Redimensioning the WTT calculation of CNG/LNG fuel in the spotlight of pathways and technology spread and its affect as externalities in the framework of the PAN-LNG Project

A. Somogyi, PhD*. T. Kocsis, PhD**
G. Lipcsei***

**Research Department, Solver Unio Ltd., Budapest, Hungary*
(Tel: +3630-9903635; e-mail: somogyi.andrea@solvergroup.hu).
*** Institute of Economic Geography, Geoeconomy and Sustainable Development,*
Corvinus University of Budapest, Hungary (e-mail: tamas.kocsis@uni-corvinus.hu)
**** Engineering Department, Solver Unio Ltd., Budapest, Hungary,*
(e-mail: lipcsei.gabor@solvergorup.hu)

Abstract: The new approach of the Well-to-Tank (WTT) method evaluating the pathway of a fuel from its source to the fuel tank specified to Hungary was necessary to better understand the essence of PAN-LNG project. We examined a number of pathways and as result, it was determined the real CNG/LNG potential for Hungary. We analyzed several Tank-to-Wheel (TTW) external cost scenarios as well thanks to which we determined the level of cost reduction to be achieved by the penetration of gas-powered vehicles in 2020, 2025 and 2030.

1. INTRODUCTION

In the 3rd chapter of the PAN-LNG project we evaluated and figured out the exposure of Hungary to energy, the potential opportunity in the natural gas infrastructure network. Based on the State of the Art, we reconsidered the context of CNG/LNG Well-to-Tanks and Well-to-Wheels matrix taking into account the methodology of the EU’s JRC Technical Report. Special attention was paid to externalities. The calculation does not in itself provide externality results, but always compered to something. It means that we estimated the expected savings (in monetary terms) by the spread of CNG/LNG fuels.

1.1. Well-to-Tank

The Well-to-Tank (WTT) method evaluates the pathway of a fuel from its source to the fuel tank. This life cycle analysis evaluates the various pathways based on the expended energy and the emitted greenhouse gases (GHG). The WTT analysation carried out during the PAN-LNG project was based on the JRC Technical Reports: Well-To-Tank Report Version 4.0 (JRC, 2013). The methodology is the same and the input data of the common technological steps are used. The pathways are specified to Hungary and to LNG/CNG fuel. The analysis concentrates to energy demand and GHG emission. The building and installation of the technological equipment are not considered in this analysis.

1.2. Tank-to-Wheel (TTW) external cost scenarios

We start our analysis at the estimated Hungarian vehicle stock for the years of 2020, 2025 and 2030 calculated by the KTI. Here, the future spreading level of the CNG/LNG driven vehicles was also estimated. Data are available for seven vehicle categories *(Appendix A)* and three spreading scenarios (low, medium, high) (*Table 1*).

Table 1. Vehicle scenarios for Hungary for the years 2020, 2025, 2030 (Source: KTI,

2016)

	Category	Amount	Annual run (km)	Low	Medium	High
2020	m1	3,428,000	13,000	0.5%	1.0%	2.0%
	n1	365,000	45,000	0.5%	1.0%	3.0%
	n2	74,000	90,000	0.5%	2.0%	3.5%
	m3/i,ii	7,300	80,000	7.0%	10.0%	20.0%
	m3/iii	7,300	125,000	0.0%	0.5%	2.0%
	n3*	6,600	70,000	1.5%	2.0%	5.0%
	n3+04	35,000	125,000	1.0%	7.0%	10.0%

				CNG/LNG spread		
	Category	Amount	Annual run (km)	Low	Medium	High
2025	m1	3,740,000	13,000	1.0%	5.0%	7.0%
	n1	414,000	45,000	1.0%	5.0%	7.0%
	n2	84,500	90,000	1.0%	5.0%	10.0%
	m3/i,ii	7,100	80,000	10.0%	20.0%	40.0%
	m3/iii	7,100	125,000	2.0%	4.0%	15.0%
	n3*	7,500	70,000	5.0%	7.0%	15.0%
	n3+04	40,000	125,000	2.0%	15.0%	20.0%

				CNG/LNG spread		
	Category	Amount	Annual run (km)	Low	Medium	High
2030	m1	4,052,000	13,000	3.0%	7.0%	10.0%
	n1	431,000	45,000	3.0%	7.0%	15.0%
	n2	88,000	90,000	3.0%	10.0%	20.0%
	m3/i,ii	6,800	80,000	15.0%	40.0%	60.0%
	m3/iii	6,800	125,000	5.0%	10.0%	30.0%
	n3*	8,400	70,000	7.0%	15.0%	30.0%
	n3+04	45,000	125,000	5.0%	30.0%	40.0%

Now we analyse the specific emission values for three local air pollutants, VOC, NO_x and PM (we omitted CO as it was also omitted in Ricardo-AEA et al., 2013, on which our calculations were based) and two global air pollutants, CO_2 and CH_4.

Our basic emission's data for the CNG/LNG driven vehicles are summarized in *Table 2.* These data are constant during our projections though they will be obviously touched by future "technological development".

Table 2. Specific emission values of CNG/LNG driven vehicles meeting EURO 6 standard (g/km) (KTI, 2016)

CNG-LNG EURO 6					
Category	VOC	NO_x	PM	CO_2	CH_4
m1	0.03600	0.03200	0.00025	126.00000	0.07200
n1	0.03600	0.04200	0.00025	189.00000	0.07200
n2	0.03072	0.13248	0.00024	378.00000	0.07200
m3/i,ii	0.07851	0.33856	0.00061	578.34000	0.18400
m3/iii	0.03584	0.30912	0.00007	694.00800	0.07467
n3*	0.03072	0.13248	0.00024	451.10520	0.07200
n3+04	0.03840	0.33120	0.00008	766.87884	0.08000

We suppose that the spread of gas driven vehicles does not change the pace of gradually "disappear" of vehicles of older standards, in itself. However, during calculations, choosing the reference has a strategic role: which type of vehicles are substituted by the CNG/LNG driven vehicles? In turn, without spreading of the gas drive, what kind of drives would characterize the vehicle fleet of *Table 1*? The importance of this question is highlighted by the fact that *external cost calculations' outputs are not understandable in themselves but relative to something*. Thus, we estimate here how many external costs can be avoided by the projected spread of CNG/LNG driven vehicles. This type of calculations is sensitive to the assumption about the "pushed out" vehicles.

2. METHODOLOGY

There are basically 5+1 different pathways analysed in this work. 5 are evaluated for LNG and CNG (with the adding of a vaporisation unit to the end) and +1 for exclusively CNG. The pathways are divided to standard steps for the sake of comparability (JRC, 2013) as the followings: Production & conditioning at source (P&C) – Transformation at source (TF) – Transportation (TP) – Conditioning & distribution (C&D).

Within these steps the real technical processes are evaluated which follow the track of the fuel from the location of the production until the fuel tank. The above mentioned 5+1 pathways are described below.

2.1. WTT Pathways

About the acronym: the first letters refer to the source, the last three letters refer to the fuel type at the end of the pathways.

- *ING-CNG:* Hungarian mix natural gas, compression to CNG at retail point.
- *ILNG:* remote natural gas liquefied at source, LNG sea transport to Rotterdam, transport by road as LNG (LNG truck) within the EU to Hungary, distribution and use as LNG.
- *ILNG-CNG:* remote natural gas liquefied at source, LNG sea transport to Rotterdam, transport by road as LNG (LNG truck) within the EU to Hungary, distribution as LNG, compression / vaporisation to CNG at retail point.
- *HNG-LNG:* Hungarian natural gas liquefied at source, transport and distribution by road (LNG truck) and use as LNG.
- *HNG-LNG-CNG:* Hungarian natural gas liquefied at source, transport and distribution by road (LNG truck) as LNG, compression / vaporisation to CNG at retail point.
- *HLG-LNG:* Hungarian landfill gas liquefied at source, transport and distribution by road (LNG truck) and use as LNG.

- *HLG-LNG-CNG:* Hungarian landfill gas liquefied at source, transport and distribution by road (LNG truck) as LNG, compression / vaporisation to CNG at retail point.
- *HSG_N-LNG:* Hungarian synthetic methane liquefied at source (production and liquefaction based on nuclear energy), transport and distribution by road (LNG truck) and use as LNG.
- *HSG_N-LNG-CNG:* Hungarian synthetic methane liquefied at source (production and liquefaction based on nuclear energy), transport and distribution by road (LNG truck) as LNG, compression / vaporisation to CNG at retail point.
- *HSG_R-LNG:* Hungarian synthetic methane liquefied at source (production and liquefaction based on renewable energy), transport and distribution by road (LNG truck) and use as LNG.
- *HSG_R-LNG-CNG:* Hungarian synthetic methane liquefied at source (production and liquefaction based on renewable energy), transport and distribution by road (LNG truck) as LNG, compression / vaporisation to CNG at retail point.

2.2 Methodology for TTW

During our calculations we chose the most conservative assumption. We suppose that all introduced CNG/LNG driven vehicle are pushing out the most up-to-date diesel vehicles meeting the EURO 6 standards. *All other assumptions supposing pushing out of vehicles by older standards would result in higher amount of avoided external costs.*

EURO 6 diesel vehicles specific emissions are summarized in *Table 3.* We also suppose that these values are constant until 2030.

Table 3. Specific emissions of diesel driven vehicles meeting Euro 6 standards (g/km) (KTI, 2016)

Diesel EURO 6					
Category	VOC	NO_x	PM	CO_2	CH_4
m1	0.09000	0.32000	0.00450	140.00000	0
n1	0.09000	0.42000	0.00450	210.00000	0
n2	0.02304	1.10400	0.00672	420.00000	0
m3/i,ii	0.05888	2.82133	0.01717	642.60000	0
m3/iii	0.02389	3.43467	0.00672	771.12000	0
n3*	0.02304	1.10400	0.00672	501.22800	0
n3+04	0.02560	3.68000	0.00720	852.08760	0

As the differences of *Table 2 and Table 3* we gain those specific gains which can be reaped by driving one kilometer distance by a CNG/LNG driven vehicle instead of a Euro 6 diesel vehicle *(Table 4)*. This calculation also supposes no change in the future technology however this affects the *difference* of CNG/LNG and diesel driven vehicles. This is also a highly conservative assumption as in the development of CNG/LNG drive seem far more potential today as in the diesel drive getting in its mature development phase.

Table 4. Specific advantages of CNG/LNG driven vehicles to the diesel driven vehicles meeting Euro 6 standards (g/km); negative values indicate the disadvantage of gas drive

Difference of diesel EURO 6 - CNG-LNG engines emissions					
Category	VOC	NO_x	PM	CO_2	CH_4
m1	0.05400	0.28800	0.00425	14.00000	-0.07200
n1	0.05400	0.37800	0.00425	21.00000	-0.07200
n2	-0.00768	0.97152	0.00648	42.00000	-0.07200
m3/i,ii	-0.01963	2.48277	0.01656	64.26000	-0.18400
m3/iii	-0.01195	3.12555	0.00665	77.11200	-0.07467
n3*	-0.00768	0.97152	0.00648	50.12280	-0.07200
n3+04	-0.01280	3.34880	0.00712	85.20876	-0.08000

Based on *Table 1*, the projected annual run of CNG/LNG driven vehicles can now be calculated for the years of 2020, 2025 and 2030. These values combined by *Table 4* we gain those environmental savings which are available by the advanced environmental parameters of CNG/LNG driven vehicles based on the specific future projection.

3. RESULTS

3.1. WTT calculations

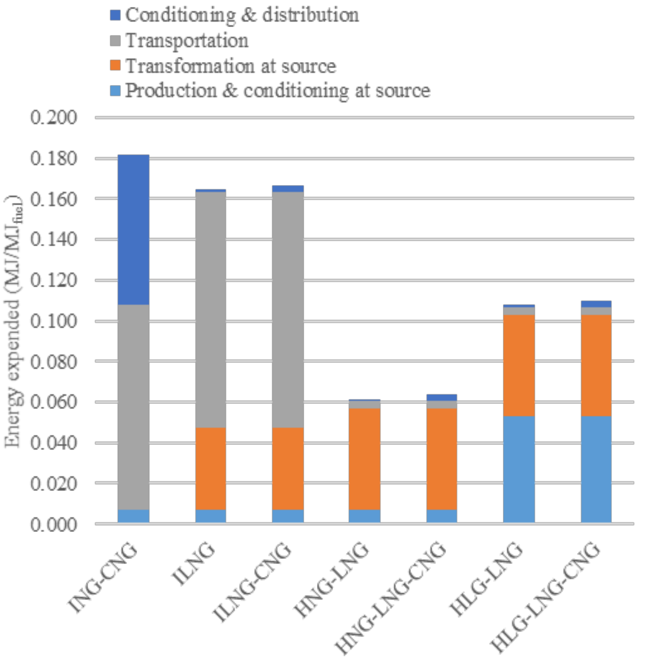

Fig. 1. Expended energy values of the various WTT pathways

(without syngas: *HSG_N-LNG, HSG_NLNG-CNG, HSG_R-LNG, HSG_R-LNG-CNG)*

Fig. 1. does not contain pathways with syngas utilization because of the different magnitude of their energy demand. The value of the omitted pathways in the same unit as in *Fig. 1.* in order of (**Total**; P&C; TF; TP; C&D): HSG_N-LNG (**2.949**; 2.000; 0.944; 0.004; 0.001) HSG_N-LNG-CNG (**2.951**; 2.000; 0.944; 0.004; 0.003) HSG_R-LNG (**1.049**; 0.000; 1.044; 0.004; 0.001) HSG_R-LNG-CNG (**1.051**; 0.000; 1.044; 0.004; 0.003)

The higher magnitude of the syngas pathways can be explained with the high energy intensity of the syngas production technologies (carbon captures, electrolysis). The difference between the nuclear and renewable produced syngas pathways stem from the agreed efficiency values (nuclear: 0.33, renewable: 1.00).

Understandably the lowest value comes from the domestic gas production with local liquefaction plant because of the short transportation and distribution lengths.

landfill gas: the higher value of the production step is compensated with the minimal energy demand of the transportation compared to the import pathways.

Apart from the syngas pathways, the domestic gas productions always bring lower values than the imports. There is no significant difference between the pipeline import or the road transport import.

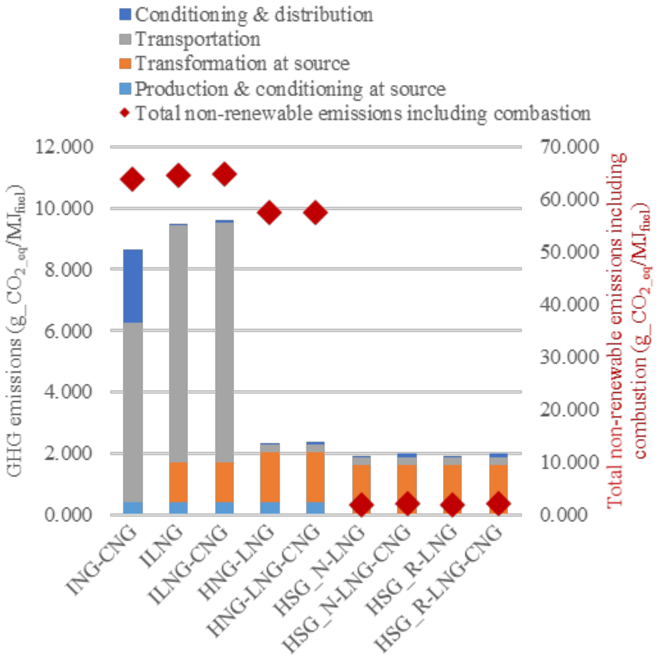

Fig. 2. GHG emissions of the various WTT pathways (without landfill gas: HLG-LNG, HLG-LNG-CNG*)*

Fig. 2. does not contain pathways with landfill gas utilization because of their large negative value. (In the same unit as in *Fig. 2.* in order of (**Total**; P&C; TF; TP; C&D): HLG-LNG (**-556.407**; -558.322; 1.626; 0.256; 0.033), HLG-LNG-CNG (**-556.334**; -558.322; 1.626; 0.256; 0.105). In case of landfill- and syngas utilization, total values are equal to the “Total non-renewable emissions including combustion” value because the combustion of landfill- and syngas can be considered carbon neutral. The high negative value of HLG-LNG and HLG-LNG-CNG regarding the GHG emissions can be explained with the bas case of no utilization of the landfill gas. The assumption was that the nascent landfill gas leaves to the atmosphere thus any utilization makes a huge impact of GHG emissions making these pathways net carbon sinks.

Fig.2. shows that the lowest GHG emissions (apart from the landfill gas utilization) stem from the syngas pathways. Between those, there is no major difference because of the carbon neutral property of the nuclear and renewable energy production.

The largest impacts on GHG emissions can be related to the long distance transports in case of ING-CNG, ILNG and ILNG-CNG. ING-CNG also has a uniquely larger value at C&D because in this case the last step means transforming natural gas to CNG with compression. All the other examined pathways with CNG fuel ends with transforming LNG to CNG by vaporisation.

Since landfill gas utilization pathways can be considered as CO_2 sinks, they are the best case regarding GHG and they are right after the lowest HNG pathways in energy demand. HSG pathways has good values in GHG emissions, however, this advantage is overshadowed by their outstanding value in energy demand.

The pathways with long distance road transport are in the same magnitude regarding both energy demand and GHG emissions as the pathway with conventional pipeline (ING-CNG) transport. The pathways with Hungarian natural gas production (HNG-LNG, HNG-LNG-CNG) are fairly beneficial in both ways.

3.2. Calculating possible external cost savings of local air pollution (TTW)

Here environmental savings based on CNG/LNG projections will be derived regarding the local pollutants of VOC, NO_x and PM. *Table 5, 6 and 7* demonstrate absolute environmental savings using different LNG/CNG spreading projections (low, medium, high).

Table 5. Absolute local environmental savings supposing different CNG/LNG spreading projections for 2020, Hungary (ton/year); negative values indicate the disadvantage of gas

Savings of CNG-LNG (ton/year)

	Low	Medium	High	Low	Medium	High	Low	Medium	High	Category
2020	12.0323	24.0646	48.1291	64.1722	128.3443	256.6886	0.9470	1.8940	3.7879	m1
	4.4348	8.8695	26.6085	31.0433	62.0865	186.2595	0.3490	0.6981	2.0942	n1
	-0.2557	-1.0230	-1.7902	32.3516	129.4065	226.4613	0.2158	0.8631	1.5105	n2
	-0.8023	-1.1462	-2.2924	101.4958	144.9940	289.9879	0.6770	0.9671	1.9342	m3/i,ii
	0.0000	-0.0545	-0.2180	0.0000	14.2603	57.0412	0.0000	0.0303	0.1213	m3/iii
	-0.0532	-0.0710	-0.1774	6.7326	8.9768	22.4421	0.0449	0.0599	0.1497	n3*
	-0.5600	-3.9200	-5.6000	146.5100	1025.5700	1465.1000	0.3115	2.1805	3.1150	n3+04
	SUM VOC			**SUM NO$_x$**			**SUM PM**			
drive	**14.7957**	**26.7194**	**64.6596**	**382.3054**	**1513.6384**	**2503.9807**	**2.5452**	**6.6930**	**12.7128**	

Table 6. Absolute local environmental savings supposing different CNG/LNG spreading projections for 2025, Hungary (ton/year); negative values indicate the disadvantage of gas

Savings of CNG-LNG (ton/year)

	Low	Medium	High	Low	Medium	High	Low	Medium	High	Category
2025	26.2548	131.2740	183.7836	140.0256	700.1280	980.1792	2.0664	10.3318	14.4645	m1
	10.0602	50.3010	70.4214	70.4214	352.1070	492.9498	0.7918	3.9589	5.5424	n1
	-0.5841	-2.9203	-5.8406	73.8841	369.4205	738.8410	0.4928	2.4640	4.9280	n2
	-1.1148	-2.2296	-4.4592	141.0215	282.0431	564.0861	0.9406	1.8812	3.7624	m3/i,ii
	-0.2121	-0.4241	-1.5904	55.4785	110.9569	416.0884	0.1180	0.2359	0.8847	m3/iii
	-0.2016	-0.2822	-0.6048	25.5024	35.7034	76.5072	0.1701	0.2381	0.5103	n3*
	-1.2800	-9.6000	-12.8000	334.8800	2511.6000	3348.8000	0.7120	5.3400	7.1200	n3+04
	SUM VOC			**SUM NOx**			**SUM PM**			
drive	**32.9225**	**166.1187**	**228.9100**	**841.2135**	**4361.9588**	**6617.4517**	**5.2916**	**24.4499**	**37.2123**	

Table 7. Absolute local environmental savings supposing different CNG/LNG spreading projections for 2030, Hungary (ton/year); negative values indicate the disadvantage of gas

Savings of CNG-LNG (ton/year)

	Low	Medium	High	Low	Medium	High	Low	Medium	High	Category
2030	85.3351	199.1153	284.4504	455.1206	1061.9482	1517.0688	6.7162	15.6711	22.3873	m1
	31.4199	73.3131	157.0995	219.9393	513.1917	1099.6965	2.4729	5.7700	12.3643	n1
	-1.8248	-6.0826	-12.1651	230.8332	769.4438	1538.8877	1.5396	5.1322	10.2643	n2
	-1.6015	-4.2708	-6.4061	202.5943	540.2515	810.3772	1.3513	3.6035	5.4052	m3/i,ii
	-0.5077	-1.0155	-3.0464	132.8357	265.6715	797.0144	0.2824	0.5649	1.6946	m3/iii
	-0.3161	-0.6774	-1.3548	39.9878	85.6881	171.3761	0.2667	0.5715	1.1431	n3*
	-3.6000	-21.6000	-28.8000	941.8500	5651.1000	7534.8000	2.0025	12.0150	16.0200	n3+04
	SUM VOC			**SUM NOx**			**SUM PM**			
drive	**108.9049**	**238.7822**	**389.7775**	**2223.1609**	**8887.2947**	**13469.2207**	**14.6316**	**43.3281**	**69.2787**	

As a last step of our calculations we monetize these environmental savings based on the latest document used also by the European Union (Ricardo-AEA, 2013). According to this the environmental cost of 1 ton of emitted VOC by traffic-transport is 1,569 EUR, 1 ton of emitted NO$_x$ is 19,580 EUR, 1 ton of emitted PM is 51,045 EUR (cf. Preiss–Klotz, 2007). Regarding particulate matters (PM) we used the mean of the provided values which contain different effects under urban, suburban, highway and motorway conditions. It is important to note that these monetary values are specific for Hungary, updating of older data were based on the Hungarian income for the year of 2010 (Ricardo-AEA, 2013). Regarding the external costs of local air pollution more accurate values only could be gained by the use of local specific models – which need extremely huge amount of data (Stróbl et al., 2011). We suppose that the above, Hungarian specific average costs were gained by using those kind of complex models.

As continuous rise of the Hungarian incomes can be supposed in the future, our estimations can be regarded very conservative from this perspective, too.

Table 8, 9 and 10 show local external cost savings by CNG/LNG drive for the analyzed pollutants by projections, vehicle categories and years.

Table 8. Local air pollution external cost savings by CNG/LNG driven vehicles in Hungary, 2020 (EUR/year); negative value means higher external

	Low	Medium	High	Low	Medium	High	Low	Medium	High	Category
2020	18,878	37,756	75,512	1,256,461	2,512,922	5,025,845	48,339	96,679	193,357	m1
	6,958	13,916	41,747	607,812	1,215,625	3,646,875	17,816	35,633	106,899	n1
	-401	-1,605	-2,809	633,430	2,533,719	4,434,008	11,015	44,059	77,104	n2
	-1,259	-1,798	-3,597	1,987,240	2,838,915	5,677,829	34,556	49,366	98,733	m3/i,ii
	0	-86	-342	0	279,210	1,116,841	0	1,548	6,191	m3/iii
	-84	-111	-278	131,822	175,762	439,406	2,292	3,056	7,641	n3*
	-879	-6,150	-8,786	2,868,598	20,080,186	28,685,979	15,901	111,305	159,007	n3+04
	SUM VOC			**SUM NOx**			**SUM PM**			
cost	**23,214**	**41,921**	**101,447**	**7,485,363**	**29,636,339**	**49,026,783**	**129,920**	**341,645**	**648,930**	

Table 9. Local air pollution external cost savings by CNG/LNG driven vehicles in Hungary, 2025 (EUR/year); negative value means higher external

	Low	Medium	High	Low	Medium	High	Low	Medium	High	Category
2025	41,192	205,961	288,345	2,741,636	13,708,182	19,191,455	105,478	527,389	738,344	m1
	15,784	78,919	110,487	1,378,818	6,894,092	9,651,729	40,417	202,083	282,916	n1
	-916	-4,582	-9,164	1,446,616	7,233,082	14,466,164	25,155	125,777	251,554	n2
	-1,749	-3,498	-6,996	2,761,136	5,522,272	11,044,545	48,014	96,028	192,055	m3/i,ii
	-333	-665	-2,495	1,086,242	2,172,485	8,146,818	6,021	12,042	45,158	m3/iii
	-316	-443	-949	499,325	699,055	1,497,976	8,683	12,156	26,048	n3*
	-2,008	-15,062	-20,082	6,556,795	49,175,965	65,567,953	36,344	272,583	363,444	n3+04
	SUM VOC			**SUM NOx**			**SUM PM**			
cost	**51,653**	**260,630**	**359,146**	**16,470,570**	**85,405,133**	**129,566,638**	**270,112**	**1,248,057**	**1,899,519**	

Table 10. Local air pollution external cost savings by CNG/LNG driven vehicles in Hungary, 2030 (EUR/year); negative value means higher external

	Low	Medium	High	Low	Medium	High	Low	Medium	High	Category
2030	133,886	312,400	446,285	8,911,051	20,792,453	29,703,504	342,831	799,939	1,142,770	m1
	49,296	115,024	246,479	4,306,310	10,048,056	21,531,548	126,228	294,533	631,142	n1
	-2,863	-9,543	-19,086	4,519,606	15,065,354	30,130,708	78,592	261,973	523,947	n2
	-2,513	-6,701	-10,051	3,966,703	10,577,874	15,866,811	68,978	183,940	275,910	m3/i,ii
	-797	-1,593	-4,780	2,600,862	5,201,724	15,605,173	14,417	28,833	86,500	m3/iii
	-496	-1,063	-2,126	782,942	1,677,733	3,355,465	13,615	29,174	58,349	n3*
	-5,648	-33,889	-45,185	18,440,987	110,645,920	147,527,894	102,219	613,311	817,748	n3+04
	SUM VOC			**SUM NO$_x$**			**SUM PM**			
cost	**170,865**	**374,635**	**611,537**	**43,528,461**	**174,009,114**	**263,721,103**	**746,879**	**2,211,704**	**3,536,364**	

Summing up of all vehicle categories data for the year 2030, for the pollutant VOC we project 171,000 EUR (low level of gas drive spreading) or 612,000 EUR (high level of gas drive spreading) external cost savings. For the pollutant NO$_x$ we project 43,528 EUR (low level of gas drive spreading) or 263,721,000 EUR (high level of gas drive spreading) external cost savings. For the pollutant PM we project 747,000 EUR (low level of gas drive spreading) or 3,536,000 EUR (high level of gas drive spreading) external cost savings.

Summing up our data for all three analyzed local pollutants for all vehicle categories even the most pessimistic scenario gives 44.5 million EUR external cost savings, while in the most optimistic case we might have 268 million EUR external cost savings – only for the year of 2030, in Hungary. It is important to stress here that these data are the result of a very conservative estimation process (see earlier). *Fig. 3.* summarizes the possible local annual external cost savings for the individual scenarios. (For gaining the present value of those potential savings we would need to discount all those future values.)

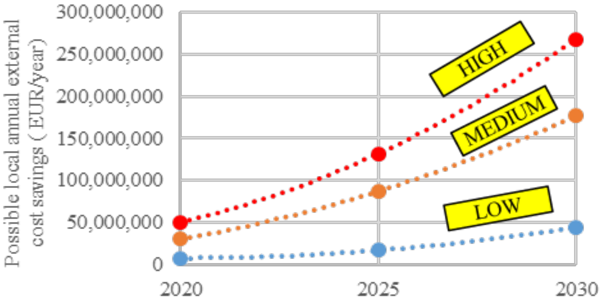

Fig. 3. Possible local annual external cost savings for the low, medium, and high spreading scenarios of CNG/LNG driven vehicles in Hungary (undiscounted values)

3.3. Calculating possible external cost savings of global air pollution (tank to wheel)

The most important two greenhouse gases of global climatic change are CO_2 and CH_4. Both are relevant regarding the spread of the CNG/LNG driven vehicles. According to *Table 4 huge advantages can be realized at CO_2 emissions and moderate disadvantages are at CH_4 emissions* when comparing gas driven vehicles to Euro 6 diesel driven ones. It is important to highlight again that we assumed that the specific differences between these two drives will be conserved at the level observed in 2015. It is an extremely conservative assumption regarding the CH_4 emission because technological development is going to significantly weak today's methane leakage of gas-driven engines soon. In any case, despite of this severe assumption, our calculations show persuasive advantages of the CNG/LNG driven vehicles against the today's best diesel driven ones. During our analysis we transformed CH_4 emissions into CO_2 equivalents based on its global warming potential (GWP).

According to the latest report of the Intergovernmental Panel on Climate Change (IPCC, 2014), one ton of CH_4 equals to 28 tons of CO_2 in global warming potential. Thus, the two types of emissions have now a common measure and potential savings will be given in CO_2 equivalents later. *Table 11* illustrates absolute savings by years, drives and scenarios.

Table 11. Absolute global environmental savings supposing different CNG/LNG spreading projections for 2020, 2025 and 2030, Hungary in CO_2 equivalent (ton/year, CO_2 and CH_4 together)

	Low	Medium	High		Low	Medium	High		Low	Medium	High	Category
2020	2,670	5,341	10,681	**2025**	5,827	29,133	40,786	**2030**	18,938	44,189	63,127	m1
	1,559	3,118	9,354		3,537	17,684	24,757		11,046	25,774	55,229	n1
	1,331	5,326	9,320		3,041	15,204	30,408		9,500	31,667	63,335	n2
	2,416	3,452	6,904		3,357	6,715	13,429		4,823	12,862	19,293	m3/i,ii
	0	342	1,369		1,332	2,663	9,987		3,188	6,377	19,130	m3/iii
	333	445	1,111		1,263	1,768	3,788		1,980	4,243	8,486	n3*
	3,630	25,409	36,299		8,297	62,227	82,969		23,335	140,010	186,680	n3+04
	SUM CO_{2e}				**SUM CO_{2e}**				**SUM CO_{2e}**			
	11,940	**43,432**	**75,039**		**26,653**	**135,393**	**206,125**		**72,811**	**265,121**	**415,280**	

As a last step of our calculations we monetize these environmental savings in CO_2 equivalent based on the latest document used also by the European Union (Ricardo-AEA, 2013). According to this the environmental cost of 1 ton of emitted CO_2 by traffic-transport is 90 EUR. Regarding the global nature of the problem this data is globally valid for the whole European Union, it is not specific for Hungary. As continuous rise of the Hungarian incomes can be supposed in the future, our estimations can also be regarded very conservative from this perspective.

Table 12 shows global external cost savings by CNG/LNG drive for the CO_2 and CH_4 by projections, vehicle categories and years.

Table 12. Global air pollution external cost savings by CNG/LNG driven vehicles in Hungary, 2020, 2025 and 2030

(EUR/year)

	Low	Medium	High		Low	Medium	High		Low	Medium	High	Category
2020	240,325	480,649	961,299	**2025**	524,396	2,621,979	3,670,771	**2030**	1,704,427	3,976,996	5,681,423	m1
	140,315	280,631	841,893		318,305	1,591,524	2,228,133		994,126	2,319,626	4,970,628	n1
	119,832	479,328	838,824		273,670	1,368,352	2,736,705		855,018	2,850,060	5,700,119	n2
	217,470	310,672	621,343		302,160	604,320	1,208,640		434,089	1,157,571	1,736,357	m3/i,ii
	0	30,806	123,223		119,847	239,693	898,849		286,957	573,913	1,721,740	m3/iii
	30,004	40,006	100,014		113,652	159,113	340,957		178,207	381,872	763,744	n3*
	326,689	2,286,826	3,266,895		746,719	5,600,391	7,467,188		2,100,147	12,600,880	16,801,174	n3+04
	SUM CO_{2e}				**SUM CO_{2e}**				**SUM CO_{2e}**			
	1,074,636	**3,908,918**	**6,753,491**		**2,398,749**	**12,185,373**	**18,551,244**		**6,552,970**	**23,860,918**	**37,375,184**	

Summing up our data for all vehicle categories even the most pessimistic spreading scenario gives 6.55 million EUR external cost savings, while in the most optimistic case we might have 37.38 million EUR external cost savings – only for the year of 2030, in Hungary. It is important to stress here that these data are the result of a very conservative estimation process as supposed that the difference between the CNG/LNG driven vehicles and the diesel (and petrol) driven vehicles will be frozen in the future. This is less realistic, especially regarding the methane slip of today's gas-driven engines. It is possible, that by 2025 there will be no CH_4 emissions from the newly developed gas driven engines.

Fig. 4. summarizes the possible local annual external cost savings for the individual scenarios. (For gaining the present value of those potential savings we would need to discount all those future values.) Though it is not related directly to the avoided external costs, there is another important relation regarding the spreading of CNG/LNG driven vehicles, namely the income from the possibly sold CO_2 quotas by Hungary.

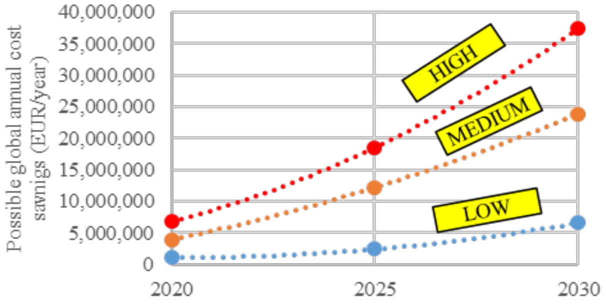

Fig. 4. Possible global annual external cost savings for the low, medium, and high spreading scenarios of CNG/LNG driven vehicles in Hungary (undiscounted values)

REFERENCES

Institute for Transport Sciences non-profit Ltd. - KTI (2016): Spread of CNG/LNG fuels, PAN-LNG Project Manuscript

IPCC (2014): Climate Change 2014: Synthesis Report; Fifth Assessment Report, AR5

JRC Technical Reports (2013): Well-to-Tank Report Version 4.0. JEC Well-to-Wheels analysis

Preiss, P. – Klotz, V. (2007): Description of updated and extended draft tools for the detailed site-dependent assessment of external costs; Technical Paper No. 7.4 – RS 1b

Ricardo-AEA et al. (2013): Update of the Handbook on External Costs of Transport. Final Report. Report for the European Commission: DG Move

Appendix A. VEHICLE CATEGORIES

m1: passenger car
n1: pick-up truck (Gross Vehicle Weight (GVW) <3,5 t)
n2: commercial truck (GVW 3,5-12,0 t)
m3/i,ii: line-haul bus
m3/iii: long-distance bus
n3*: commercial truck (GVW >12,0 t)
n3 + o4: commercial truck and trailer (GVW 30,0-40,0 t)