

## Phase 2 fuel efficiency rules for box vans: Comparison of compliance equation with GEM model

### Purpose

The purpose of the following is to compare the box van compliance equation specified in the Phase 2 Fuel Efficiency rule with the predictions of the GEM Greenhouse Gas Efficiency model. The range of agreement is analyzed, and a modified equation is provided which fits the GEM model more closely than the compliance equation over the full range of valid input variables.

### Background

Fuel efficiency standards for heavy duty vehicles have been in place for engine and tractor manufacturers since 2012. Starting with the 2017 model year, standards were extended to trailers as well. Trailer manufacturers must now certify that all vehicles sold commercially in the United States meet the standards.

Engine and tractor manufacturers use a computer model provided by EPA, the [Greenhouse Gas Emissions Model](#) (GEM), to demonstrate that their vehicles are equipped to meet the standards. To ease the regulatory burden on trailer manufacturers, the Phase 2 rule specifies a simplified equation, referred to in the rule as the “compliance equation”, that approximates the GEM model for a range of standard box vans. Manufacturers of box vans can use the compliance equation instead of running the full GEM model to calculate expected emissions.

To use the compliance equation, a manufacturer must determine three input variables for each trailer being evaluated: a drag coefficient, a measure of rolling resistance (largely determined by the tires supplied with the trailer), and the difference between the weight of the trailer and a specified baseline weight. Each of those numbers is multiplied by a constant numerical coefficient specified in the regulation, and the results are added to another specified constant. The total of those quantities is the estimated emission rate due to the trailer. In order for the trailer to be certified, the emission rate must be below the threshold specified for the current model year.

One potential problem with the compliance equation as specified in the rule is that it treats the input variables as if their effects on the emission rate were independent of each other. While drag is nearly independent of rolling resistance and weight, the last two inputs do not act independently. As weight increases, so does rolling resistance. Instead of constant coefficients, the coefficient multiplying the tire rolling resistance measure should vary somewhat as the weight of the trailer changes, and the coefficient multiplying the weight reduction should depend somewhat on the tires. In the compliance equation, both coefficients are assumed to be constant. This limits the ability of the compliance equation to approximate a model like GEM.

### Comparison

The GEM model (version 3.0, downloaded 8/25/17) was run for a range of trailer input variables spanning the allowable values from 3.0 to 20.0 kg/ton rolling resistance, and 0 to 10,000 lb weight reduction, for a 53 foot, non-refrigerated box van. The drag term was fixed at the baseline value (delta = 0). The results, indicating the calculated emission in gm CO<sub>2</sub> equivalent per ton-mile for each combination of rolling resistance and weight reduction, are collected in table 1.

Table 2 shows the calculated emission over the same range of variables as determined from the compliance equation, using the constant coefficients specified in the rule. Table 3 shows the difference between the GEM calculation in Table 1 and the compliance equation result in Table 2 for each combination of variables.

GEM	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0	81.1	82.7	84.4	86.1	87.7	89.4	91.1	92.8	94.4	96.1	97.8	99.5	101.2	102.9	104.6	106.3	108.0	109.7
500	80.6	82.2	83.9	85.5	87.2	88.9	90.5	92.2	93.8	95.5	97.2	98.9	100.5	102.2	103.9	105.6	107.3	109.0
1000	80.1	81.7	83.4	85.0	86.7	88.3	89.9	91.6	93.2	94.9	96.6	98.2	99.9	101.5	103.2	104.9	106.6	108.3
1500	79.6	81.2	82.9	84.5	86.1	87.7	89.4	91.0	92.6	94.3	95.9	97.6	99.2	100.9	102.6	104.2	105.9	107.6
2000	79.1	80.7	82.4	84.0	85.6	87.2	88.8	90.4	92.1	93.7	95.3	96.9	98.6	100.2	101.9	103.6	105.2	106.9
2500	78.7	80.3	81.9	83.4	85.0	86.7	88.3	89.9	91.5	93.1	94.7	96.3	97.9	99.6	101.2	102.9	104.5	106.2
3000	78.2	79.8	81.4	82.9	84.5	86.1	87.7	89.3	90.9	92.5	94.1	95.7	97.3	98.9	100.6	102.2	103.8	105.5
3500	77.7	79.3	80.9	82.4	84.0	85.6	87.2	88.7	90.3	91.9	93.5	95.1	96.7	98.3	99.9	101.5	103.1	104.8
4000	77.3	78.8	80.4	81.9	83.5	85.0	86.6	88.2	89.8	91.3	92.9	94.5	96.1	97.7	99.3	100.8	102.5	104.1
4500	76.8	78.4	79.9	81.4	83.0	84.5	86.1	87.6	89.2	90.7	92.3	93.9	95.4	97.0	98.6	100.2	101.8	103.4
5000	76.4	77.9	79.4	80.9	82.5	84.0	85.5	87.1	88.6	90.2	91.7	93.3	94.8	96.4	98.0	99.5	101.1	102.7
5500	75.9	77.4	78.9	80.5	82.0	83.5	85.0	86.5	88.1	89.6	91.1	92.7	94.2	95.8	97.3	98.9	100.4	102.0
6000	75.5	77.0	78.5	80.0	81.5	83.0	84.5	86.0	87.5	89.0	90.6	92.1	93.6	95.2	96.7	98.2	99.8	101.4
6500	75.0	76.5	78.0	79.5	81.0	82.5	84.0	85.5	87.0	88.5	90.0	91.5	93.0	94.6	96.1	97.6	99.1	100.7
7000	74.6	76.1	77.5	79.0	80.5	82.0	83.4	84.9	86.4	87.9	89.4	90.9	92.4	93.9	95.5	97.0	98.5	100.0
7500	74.2	75.6	77.1	78.5	80.0	81.5	82.9	84.4	85.9	87.4	88.8	90.3	91.8	93.3	94.9	96.4	97.9	99.4
8000	73.7	75.2	76.6	78.1	79.5	81.0	82.4	83.9	85.4	86.8	88.3	89.8	91.3	92.8	94.2	95.7	97.2	98.7
8500	73.3	74.7	76.2	77.6	79.0	80.5	81.9	83.4	84.8	86.3	87.7	89.2	90.7	92.2	93.6	95.1	96.6	98.1
9000	72.9	74.3	75.7	77.1	78.6	80.0	81.4	82.9	84.3	85.7	87.2	88.7	90.1	91.6	93.0	94.5	96.0	97.4
9500	72.5	73.9	75.3	76.7	78.1	79.5	80.9	82.4	83.8	85.2	86.6	88.1	89.5	91.0	92.4	93.9	95.3	96.8
10000	72.0	73.4	74.8	76.2	77.6	79.0	80.4	81.8	83.3	84.7	86.1	87.5	89.0	90.4	91.9	93.3	94.7	96.2

Table 1. GEM model for rolling resistance 3 – 20 kg/ton, weight reduction 0 – 10,000 lb

compl	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0	81.1	82.8	84.5	86.1	87.8	89.5	91.1	92.8	94.5	96.1	97.8	99.5	101.2	102.8	104.5	106.2	107.8	109.5
500	80.6	82.3	83.9	85.6	87.3	88.9	90.6	92.3	94.0	95.6	97.3	99.0	100.6	102.3	104.0	105.6	107.3	109.0
1000	80.1	81.8	83.4	85.1	86.8	88.4	90.1	91.8	93.4	95.1	96.8	98.5	100.1	101.8	103.5	105.1	106.8	108.5
1500	79.6	81.2	82.9	84.6	86.2	87.9	89.6	91.3	92.9	94.6	96.3	97.9	99.6	101.3	102.9	104.6	106.3	108.0
2000	79.1	80.7	82.4	84.1	85.7	87.4	89.1	90.7	92.4	94.1	95.8	97.4	99.1	100.8	102.4	104.1	105.8	107.4
2500	78.5	80.2	81.9	83.5	85.2	86.9	88.6	90.2	91.9	93.6	95.2	96.9	98.6	100.2	101.9	103.6	105.3	106.9
3000	78.0	79.7	81.4	83.0	84.7	86.4	88.0	89.7	91.4	93.1	94.7	96.4	98.1	99.7	101.4	103.1	104.7	106.4
3500	77.5	79.2	80.8	82.5	84.2	85.9	87.5	89.2	90.9	92.5	94.2	95.9	97.5	99.2	100.9	102.6	104.2	105.9
4000	77.0	78.7	80.3	82.0	83.7	85.3	87.0	88.7	90.4	92.0	93.7	95.4	97.0	98.7	100.4	102.0	103.7	105.4
4500	76.5	78.1	79.8	81.5	83.2	84.8	86.5	88.2	89.8	91.5	93.2	94.8	96.5	98.2	99.9	101.5	103.2	104.9
5000	76.0	77.6	79.3	81.0	82.6	84.3	86.0	87.7	89.3	91.0	92.7	94.3	96.0	97.7	99.3	101.0	102.7	104.4
5500	75.4	77.1	78.8	80.5	82.1	83.8	85.5	87.1	88.8	90.5	92.1	93.8	95.5	97.2	98.8	100.5	102.2	103.8
6000	74.9	76.6	78.3	79.9	81.6	83.3	85.0	86.6	88.3	90.0	91.6	93.3	95.0	96.6	98.3	100.0	101.7	103.3
6500	74.4	76.1	77.8	79.4	81.1	82.8	84.4	86.1	87.8	89.4	91.1	92.8	94.5	96.1	97.8	99.5	101.1	102.8
7000	73.9	75.6	77.2	78.9	80.6	82.3	83.9	85.6	87.3	88.9	90.6	92.3	93.9	95.6	97.3	99.0	100.6	102.3
7500	73.4	75.1	76.7	78.4	80.1	81.7	83.4	85.1	86.7	88.4	90.1	91.8	93.4	95.1	96.8	98.4	100.1	101.8
8000	72.9	74.5	76.2	77.9	79.6	81.2	82.9	84.6	86.2	87.9	89.6	91.2	92.9	94.6	96.3	97.9	99.6	101.3
8500	72.4	74.0	75.7	77.4	79.0	80.7	82.4	84.0	85.7	87.4	89.1	90.7	92.4	94.1	95.7	97.4	99.1	100.7
9000	71.8	73.5	75.2	76.9	78.5	80.2	81.9	83.5	85.2	86.9	88.5	90.2	91.9	93.6	95.2	96.9	98.6	100.2
9500	71.3	73.0	74.7	76.3	78.0	79.7	81.3	83.0	84.7	86.4	88.0	89.7	91.4	93.0	94.7	96.4	98.0	99.7
10000	70.8	72.5	74.2	75.8	77.5	79.2	80.8	82.5	84.2	85.8	87.5	89.2	90.9	92.5	94.2	95.9	97.5	99.2

Table 2. Compliance equation for rolling resistance 3 – 20 kg/ton, weight reduction 0 – 10,000 lb

diff	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0	0.03	0.04	0.05	0.05	0.05	0.05	0.04	0.03	0.02	0.01	0.00	-0.03	-0.05	-0.06	-0.13	-0.15	-0.20	-0.24
500	0.01	0.03	0.05	0.07	0.08	0.09	0.10	0.11	0.11	0.11	0.11	0.11	0.10	0.10	0.05	0.02	-0.01	-0.02
1000	-0.02	0.01	0.05	0.07	0.11	0.14	0.16	0.18	0.20	0.21	0.23	0.24	0.24	0.25	0.21	0.20	0.18	0.17
1500	-0.06	-0.01	0.05	0.09	0.13	0.17	0.21	0.24	0.28	0.31	0.34	0.36	0.37	0.39	0.38	0.37	0.38	0.37
2000	-0.10	-0.03	0.04	0.10	0.15	0.21	0.26	0.30	0.35	0.40	0.44	0.48	0.51	0.53	0.55	0.54	0.56	0.58
2500	-0.14	-0.06	0.02	0.10	0.17	0.22	0.30	0.36	0.42	0.48	0.54	0.59	0.64	0.67	0.70	0.71	0.73	0.76
3000	-0.18	-0.09	0.00	0.09	0.18	0.26	0.34	0.41	0.48	0.56	0.63	0.69	0.76	0.80	0.84	0.87	0.91	0.95
3500	-0.23	-0.13	-0.02	0.08	0.18	0.28	0.37	0.46	0.54	0.63	0.72	0.79	0.87	0.93	0.98	1.05	1.08	1.13
4000	-0.29	-0.17	-0.05	0.07	0.18	0.29	0.40	0.49	0.60	0.70	0.80	0.89	0.98	1.05	1.12	1.19	1.24	1.31
4500	-0.34	-0.21	-0.08	0.05	0.18	0.30	0.42	0.54	0.65	0.76	0.87	0.98	1.08	1.16	1.25	1.33	1.40	1.48
5000	-0.41	-0.26	-0.11	0.03	0.17	0.31	0.44	0.57	0.70	0.82	0.94	1.07	1.17	1.27	1.37	1.47	1.57	1.65
5500	-0.47	-0.31	-0.15	0.00	0.16	0.31	0.46	0.60	0.74	0.87	1.01	1.15	1.26	1.38	1.49	1.60	1.72	1.81
6000	-0.54	-0.37	-0.19	-0.02	0.14	0.31	0.47	0.62	0.77	0.92	1.07	1.22	1.35	1.48	1.60	1.73	1.85	1.96
6500	-0.61	-0.43	-0.24	-0.06	0.12	0.30	0.47	0.64	0.80	0.97	1.13	1.29	1.43	1.57	1.71	1.85	1.99	2.13
7000	-0.69	-0.49	-0.29	-0.10	0.10	0.29	0.47	0.66	0.83	1.01	1.19	1.35	1.51	1.66	1.81	1.97	2.12	2.27
7500	-0.77	-0.56	-0.35	-0.14	0.07	0.27	0.47	0.67	0.85	1.05	1.24	1.41	1.58	1.75	1.91	2.08	2.25	2.41
8000	-0.85	-0.63	-0.40	-0.18	0.04	0.25	0.46	0.67	0.87	1.08	1.28	1.47	1.65	1.83	2.01	2.19	2.37	2.54
8500	-0.94	-0.70	-0.47	-0.23	0.00	0.23	0.45	0.67	0.89	1.10	1.32	1.51	1.71	1.90	2.09	2.29	2.48	2.68
9000	-1.03	-0.78	-0.53	-0.28	-0.04	0.20	0.43	0.67	0.90	1.13	1.35	1.56	1.77	1.97	2.18	2.38	2.59	2.80
9500	-1.13	-0.86	-0.60	-0.34	-0.08	0.16	0.41	0.66	0.90	1.14	1.38	1.60	1.82	2.04	2.26	2.48	2.70	2.91
10000	-1.23	-0.95	-0.67	-0.40	-0.13	0.13	0.39	0.65	0.91	1.16	1.40	1.63	1.87	2.10	2.33	2.57	2.79	3.03

Table 3. Difference between GEM model and compliance equation

In Table 3, combinations of rolling resistance and weight reduction for which the compliance equation predicts a higher value than the GEM model appear red, and those for which the GEM model prediction is higher appear green. The difference is greatest toward the lower right (poorest rolling resistance, best weight reduction), and runs as high as 2 – 3 g/ton-mile in the lower right corner. To put that amount of difference in perspective, the increment of improvement specified in the rule between the 2018 and the 2021 model year, the first improvement mandated in the rule, amounts to 2.4 g/ton-mile (81.3 g/ton-mile starting in 2018, vs. 78.9 starting in 2021).

Closer fit

The advantage of the compliance equation is the simplicity of dealing with constant coefficients. It is possible to construct an equation that is a much closer fit to the GEM model, using the same input variables, while maintaining the advantage of constant coefficients. The cost is one extra term in the equation.

Table 4 shows the results from a modified compliance equation that conforms more closely to the GEM model (the GEM table is repeated for comparison), and Table 5 on the following page shows the difference between the GEM calculation and the modified equation.

GEM	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0	81.1	82.7	84.4	86.1	87.7	89.4	91.1	92.8	94.4	96.1	97.8	99.5	101.2	102.9	104.6	106.3	108.0	109.7
500	80.6	82.2	83.9	85.5	87.2	88.9	90.5	92.2	93.8	95.5	97.2	98.9	100.5	102.2	103.9	105.6	107.3	109.0
1000	80.1	81.7	83.4	85.0	86.7	88.3	89.9	91.6	93.2	94.9	96.6	98.2	99.9	101.5	103.2	104.9	106.6	108.3
1500	79.6	81.2	82.9	84.5	86.1	87.7	89.4	91.0	92.6	94.3	95.9	97.6	99.2	100.9	102.6	104.2	105.9	107.6
2000	79.1	80.7	82.4	84.0	85.6	87.2	88.8	90.4	92.1	93.7	95.3	96.9	98.6	100.2	101.9	103.6	105.2	106.9
2500	78.7	80.3	81.9	83.4	85.0	86.7	88.3	89.9	91.5	93.1	94.7	96.3	97.9	99.6	101.2	102.9	104.5	106.2
3000	78.2	79.8	81.4	82.9	84.5	86.1	87.7	89.3	90.9	92.5	94.1	95.7	97.3	98.9	100.6	102.2	103.8	105.5
3500	77.7	79.3	80.9	82.4	84.0	85.6	87.2	88.7	90.3	91.9	93.5	95.1	96.7	98.3	99.9	101.5	103.1	104.8
4000	77.3	78.8	80.4	81.9	83.5	85.0	86.6	88.2	89.8	91.3	92.9	94.5	96.1	97.7	99.3	100.8	102.5	104.1
4500	76.8	78.4	79.9	81.4	83.0	84.5	86.1	87.6	89.2	90.7	92.3	93.9	95.4	97.0	98.6	100.2	101.8	103.4
5000	76.4	77.9	79.4	80.9	82.5	84.0	85.5	87.1	88.6	90.2	91.7	93.3	94.8	96.4	98.0	99.5	101.1	102.7
5500	75.9	77.4	78.9	80.5	82.0	83.5	85.0	86.5	88.1	89.6	91.1	92.7	94.2	95.8	97.3	98.9	100.4	102.0
6000	75.5	77.0	78.5	80.0	81.5	83.0	84.5	86.0	87.5	89.0	90.6	92.1	93.6	95.2	96.7	98.2	99.8	101.4
6500	75.0	76.5	78.0	79.5	81.0	82.5	84.0	85.5	87.0	88.5	90.0	91.5	93.0	94.6	96.1	97.6	99.1	100.7
7000	74.6	76.1	77.5	79.0	80.5	82.0	83.4	84.9	86.4	87.9	89.4	90.9	92.4	93.9	95.5	97.0	98.5	100.0
7500	74.2	75.6	77.1	78.5	80.0	81.5	82.9	84.4	85.9	87.4	88.8	90.3	91.8	93.3	94.9	96.4	97.9	99.4
8000	73.7	75.2	76.6	78.1	79.5	81.0	82.4	83.9	85.4	86.8	88.3	89.8	91.3	92.8	94.2	95.7	97.2	98.7
8500	73.3	74.7	76.2	77.6	79.0	80.5	81.9	83.4	84.8	86.3	87.7	89.2	90.7	92.2	93.6	95.1	96.6	98.1
9000	72.9	74.3	75.7	77.1	78.6	80.0	81.4	82.9	84.3	85.7	87.2	88.7	90.1	91.6	93.0	94.5	96.0	97.4
9500	72.5	73.9	75.3	76.7	78.1	79.5	80.9	82.4	83.8	85.2	86.6	88.1	89.5	91.0	92.4	93.9	95.3	96.8
10000	72.0	73.4	74.8	76.2	77.6	79.0	80.4	81.8	83.3	84.7	86.1	87.5	89.0	90.4	91.9	93.3	94.7	96.2

Table 1. GEM model for rolling resistance 3 – 20 kg/ton, weight reduction 0 – 10,000 lb

mod	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0	81.0	82.7	84.4	86.1	87.8	89.4	91.1	92.8	94.5	96.2	97.9	99.6	101.2	102.9	104.6	106.3	108.0	109.7
500	80.6	82.2	83.9	85.6	87.3	88.9	90.6	92.3	93.9	95.6	97.3	99.0	100.6	102.3	104.0	105.6	107.3	109.0
1000	80.1	81.8	83.4	85.1	86.7	88.4	90.1	91.7	93.4	95.0	96.7	98.4	100.0	101.7	103.3	105.0	106.7	108.3
1500	79.7	81.3	82.9	84.6	86.2	87.9	89.5	91.2	92.8	94.5	96.1	97.8	99.4	101.1	102.7	104.3	106.0	107.6
2000	79.2	80.8	82.5	84.1	85.7	87.4	89.0	90.6	92.3	93.9	95.5	97.2	98.8	100.4	102.1	103.7	105.3	107.0
2500	78.8	80.4	82.0	83.6	85.2	86.8	88.5	90.1	91.7	93.3	94.9	96.6	98.2	99.8	101.4	103.0	104.7	106.3
3000	78.3	79.9	81.5	83.1	84.7	86.3	87.9	89.5	91.1	92.7	94.4	96.0	97.6	99.2	100.8	102.4	104.0	105.6
3500	77.8	79.4	81.0	82.6	84.2	85.8	87.4	89.0	90.6	92.2	93.8	95.4	97.0	98.5	100.1	101.7	103.3	104.9
4000	77.4	79.0	80.6	82.1	83.7	85.3	86.9	88.4	90.0	91.6	93.2	94.8	96.3	97.9	99.5	101.1	102.7	104.2
4500	76.9	78.5	80.1	81.6	83.2	84.8	86.3	87.9	89.5	91.0	92.6	94.2	95.7	97.3	98.9	100.4	102.0	103.6
5000	76.5	78.0	79.6	81.1	82.7	84.2	85.8	87.4	88.9	90.5	92.0	93.6	95.1	96.7	98.2	99.8	101.3	102.9
5500	76.0	77.6	79.1	80.7	82.2	83.7	85.3	86.8	88.3	89.9	91.4	93.0	94.5	96.0	97.6	99.1	100.7	102.2
6000	75.6	77.1	78.6	80.2	81.7	83.2	84.7	86.3	87.8	89.3	90.8	92.4	93.9	95.4	96.9	98.5	100.0	101.5
6500	75.1	76.6	78.2	79.7	81.2	82.7	84.2	85.7	87.2	88.7	90.2	91.8	93.3	94.8	96.3	97.8	99.3	100.8
7000	74.7	76.2	77.7	79.2	80.7	82.2	83.7	85.2	86.7	88.2	89.7	91.2	92.7	94.2	95.7	97.2	98.6	100.1
7500	74.2	75.7	77.2	78.7	80.2	81.7	83.1	84.6	86.1	87.6	89.1	90.6	92.0	93.5	95.0	96.5	98.0	99.5
8000	73.8	75.2	76.7	78.2	79.7	81.1	82.6	84.1	85.5	87.0	88.5	90.0	91.4	92.9	94.4	95.8	97.3	98.8
8500	73.3	74.8	76.2	77.7	79.2	80.6	82.1	83.5	85.0	86.4	87.9	89.4	90.8	92.3	93.7	95.2	96.6	98.1
9000	72.9	74.3	75.8	77.2	78.7	80.1	81.5	83.0	84.4	85.9	87.3	88.8	90.2	91.6	93.1	94.5	96.0	97.4
9500	72.4	73.9	75.3	76.7	78.1	79.6	81.0	82.4	83.9	85.3	86.7	88.2	89.6	91.0	92.5	93.9	95.3	96.7
10000	72.0	73.4	74.8	76.2	77.6	79.1	80.5	81.9	83.3	84.7	86.1	87.6	89.0	90.4	91.8	93.2	94.6	96.1

Table 4. Modified compliance equation

mod diff	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0	-0.07	-0.04	-0.02	0.00	0.02	0.03	0.04	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.00	-0.01	-0.04	-0.07
500	-0.03	0.00	0.02	0.04	0.06	0.07	0.08	0.09	0.10	0.10	0.11	0.11	0.10	0.10	0.05	0.02	0.00	-0.01
1000	0.00	0.03	0.06	0.07	0.09	0.11	0.12	0.13	0.14	0.14	0.15	0.15	0.14	0.13	0.09	0.07	0.04	0.01
1500	0.03	0.06	0.09	0.11	0.13	0.14	0.15	0.16	0.17	0.18	0.19	0.19	0.17	0.17	0.13	0.10	0.08	0.05
2000	0.06	0.09	0.11	0.14	0.16	0.17	0.18	0.19	0.20	0.21	0.22	0.22	0.21	0.20	0.18	0.13	0.11	0.09
2500	0.08	0.11	0.13	0.16	0.18	0.18	0.21	0.22	0.23	0.24	0.24	0.24	0.24	0.22	0.20	0.16	0.13	0.11
3000	0.09	0.12	0.15	0.18	0.20	0.22	0.23	0.24	0.25	0.26	0.26	0.26	0.26	0.24	0.22	0.18	0.16	0.13
3500	0.11	0.14	0.17	0.19	0.21	0.23	0.24	0.25	0.26	0.27	0.28	0.28	0.28	0.26	0.23	0.22	0.17	0.15
4000	0.12	0.15	0.17	0.20	0.22	0.24	0.25	0.25	0.27	0.28	0.29	0.29	0.28	0.27	0.24	0.23	0.18	0.16
4500	0.12	0.15	0.18	0.21	0.23	0.25	0.26	0.27	0.28	0.29	0.29	0.29	0.29	0.27	0.25	0.23	0.19	0.17
5000	0.12	0.15	0.18	0.21	0.23	0.25	0.26	0.27	0.28	0.28	0.29	0.29	0.28	0.27	0.25	0.23	0.21	0.17
5500	0.12	0.15	0.18	0.20	0.23	0.24	0.26	0.27	0.28	0.28	0.29	0.29	0.28	0.26	0.24	0.22	0.20	0.16
6000	0.12	0.15	0.17	0.20	0.22	0.24	0.25	0.26	0.27	0.27	0.28	0.28	0.26	0.25	0.23	0.21	0.18	0.15
6500	0.11	0.13	0.16	0.19	0.21	0.22	0.24	0.25	0.25	0.26	0.27	0.26	0.25	0.23	0.21	0.19	0.17	0.15
7000	0.09	0.12	0.15	0.17	0.19	0.21	0.22	0.23	0.24	0.24	0.25	0.24	0.22	0.21	0.19	0.17	0.15	0.12
7500	0.07	0.10	0.13	0.15	0.17	0.19	0.20	0.21	0.21	0.22	0.23	0.22	0.20	0.18	0.16	0.14	0.13	0.10
8000	0.05	0.08	0.11	0.13	0.15	0.17	0.18	0.18	0.19	0.19	0.20	0.19	0.17	0.15	0.13	0.11	0.09	0.07
8500	0.03	0.06	0.08	0.10	0.12	0.14	0.14	0.15	0.16	0.16	0.16	0.15	0.13	0.11	0.09	0.07	0.05	0.04
9000	0.00	0.03	0.05	0.07	0.09	0.10	0.11	0.12	0.12	0.13	0.12	0.11	0.09	0.07	0.05	0.03	0.01	-0.01
9500	-0.03	-0.01	0.02	0.04	0.05	0.06	0.07	0.08	0.09	0.09	0.08	0.06	0.05	0.03	0.01	-0.02	-0.04	-0.06
10000	-0.07	-0.04	-0.02	0.00	0.02	0.02	0.03	0.04	0.04	0.04	0.03	0.01	0.00	-0.02	-0.04	-0.07	-0.09	-0.11

Table 5. Difference between GEM model and modified compliance equation

The modified equation differs from the GEM model by less than 0.3 g/ton-mile throughout the range of validity of the model.

The modified equation, and the associated coefficients, are written out explicitly in the Appendix.

### Implications

The graph on the following page compares the emission levels as calculated according to the compliance equation (dotted blue lines) with the levels calculated according to GEM (as approximated by the modified compliance equation, solid green lines). Each line is labeled with the emission level it represents, in grams of CO<sub>2</sub> emission per ton-mile. On the graph, the best (highest) weight reduction is toward the right, while the best (lowest) rolling resistance is toward the bottom. The deviation between GEM and the compliance equation is, as noted above, greatest for high rolling resistance values and large weight reductions.

The two calculations are in close agreement for emission levels close to the 2018 standard of 81.3 g/ton-mile. For relatively poorly performing models, whose emissions are above the 80 g/ton-mile level, the compliance equation *overestimates* emissions. But the graph also indicates that, as the standards become tighter, below 80 g/ton-mile, the direction of the difference between the calculations changes, with the compliance equation *underestimating* emissions as compared to GEM.

In practical terms, for models which are close to the current standard, the compliance equation is a good approximation to the GEM model. As the standards tighten, if the coefficients specified in the current rule are not adjusted, the compliance equation will begin to allow more models to meet the standards than would be the case if they were held to the GEM calculation. To avoid adjusting the coefficients each time the standards change, a one-time change to the modified equation would serve the same purpose.

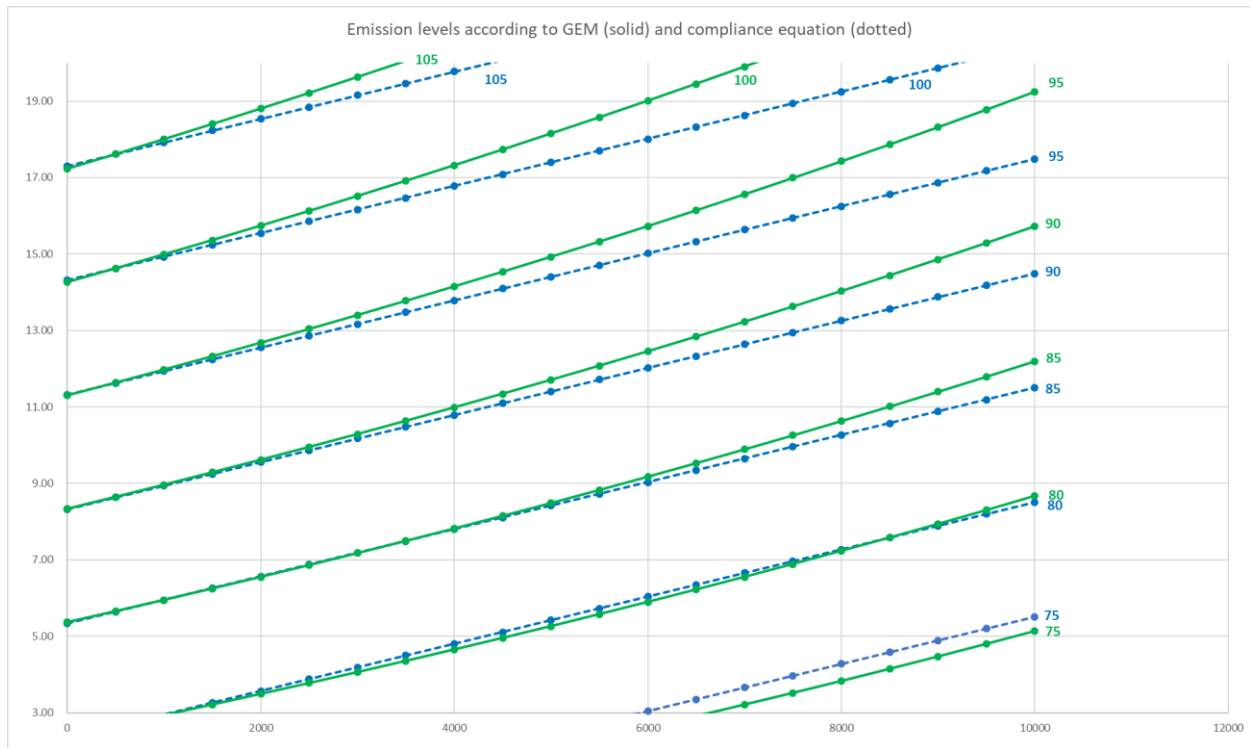


Figure 1. Comparison graph of emission levels as calculated according to the compliance equation, and according to GEM. The curves representing the GEM calculations were generated from the modified compliance equation (see Appendix).

### Appendix

The relevant terms in the compliance equation and the modified equation are written out below. The drag term has been set to zero (the baseline case), since it does not substantially affect the comparison. The compliance equation also includes an overall factor meant to provide an incentive for installing tire pressure monitoring equipment – this also does not affect the comparison, and has been set equal to 1.

$$\text{Emission (per compliance equation)} = C1 + C2 \cdot \text{TRRL} + C4 \cdot \text{WR}$$

$$\text{Emission (per modified equation)} = C1' + C2' \cdot \text{TRRL}' + C4' \cdot \text{WR} + C6' \cdot \text{TRRL}' \cdot \text{WR}$$

where TRRL is the tire rolling resistance level in kg/ton (supplied by the tire manufacturer),  $\text{TRRL}' = \text{TRRL} - 6.0$ , and WR is the weight reduction (below a specified baseline value) in pounds. The C's are constant coefficients. They differ between the two equations, but are constant in each case.

The extra computational burden required for the modified equation is minimal.

The coefficients for each equation are tabulated below. The coefficients for the compliance equation are specified in the phase 2 fuel efficiency rule; the coefficients of the modified equation may be derived by fitting baseline case slopes ( $\text{WR} = 0$ ,  $\text{TRRL} = 6.0$ ) to the GEM model, and adjusting  $C6'$  for best least-squares fit.

Coefficients for:	C1(')	C2(')	C4(')	C6(')
Compliance equation	76.1	1.67	-0.0010300	---
Modified equation	86.1	1.69	-0.0009849	-0.00002688