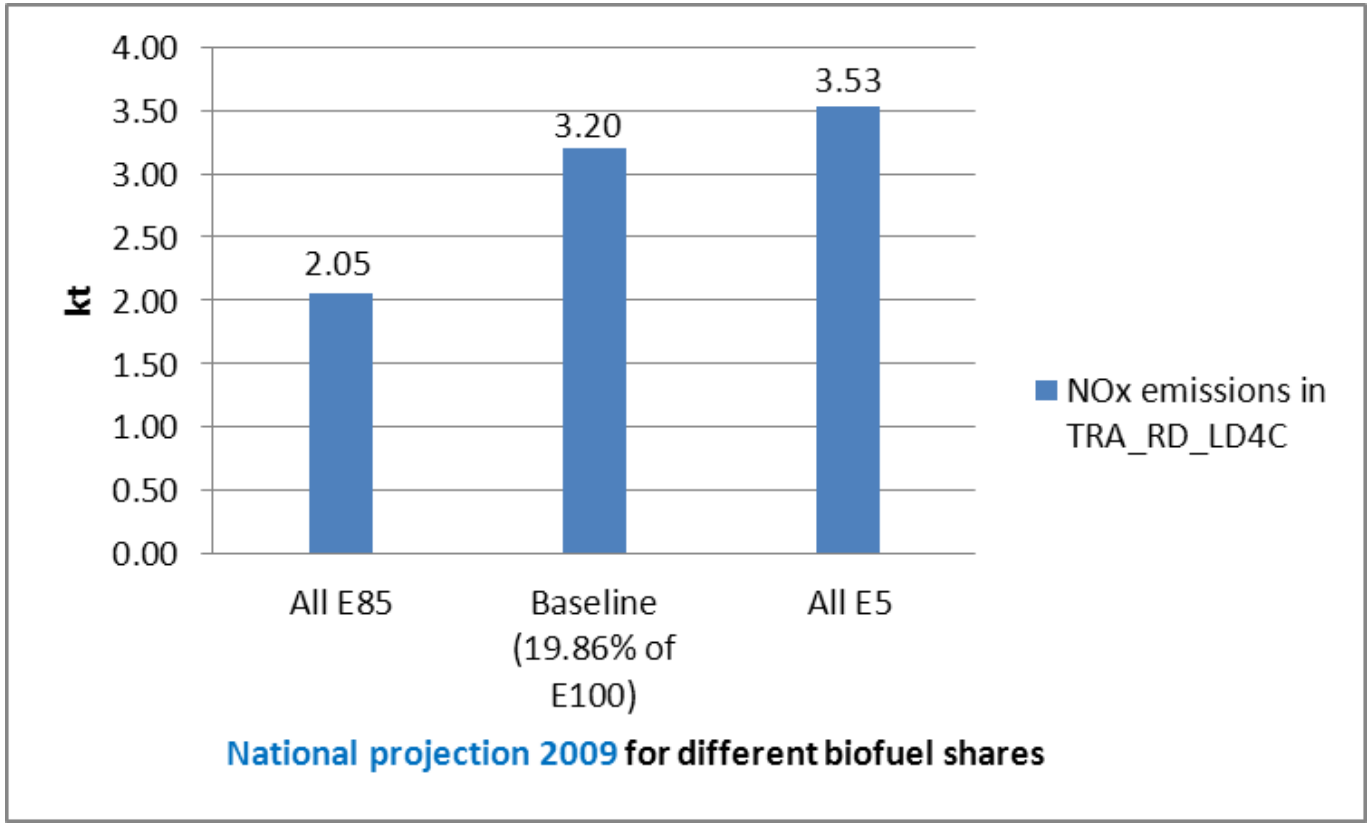
Best available knowledge: same removal efficiency (in %) for Euro standards applied for gasoline and ethanol fuelled cars. In this case no additional script changes needed.

In case of different removal efficiencies the equation above can be used, in case of known ratios of emission factors for each Euro class.

Potential problem: implementation rates for Euro on E85-cars are not the same as for E5-cars.

Emission calculation results

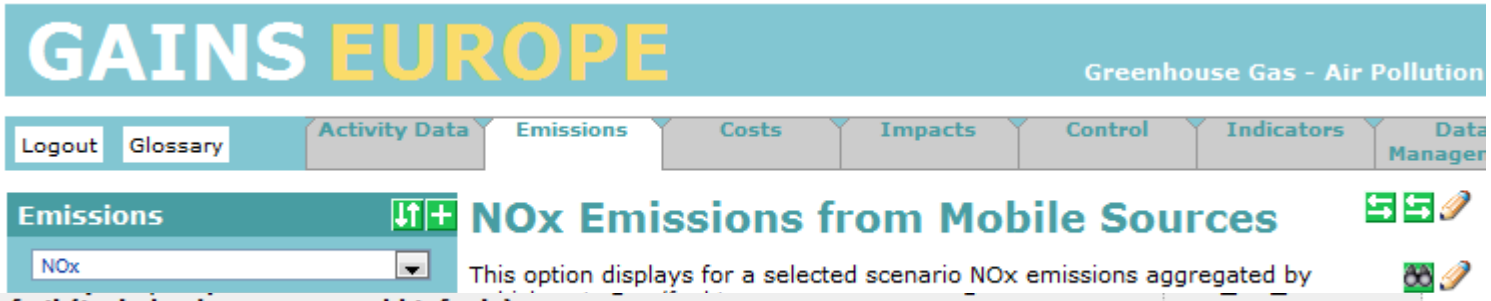
Total NOx emissions from TRA_RD_LD4C in 2020 (Sweden) for all E5, all E85 and baseline scenario Nat. projection 2009



National projection 2009 for different biofuel shares

NOx emissions without considering biofuels

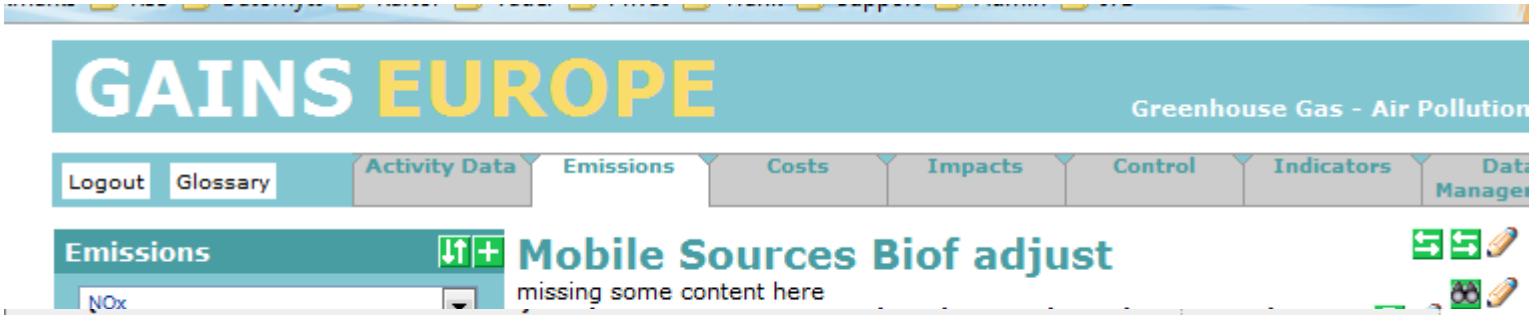
TRA_RD_LD4C in 2020 (Sweden) for all E5, all E85 and baseline scenario Nat. projection 2009



of oil (includes kerosoene and biofuels)						
Light duty vehicles: cars and small buses with 4-stroke engines -Natural gas (incl. other gases)	TRA_RD_LD4C-GAS	...	0.041	...	...	0.079
Light duty vehicles: cars and small buses with 4-stroke engines -Gasoline and other light fractions of oil (includes kerosoene and biofuels)	TRA_RD_LD4C-GSL	39.399	22.023	12.206	7.153	3.531
Light duty vehicles: cars and small buses with 4-stroke engines -Hydrogen	TRA_RD_LD4C-H2	...	0.000	...	...	...
Light duty vehicles: cars and small buses with 4-stroke engines -Liquefied petroleum gas	TRA_RD_LD4C-LPG	0.001	...	0.000	0.000	...
Light duty vehicles: cars and small buses with 4-stroke engines -Medium distillates (diesel, light fuel oil; includes biofuels)	TRA_RD_LD4C-MD	2.466	4.052	5.039	4.404	4.860
Light duty vehicles: light commercial trucks with 4-stroke engines-Gasoline and other light fractions of oil (includes kerosoene and biofuels)	TRA_RD_LD4T-GSL	5.248	0.978	0.971	0.438	0.066
Light duty vehicles: light commercial trucks with 4-stroke engines-Medium distillates (diesel, light fuel oil; includes biofuels)	TRA_RD_LD4T-MD	8.985	5.157	6.283	4.677	2.948
Motorcycles with 4-stroke engines-Gasoline and other light fractions of oil (includes kerosoene and biofuels)	TRA_RD_M4-GSL	0.069	0.134	0.069	0.061	0.086
Sum	Sum	184.046	126.144	125.190	88.629	51.416

NOx emissions considering biofuels

TRA_RD_LD4C in 2020 (Sweden) for all E5, all E85 and baseline scenario Nat. projection 2009



Light duty vehicles: cars and small buses with 4-stroke engines -Natural gas (incl. other gases)	TRA_RD_LD4C-GAS	...	0.041	...	...	0.079
Light duty vehicles: cars and small buses with 4-stroke engines -Gasoline and other light fractions of oil (includes kerosoene and biofuels)	TRA_RD_LD4C-GSL	40.120	21.994	11.820	6.782	3.205
Light duty vehicles: cars and small buses with 4-stroke engines -Hydrogen	TRA_RD_LD4C-H2	...	0.000	...	...	...
Light duty vehicles: cars and small buses with 4-stroke engines -Liquefied petroleum gas	TRA_RD_LD4C-LPG	0.001	...	0.000	0.000	...
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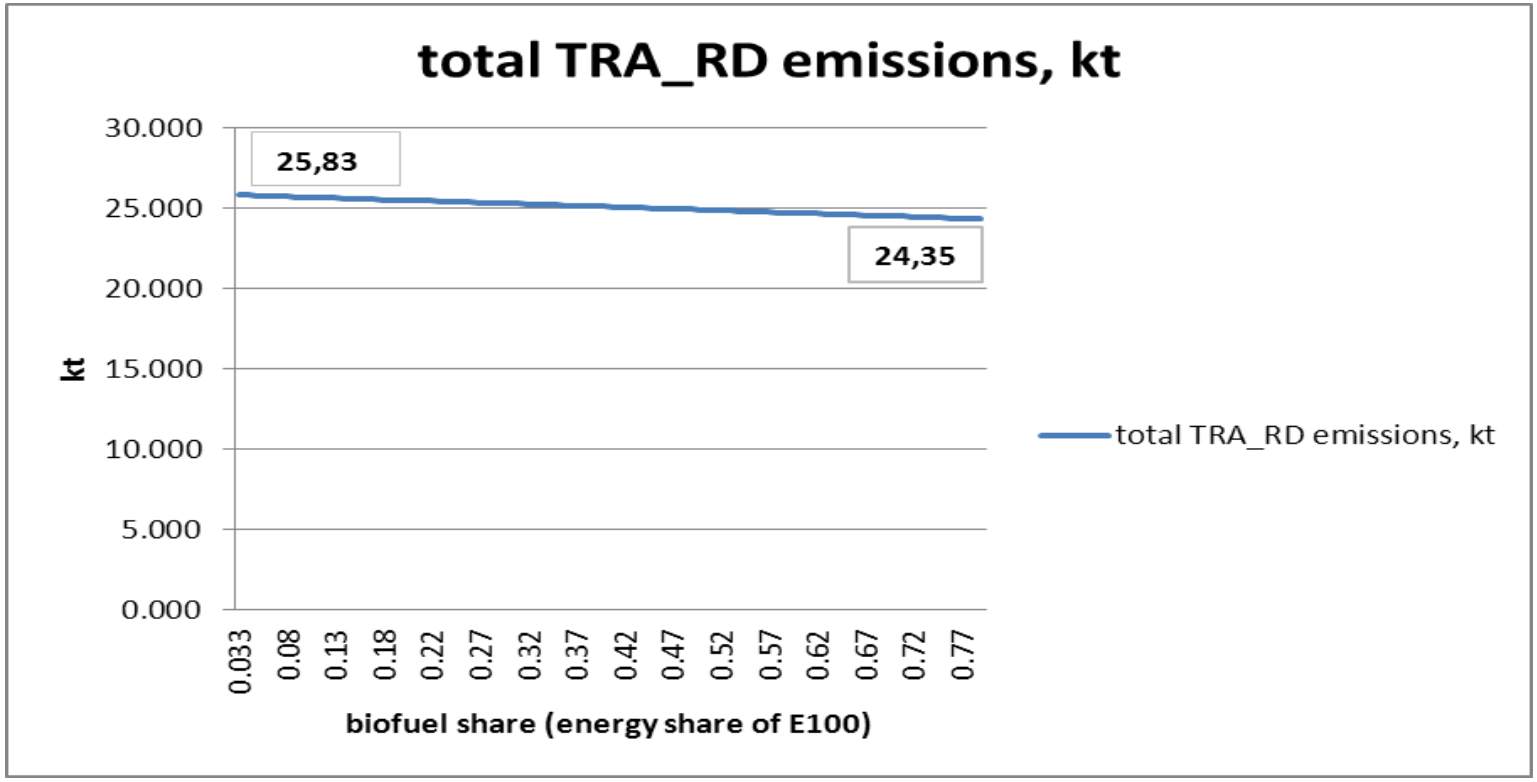
Motorcycles with 4-stroke engines-Gasoline and other light fractions of oil (includes kerosoene and biofuels)	TRA_RD_M4-GSL	0.069	0.134	0.069	0.061	0.086
Sum	Sum	184.768	126.115	124.804	88.258	51.090

Emission calculation results

Total NOx emissions from TRA_RD_LD4C in 2020 (Sweden) depending on biofuel shares (ethanol in passenger cars)

Scenario: Nat. projection 2009



Advantages of the suggested approach

- The approach can potentially be used for different pollutants (e.g. PM, VOC), fuel blends and transport sectors. Re-calculation of equation parameters can be easily performed in Excel.
- New equation is easy to introduce into a model script
- The approach enables further exploration of co-benefits between climate and air pollution measures in GAINS

Existing problems and further work

- More detailed research on the background data on emission factors from biofuels is needed.
- Including other pollutants. For VOC it should be found a way to include evaporative emissions. VOC emissions might be reduced, but will probably be more toxic.
- Biofuel shares in GAINS refer to the whole transport sector (fuels GSL, GAS, MD). In our calculations only biofuel shares in TRA_RD_4C (passenger cars) were varied, which would mean that in other transport sub-sectors shares would change proportionally. Possibilities to separate varying biofuel shares for different sub-sectors need further investigation.
- Increased use of diesel in transport projections reduces the impact from ethanol use on emissions

Conclusions

- An approach for compilation of emission factors for biofuels into GAINS script is suggested;
- A calculation equation is derived, where emissions are a linear function of energy share of pure biofuel;
- Quantified parameters in the equation for NOx emissions are based on the relation of emission factors from gasoline-fuelled and ethanol-fuelled passenger cars, reported by IVL experts;
- The approach is potentially applicable for other pollutants in different transport sectors;
- The emission equation is introduced into the script by modification of the emission factor for gasoline;
- Calculations performed for *National projection 2009* scenario (2020) show the difference by 1.48 kt NOx when comparing *all E5* to *all E85* options. This corresponds to approximately 6% of NOx emissions from road traffic, or 1.3% of national total NOx emissions in Sweden (113 kt).

We would appreciate feedback from you!

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