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Method of assessing the fuel consumption of a car engine in its long-term natural operation

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The article presents a method based on the theory of cumulative fuel consumption. The outline of the method is presented using data from long-term (many years), natural operation of a middle-class passenger car covering a mileage of over 320,000 km and 647 refuelings. The results of the research and analyses turned out to be extremely adequate for the operational data. The correlation coefficient of the mathematical model describing CFC (cumulative fuel consumption) as a function of mileage (km) was $R^2 > 0.9999$. Such an analysis result can be the basis for determining the ICFC (intensity of cumulative fuel consumption) and SCFC (specifically cumulative fuel consumption) courses as a function of mileage curves (irrespective of other parameters, such as ambient temperature). The three models mentioned collectively constitute the vehicle's energy footprint. It has been shown that the assessment of vehicle fuel consumption created solely on the basis of known indicators, such as FE (average fuel consumption between cycles or its average value (AFE) may not be adequate for assessing the fuel consumption of the car engine, and that is a new finding in the literature on this topic.

Key words: *natural operation, long-term, car engine. fuel consumption, assessing method*

1. Introduction

The fuel consumption is a critical parameter for assessing the performance of combustion engine vehicles (ICEVs) in real-world conditions. Fuel consumption depends on many factors, including driver behavior, traffic conditions, vehicle load, vehicle technical condition, as well as terrain and climate.

The multitude of these factors influencing fuel consumption is not reflected in laboratory tests conducted under standardized driving cycles such as the "old" NEDC (New European Driving Cycle) or the "new" WLTP (Worldwide Harmonized Light Vehicles Test Procedure).

The discrepancies between fuel consumption values determined in laboratory tests and real-world fuel consumption are widely documented, often showing that real-world fuel consumption is significantly higher than the official values.

The problem, however, is how the fuel consumption is determined in real-world driving conditions. The issues related to this are addressed in this article, which presents an original method for assessing fuel consumption in the long-term natural operation of vehicles.

The accurate assessment of long-term fuel consumption in natural operation (i.e., real-life vehicle use over an extended period) is essential for multiple stakeholders, including:

1) Vehicle manufacturers, who must design more fuel-efficient vehicles while complying with emissions regulations

For vehicle manufacturers, real-world fuel consumption is a crucial design parameter that influences consumer choices and compliance with regulations. The growing emphasis on corporate average fuel economy (CAFE) standards [5] and CO_2 emission targets compels manufacturers to:

– develop lighter, more aerodynamic vehicle structures
– improve engine efficiency and integrate hybridization technologies
– optimize powertrain management systems for better fuel economy in variable driving conditions.

Failure to meet regulatory requirements can result in heavy fines and loss of market competitiveness.

2) Individual consumers, who seek fuel-efficient vehicles to reduce operating costs

For individual (private) vehicle users, fuel costs constitute a significant portion of total vehicle ownership expenses. Real-world fuel consumption data allow consumers to:

– make informed decisions when purchasing vehicles
– adapt eco-driving techniques to minimize fuel use
– optimize vehicle maintenance to prevent excessive fuel consumption.

A discrepancy between laboratory and real-world fuel consumption [2] can lead to dissatisfaction, as many consumers base their purchase decisions on official fuel efficiency ratings.

3) Fleet operators, who rely on precise fuel data for cost-effective transportation management

For businesses operating large vehicle fleets, fuel expenses have a direct impact on operational costs and profitability. Logistics and transportation companies use fuel consumption data for:

– fleet optimization, including route planning and load management
– driver training programs to enhance fuel efficiency through better driving practices
– monitoring and reducing carbon footprints to meet sustainability targets.

Studies indicate that fuel-efficient fleet management can reduce fuel costs by up to 20% through data-driven decision-making [8].

4) Policy makers, who need realistic data to shape regulations, taxation policies, and environmental strategies at local, national, and global levels.

At local, national, and global levels, policymakers rely on real-world fuel consumption data to:

– implement realistic fuel economy and emissions standards
– design policies that promote alternative fuels and electric mobility
– develop urban planning solutions that optimize public transportation and traffic flow.

As cities and governments strive for the decarbonization of transportation, accurately assessing fuel consumption is crucial to ensure effective environmental policies and sustainable transportation planning [1, 16].

Given the rising fuel costs and stringent environmental policies aimed at reducing carbon emissions and urban air pollution, assessing real-world fuel consumption is crucial for improving economic efficiency and environmental sustainability in the transportation sector.

The multifaceted relationship between fuel consumption and human health [4] is also important, as the combustion of fossil fuels in transportation causes the emission of harmful pollutants that have a significant impact on public health and contribute to external costs borne not directly by vehicle users, but by society as a whole.

We know that the primary pollutants generated from fuel combustion in ICEV-s include particulate matter ($PM_{2.5}$ and PM_{10}), nitrogen oxides (NO_x), carbon monoxide (CO), volatile organic compounds (VOCs), sulphur dioxide (SO_x), and greenhouse gases (GHGs) such as carbon dioxide (CO_2). These emissions contribute to climate change and associated health risks. Studies by the World Health Organization (WHO) and the European Environment Agency (EEA) indicate that air pollution from vehicle emissions is responsible for millions of premature deaths annually, with urban areas being particularly affected due to high traffic density.

The external costs [6] of these health impacts are substantial. The OECD estimates that the economic burden of air pollution-related diseases, encompassing healthcare expenditures, lost productivity, and reduced life expectancy, amounts to over 5% of global GDP.

In conclusion, the adverse health effects of fuel consumption extend far beyond individual vehicle users, imposing significant social, economic, and environmental burdens. Urgent action is needed to reduce transport-related fuel consumption and emissions [9], improve air quality, and mitigate climate-related health risks through technological advancements, behavioural changes, and regulatory measures. However, this cannot be achieved without adequate methods to assess the actual fuel consumption of vehicles in their long-term (over many years) natural operation.

2. Objectives of this study

This article aims to present a method tool that will be helpful in further studies on the assessment of fuel consumption (and more broadly, energy carriers) in:

– review existing methodologies for measuring fuel consumption in real-world conditions
– analyze the discrepancies between laboratory and real-world fuel efficiency results
– discuss best practices for improving fuel economy in vehicle design, fleet management, and driving behavior
– evaluate the policy implications of real-world fuel consumption data.

By addressing these topics, this study provides a comprehensive framework for assessing long-term fuel consumption in natural vehicle operation, offering insights for manufacturers, consumers, fleet operators, and policymakers.

The main methods used so far to evaluate fuel consumption [7], in real-world conditions [3], are:

• Full Tank Method ("Tank-to-Tank")

This is a simple and fairly accurate method used by drivers and fleet operators. Pros: Simple, reliable for long-distance (great mileage) assessments. Cons: Does not provide real-time consumption changes.

• On-Board Computer Readings

Most modern vehicles have an onboard computer that displays both average and real-time fuel consumption.

Pros: Instant results, useful for adjusting driving habits. Provides both average and instantaneous fuel consumption. Cons: There can be a 5–10% error margin. Older vehicles may lack this feature.

• OBD-II Diagnostics + Mobile Apps

If the vehicle has an OBD-II (On-Board Diagnostics) port, you can use a Bluetooth scanner (such as the ELM327) with apps like Torque or Car Scanner to monitor fuel consumption in real-time.

Pros: Provides precise real-time fuel data from the engine control unit. Allows tracking additional metrics (e.g., engine load, temperature, throttle position). Cons: Requires additional hardware and setup. Accuracy depends on sensor calibration.

• Long-Term Statistical Analysis (Fleet Management)

For commercial fleets, fuel consumption is analyzed over long periods using: Fuel purchase records (e.g., receipts, invoices). Odometer readings (from GPS or tachograph). Driving conditions (urban, highway, cargo load). Pros: Best for fleet management, helps detect inefficiencies. Cons: Requires consistent data collection.

• Real Driving Emissions (RDE) Testing with Portable Emission Measurement Systems (PEMS)

Used in regulatory and scientific studies, this method involves: Installing a portable emissions analyzer (PEMS) on the vehicle. Measuring real-time fuel consumption under real-world driving conditions. Pros: Most accurate real-world method. Cons: Expensive, used mainly in professional research.

Among the above-mentioned methods for assessing the fuel consumption of engines in long-term, natural vehicle use, the most frequently used method is the "full tank" method, also known as "Tank to Tank". However, there are two basic varieties of this method: in one of them, fuel consumption is given in units of the volume of fuel used related to the distance covered (usually in dm^3 per 100 km), in the other, the distance covered on a specific amount of fuel is given (usually in miles per gallon of fuel).

In the EU, the most commonly used factor for assessing the fuel consumption of car engines is fuel economy (FE) expressed in $dm^3/100$ km. This method is also presented in this publication. It is illustrated with the results of long-term studies of ICEV operation in natural use, conducted at the PROEKO Foundation.

A mid-range passenger car with a six-cylinder naturally aspirated V spark-ignition engine with a displacement of 3.5 dm^3 was tested.

By the assumptions that F_i – i-th refueling, t_{di} – mileage to F_i, then the fuel economy (FE) can be expressed as:

$$FE_i = 100F_i/(t_{di} - t_{di-1}) \quad (1)$$

After 647 refuelings (during the operational car investigations), it was achieving the results of fuel economy (FE) illustrated in Fig. 1.

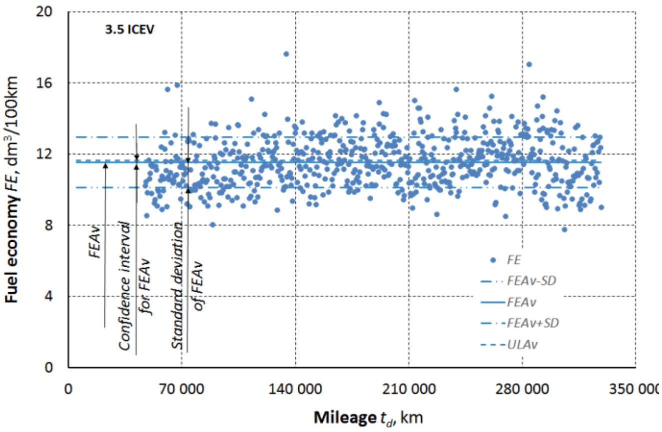

Fig. 1. Fuel economy after 647 refuelings of the investigated car

As can be seen, it is possible to conduct a comprehensive statistical analysis of the obtained results. Such an analysis was conducted, and the selected results are presented in Table 1.

Table 1. Fuel economy

Mean	11.54041
Standard error	0.05568
Median	Nov.81
Mode	Oct.99
Standard deviation	1.416291
Sample variance	2.005879
Kurtosis	0.380084
Skewness	0.423088
Range	9.879941
Minimum	7.76880
Maximum	17.64874
Sum	7466.642
Number	647
Largest (1)	17.64874
Least (1)	Jul.88
Confidence level (95.0%)	0.109336

The presented data yield interesting observations. The average of 11.5 $dm^3/100$ km does not differ from the values obtained in the operation of mid-range cars. It is interesting that the confidence interval for the average is relatively narrow.

However, the relatively large dispersion of the FE_i value from the AFE is worth noting. This is confirmed by the data concerning the hypothetical distribution of FE_i values. The kurtosis of this distribution (0.38 – Table 1) indicates that it is relatively "flat", while the skewness value (0.42 – Table 1) indicates that there are relatively many values significantly smaller than the AFE achieved in presented calculations.

The i value changed from 1 to n. By n refueling the average fuel economy (AFE_n) is as

$$AFE_n = \frac{1}{n}\sum_{i=1}^{n} FE_i \quad (2)$$

Figure 1 shows the values for i = n = 647. It is possible to calculate AFE_i for each i (from 1 to 647). After each refueling, there is AFE_i, and these values do not have to be constant – which is observed in reality. An example of the FE_i and AFE_i values calculated in the presented studies, is given in Fig. 2.

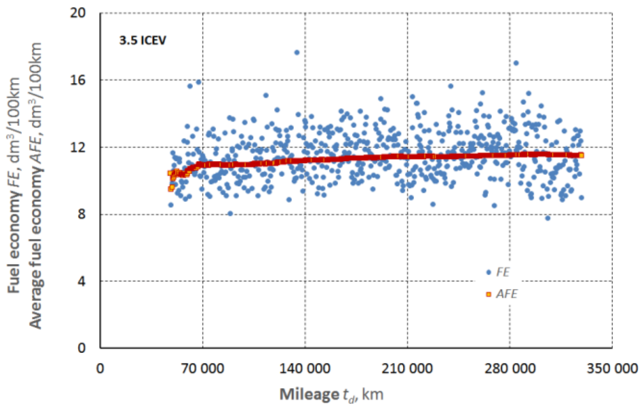

Fig. 2. FE and AFE by 647 refuelings (i = 1 to n = 647)

There are clearly visible large changes in AFE as the vehicle mileage increases. It is characteristic that in the initial period of operation, the changes in AFE are relatively large. After a longer period of operation, the AFE values stabilize. This happens despite the fact that the FE values are still characterized by relatively large value dispersions. Of course, in the existing situation, the assessment of operational fuel consumption in long-term, natural operation may not be adequate to reality. See the value of mode equate 10.98 $dm^3/100$ km – Table 1. Hence, another fuel consumption assessment method was introduced based on the theory of cumulative fuel consumption.

The assessment of the fuel (energy carrier) consumption and energy efficiency of vehicles during their natural operation is crucial for understanding the impact on people and the environment and is essential for the development and implementation of sustainable transport policies. One significant contribution to this field can be the cumulative fuel consumption theory [11], which offers a comprehensive framework for assessing fuel consumption under long-term, real-world conditions.

Furthermore, the resulting concept of the energy footprint of a vehicle provides insight into the total energy consumed over its entire life cycle, from production to disposal.

3. Theory of cumulative fuel consumption

Cumulative fuel consumption theory focuses on quantifying the total fuel consumed by a vehicle over its entire operational life, considering various real-world factors that influence fuel efficiency. This approach contrasts with standardized laboratory tests, which may not accurately reflect actual driving conditions.

The theory introduces several critical components:

– Cumulative Fuel Consumption (CFC): This metric represents the total amount of fuel (energy carrier) consumed by a vehicle over a specific period or distance. It encompasses all operational phases, offering a comprehensive view of fuel usage.

– Intensity of Cumulative Fuel Consumption (ICFC): This parameter measures the rate of fuel consumption over time, reflecting how efficiently a vehicle uses fuel during its operation.

– Specific cumulative fuel consumption (SCFC) – value similar to the AFE.

The cumulative fuel consumption over time t_d (practically mileage) after many transformations, described in detail in [11–13, 15] can be expressed as:

$$\mathrm{CFC}(t_d) = c t_d^{a+1} \tag{3}$$

where: CFC – cumulative fuel consumption, c, a – constants, t_d – the mileage.

Derivative of the (3) is the intensity of the cumulative fuel consumption.

$$\mathrm{ICFC}(t_d) = \frac{d\mathrm{CFC}(t_d)}{dt_d} = c(a+1)t_d^{a} \tag{4}$$

where: ICFC – intensity of the cumulative fuel consumption; by $t_d = 0$ the ICFC not exist.

Specific cumulative fuel consumption (SCFC)

$$\mathrm{SCFC}(t_d) = \frac{\mathrm{CFC}(t_d)}{t_d} = c t_d^{a} \tag{5}$$

SCFC is similar to the AFE but the $\mathrm{SCFC}(t_d)$ is expressed in dm^3/km.

The usefulness of the cumulative fuel consumption theory will be demonstrated here using data from the long-term operation of 3.5 ICEV test, mentioned earlier.

After each i-th refueling of the car, two main parameters can be noted, i.e. the t_{di} mileage and the amount of fuel filled into the car tank F_i.

After k-refuelings ($i \le k \le n$) existing two parameters

$$t_{dk},\quad F_{is} = \sum_1^i F_i \quad \text{for} \quad 1 \le i \le n \tag{6}$$

Selected values from the initial and final period of operational testing are presented in Table 2. Full operational data are the responsibility of the authors of this publication.

Table 2. Selected results from 3.5 ICEV long-term natural operational tests

	Datum	Distance	Refueling	Sum of refueling	CFCm [dm^3]	CFC [dm^3]	DCFC [%]
		t_{dk} [km]	F_i [dm^3]	Fis [dm^3]			
1	30.04.2010	47 198.41	36.660	36.66	4 837.84	4 803.47	–0.72
2	02.05.2010	47 658.58	48.149	84.81	4 885.99	4 852.85	–0.68
3	03.05.2010	48 192.77	45.740	130.55	4 931.73	4 910.21	–0.44
4	09.05.2010	48 754.31	55.360	185.91	4 987.09	4 970.53	–0.33
5	14.05.2010	49 233.79	55.950	241.86	5 043.04	5 022.08	–0.42
6	18.05.2010	49 730.97	52.830	294.69	5 095.87	5 075.55	–0.40
7	24.05.2010	50 242.63	55.930	350.62	5 151.80	5 130.61	–0.41
8	28.05.2010	50 706.03	52.860	403.48	5 204.66	5 180.50	–0.47
9	30.05.2010	51 277.22	55.970	459.45	5 260.63	5 242.03	–0.35
10	09.06.2010	51 737.40	52.100	511.55	5 312.73	5 291.63	–0.40
11	12.06.2010	52 200.79	52.640	564.19	5 365.37	5 341.60	–0.44
12	13.06.2010	52 694.75	45.770	609.96	5 411.14	5 394.90	–0.30
13	15.06.2010	53 253.07	52.770	662.73	5 463.91	5 455.17	–0.16
14	20.06.2010	53 692.33	49.820	712.55	5 513.73	5 502.61	–0.20
15	21.06.2010	54 052.75	40.120	752.67	5 553.85	5 541.55	–0.22
16	25.06.2010	54 601.42	49.970	802.64	5 603.82	5 600.86	–0.05
17	28.06.2010	55 021.36	42.000	844.64	5 645.82	5 646.28	0.01
18	29.06.2010	55 590.95	56.490	901.13	5 702.31	5 707.91	0.10
19	01.07.2010	56 123.53	51.420	952.55	5 753.73	5 765.56	0.21
20	05.07.2010	56 652.89	55.800	1 008.35	5 809.53	5 822.90	0.23
21	14.07.2010	57 013.31	44.700	1 053.05	5 854.23	5 861.95	0.13
22	16.07.2010	57 405.90	42.330	1 095.38	5 896.56	5 904.51	0.13
23	18.07.2010	57 724.48	28.440	1 123.82	5 925.00	5 939.06	0.24
71	07.02.2011	79 679.29	67.440	3 557.22	7 920.32	7 906.93	–0.17
644	16.01.2025	327 227.16	53.340	31 919.78	36 333.66	36 581.42	0.68
645	02.02.2025	327 577.92	45.510	31 965.29	36 386.75	36 637.74	0.69
646	17.02.2025	328 020.39	54.800	32 020.09	36 431.88	36 678.93	0.67
647	22.02.2025	328 395.29	33.830	32 053.92	36 481.46	36 734.11	0.69

An illustration of the operating data from all 647 refuellings is shown in Fig. 3.

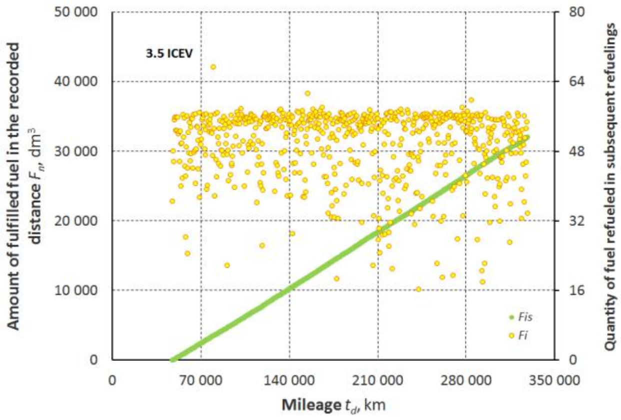

Fig. 3. A typical picture of data after any refueling (647 in this case) the car

The tests were conducted using the full tank ("Tank to Tank") method. The fuel tank capacity of a 3.5 ICEV is 65 dm^3. However, Fig. 3 shows that there are refuellings with a volume exceeding this capacity – see row 71 in Table 2. This is not an error. This is the result of multiple refuellings, of which only the last (of this mini cycle) is a refuelling to a full tank.

The analysis of the volume of refueled fuel reveals that the vast majority of the volume falls within the range of 50–55 dm³.

The F_{is} course is quasi-linear. F_{is} is an element of the cumulative fuel consumption CFC, because CFC is calculated from the moment the vehicle is put into service (by $t_d = 0$).

The situation presented in Fig. 3, where there is no data from the beginning of the vehicle's operation, occurs frequently, in fact, most often. The "missing" fuel consumption from the mileage "zero" to the beginning of the operating data recording (here, 47,198.41 km – Table 2) can be determined using advanced mathematical methods. This was also done in relation to the tested 3.5 ICEV vehicle.

By assuming that:

$$CFC_m = F_{0s} + F_{is} \tag{7}$$

this where: F_{is} –measurement amount of fuel consumed to the t_{dn} in the investigated period of car operation, F_{0s} – estimated amount fuel consumed from the $t_{dn} = 0$ (beginning of the car operation) to the t_{di} (mileage of the first registered refueling by the investigated car operation i = 1), CFCm – estimated plus measurement consumed fuel to the t_{di}, CFC – cumulative fuel consumption from beginning the vehicle operation – equation (3), DCFC – deviation of the CFCm data from CFC data.

The relevant data are given in Table 2 and illustrated here in Fig. 4.

It is worth noting the good prediction of CFC values determined based on CFCm. The percentage deviation of both values (DCFC), throughout the entire study period, does not exceed 1.00% – Fig. 4.

The statistics of model (3) are given in Table 3.

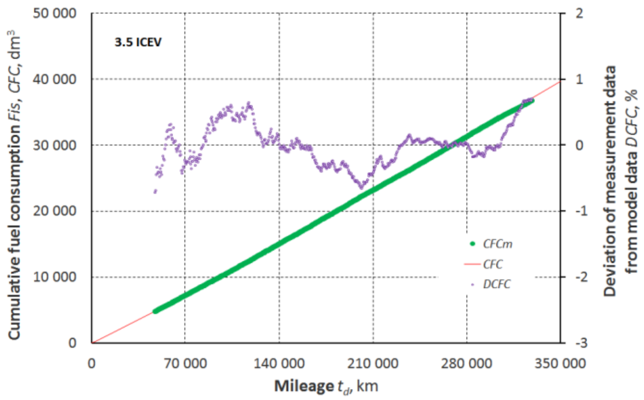

Fig. 4. Cumulative fuel consumption: CFCm – determined based on operational test data, CFC – determined based on the model (3), DCFC deviation of measured values from those determined from the model (3)

Table 3. Statistics of model (3)

Regression statistics	
Multiple R	0.999984
R squared	0.999968
Fitted R-squared	0.999968
Standard error	0.003000
Observation	647
Coefficients	
"c"	0.056862
"a"	0.054089

Having constants "c" and "a" relative to the performance of a specific vehicle, we can present the energy footprint of the vehicle [10, 14]. The energy footprint of the vehicle in the whole operating period in driving status is represented by three quantities, i.e. CFC(t_d), ICFC(t_d) and SCFC(t_d).

These quantities were calculated (for 3.5 ICEV), and their curves are shown in Fig. 5.

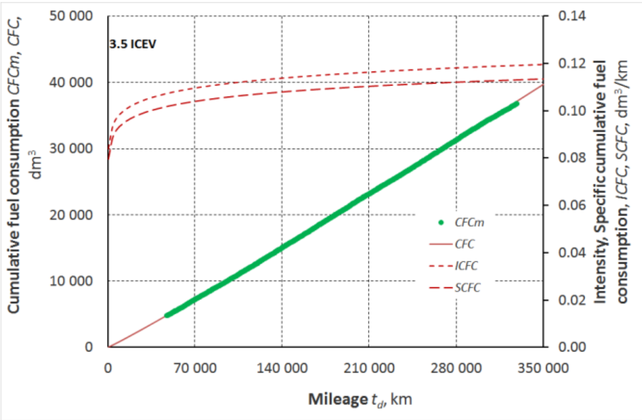

Fig. 5. The energy footprint of a car during its long natural life cycle regarding the use phase

The course of the curves is interesting. The intensity of the cumulative fuel consumption increases from the moment the car is put into service. The specific cumulative fuel consumption behaves similarly. The reasons for this state of affairs can, of course, be manifold. One of the main reasons may be, for example, a change in the operating environment. It is also interesting that the SCFC values, when multiplied by 100, seem to yield similar results to those of AFE. The result of calculations and comparisons is shown in Fig. 6.

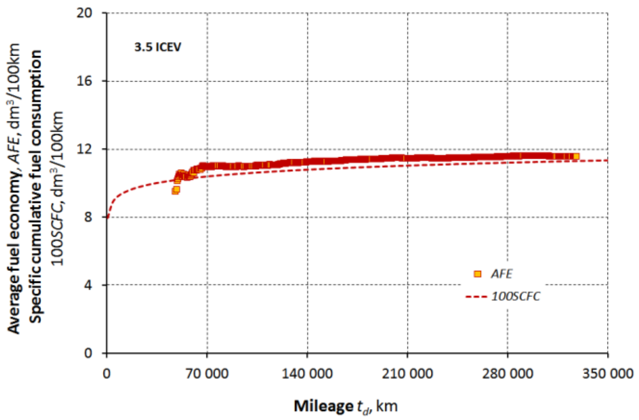

Fig. 6. The result of calculations for comparison of 100SCFC and AFE

The value of 100SCFC over the full mileage range is slightly lower than that of AFE. But 100SCFC may be closer to reality than AFE. In Table 1, we present the skewness value as 0.42, noting that the maximum of the FE statistical distribution falls within the range of fuel consumption smaller than the final AFE value after 647 refuelings, corresponding to a 100SCFC. For this reason, the parameters of the statistical distribution are likely a more effective tool for assessing fuel consumption as AFE. Obviously, it seems best to make fuel consumption assessments using SCFC.

4. Conclusions

Cumulative fuel consumption theory provides a valuable framework for understanding and quantifying fuel consumption in real-world, long-term vehicle operations, offering insights that standardized tests may miss.

The concept of a vehicle's energy footprint is introduced, based on cumulative fuel consumption theory, to more accurately assess a vehicle's energy consumption over its entire operational life.

By analyzing real-world operating data such as fuel consumption records and distances traveled, this methodology provides a comprehensive understanding of a vehicle's energy requirements under natural, long-term operating conditions. The vehicle's energy footprint is visualized using cumulative fuel consumption, cumulative fuel consumption intensity, and specific cumulative fuel consumption curves, offering insight into how fuel efficiency evolves over the vehicle's life.

The presented method of energy carrier consumption assessment has practical implications for:

- Vehicle performance assessment: By analyzing CFCs, ICFCs, and SCFCs, manufacturers and researchers can assess how vehicles perform under a variety of real-world conditions as a function of vehicle mileage (regardless of specific conditions that vary randomly over long periods of operation), leading to improvements in design and fuel efficiency.
- Policy development: Understanding cumulative fuel economy helps policymakers develop policies that promote energy efficiency and reduce environmental impact, as well as forecast energy demand, such as for e-mobility.
- Consumer awareness: Providing consumers with information about a vehicle's cumulative fuel economy can influence purchasing decisions toward more fuel-efficient options.

Combined with vehicle energy footprint analysis, these concepts are crucial for promoting sustainable transportation, informing policy decisions, and guiding consumer choices toward minimizing costs, including external transport costs and environmentally friendly options.

A separate issue is the possibility of using cumulative fuel consumption theory, and more broadly, energy footprint, as a method for multi-aspect comparisons of different vehicle powertrains, including comparisons of vehicle fleets with conventional (ICEV), hybrid (HEV and PHEV), hydrogen (H2EV), and electric (BEV) powertrains.

Based on the assumption that the presented method can be beneficial for producers, decision-makers, and consumers seeking to improve fuel efficiency and reduce environmental impact, further work utilizing it is planned. It seems important to explain the phenomenon of large dispersion in the CFC curves recorded in vehicle fleets. Since model (3) will then become a multidimensional model, artificial neural networks are planned to be used in this context.

Nomenclature

AFE	average fuel economy
CAFÉ	corporate average fuel economy
CFC	cumulative fuel consumption
FE	fuel economy
ICFC	intensity of cumulative fuel consumption
ICEV	combustion engine vehicle
NEDC	New European Driving Cycle
PEMS	portable emission measurement systems
RDE	real driving emission
SCFC	specifically cumulative fuel consumption
WLTP	Worldwide Harmonized Light Vehicles Test Procedure

Bibliography

[1] Dobranskyte-Niskota, A, Perujo A, Pregl M. Indicators to assess sustainability of transport activities. 2007.

[2] Fan P, Yin H, Lu H, Wu Y, Zhai Z, Yu L et al. Which factor contributes more to the fuel consumption gap between in-laboratory vs. real-world driving conditions? An independent component analysis. Energy Policy. 2023;182:113739. https://doi.org/10.1016/j.enpol.2023.113739

[3] Heni H, Diop SA, Coelho LC, Renaud J. Measuring fuel consumption in vehicle routing: new estimation models us-

ing supervised learning measuring fuel consumption in vehicle routing: new estimation models using supervised learning. 2019.
https://www.cirrelt.ca/documentstravail/cirrelt-2019-08.pdf
[4] Huang Y, Unger N, Harper K, Heyes C. Global climate and human health effects of the gasoline and diesel vehicle fleets. GeoHealth. 2020;4:1-13.
https://doi.org/10.1029/2019GH000240
[5] Kolb RW. Corporate Average Fuel Economy (CAFE) Standards. Encycl Bus Ethics Soc. 2008;5:456.
https://doi.org/10.4135/9781412956260.n193
[6] Lemp JD, Kockelman KM. Quantifying the external costs of vehicle use: evidence from America's top-selling light-duty models. Transp Res Part D Transp Environ. 2008;13:491-504. https://doi.org/10.1016/j.trd.2008.09.005
[7] Mahlia TMI, Tohno S, Tezuka T. A review on fuel economy test procedure for automobiles: implementation possibilities in Malaysia and lessons for other countries. Renew Sustain Energy Rev. 2012;16:4029-4046.
https://doi.org/10.1016/j.rser.2012.03.032
[8] Reduce Fuel Costs with Fleet Management Software Strategies_MoldStud.
https://moldstud.com/articles/p-how-fleet-management-software-can-help-reduce-fuel-costs
[9] Romero CA, Correa P, Ariza Echeverri EA, Vergara D. Strategies for reducing automobile fuel consumption. Appl Sci. 2024;14:1-27. https://doi.org/10.3390/app14020910
[10] Sitnik L. Operational energy footprint of vehicle. Combustion Engines. 2021;186(3):37-40.
https://doi.org/10.19206/ce-140245
[11] Sitnik L. Theory of cumulative fuel consumption and example for its application. Proceedings of the XXII International Scientific-Technical Conference TRANS&MOTAUTO '14. Scientific-technical Union of Mechanical Engineering. Varna. 2014:17-20.
[12] Sitnik L. Energy demand assessment for long term operation of vehicles. SAE Technical Paper 2020-01-2165. 2020.
https://doi.org/10.4271/2020-01-2165
[13] Sitnik L. Theory of cumulative fuel consumption by LPG powered cars. J Kones Powertrain Transp. 2015;22:275-280.
https://doi.org/10.5604/12314005.1168489
[14] Sitnik L, Andrych-Zalewska M, Dimitrov R, Mihaylov V, Mielińska A. Assessment of energy footprint of pure hydrogen-supplied vehicles in real conditions of long-term operation. Energies. 2024;17. https://doi.org/10.3390/en17143532
[15] Sitnik L, Ivanov ZD, Sroka ZJ. Energy demand assessment for long term operation of hybrid electric vehicles. 2020 IOP Conf Ser: Mater Sci Eng. 2020;1002:012026.
https://doi.org/10.1088/1757-899X/1002/1/012026
[16] Zhou M, Jin H, Wang W. A review of vehicle fuel consumption models to evaluate eco-driving and eco-routing. Transp Res Part D Transp Environ. 2016;49:203-218.
https://doi.org/10.1016/j.trd.2016.09.008

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