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COMPARISON OF TOTAL LIFECYCLE EMISSION OF AIRCRAFT WITH DIFFERENT PROPULSION SYSTEM

This paper briefly introduces a new methodology developed for total impact evaluation of the vehicles and transportation systems, compares the application of this study in conventional, hybrid and fully electric aircraft type of propulsion systems. The most important novelties of the applying methodology are as follows: (i) all the impact (environmental impact, safety and security, cost, cost benefits and sustainability are analysed), (ii) the impacts are evaluated on the vehicle and might be evaluated on the transportation system levels, and (iii) generating the total impact index. This paper discusses only the differences in determining the total impact caused by using the different propulsion concepts.

Keywords: *total impact; aircraft conventional, hybrid, electric propulsion systems; e-mobility*

INTRODUCTION

The Flightpath 2050 [1] completed by High Level Group on Aviation Research for European Commission has created the Europe's vision on future air transport. The overall, highly ambitious goal is defined as "Aviation serves the citizen, brings people together and delivers goods through seamless, safe and secure, cost effective transport chains, adding value through speed, reliability and resilience in a global network, over any distance, without negative effects on the environment."

The last words "without negative effects on the environment" generates a very serious and hard condition. Even the authors of the Flightpath 2050 [1] had defined the sub-goals of the objectives „Protecting the environment and the energy supply" as

- In 2050 technologies and procedures available allow a 75% reduction in CO2 emissions per passenger kilometre to support the ATAG (Air Transport Action Group) target and a 90% reduction in NOx emissions.
- The perceived noise emission of flying aircraft is reduced by 65%. These are relative to the capabilities of typical new aircraft in 2000.
- Aircraft movements are emission-free when taxiing.
- Air vehicles are designed and manufactured to be recyclable.
- Europe is established as a centre of excellence on sustainable alternative fuels, including those for aviation, based on a strong European energy policy.
- Europe is at the forefront of atmospheric research and takes the lead in the formulation of a prioritised environmental action plan and establishment of global environmental standards.

For achieving of this sub-goal alternative and sustainable energy must be used. The first steps in development of such new greener air transport are based on improving the technologies using the biofuel and developing the hybrid and electric propulsion systems (Fig.1.). The aircraft alternative configuration, using the hydrogen, hydrogen fuel cells and high spewed propulsion systems as scramjets, magneto - hydro - dynamic scramjets need considerable greater time for further studies.

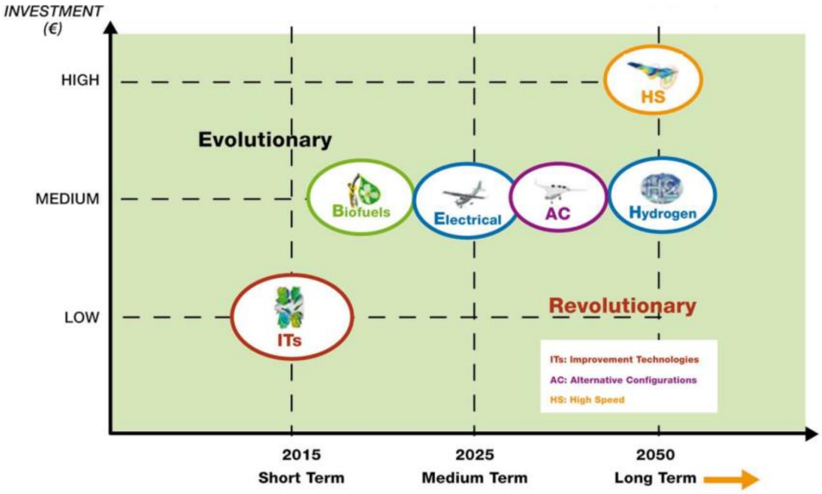

Figure 1.Technologies versus Investment/Time

The Figure 2. shows that, the electric propulsion systems might be applied to the small and medium size aircraft, only

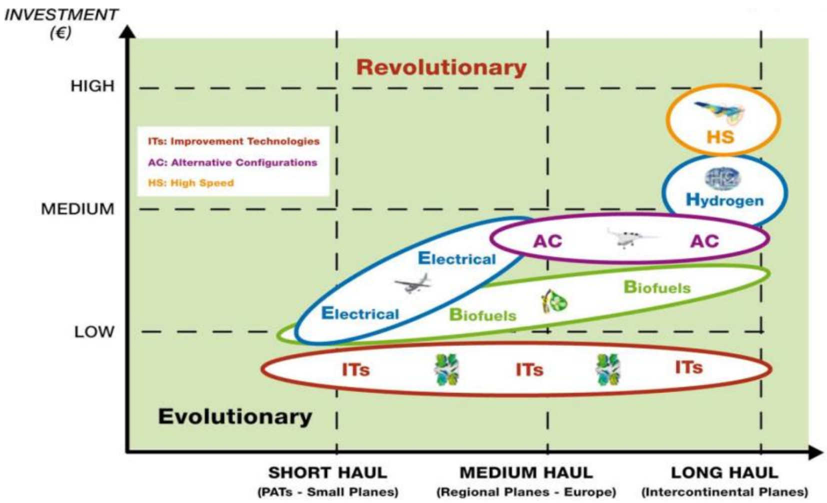

Figure 2. Technologies versus Investment/Aircraft Type

Several Hungarian projects are already dealing with developing the hybrid and electric propulsion systems, aircraft with such systems. One of them, is the EFOP-3.6.1-16-2016-00014 project supporting the contribution of this paper, too (see acknowledgment at the end of paper).

This paper deals with the possible comparison of the aircraft with conventional (piston engine), hybrid and fully electric propulsion systems based on total impact. After some preliminary considerations, the paper briefly introduces a new methodology developed for total impact evaluation of the vehicles and transportation systems and its application to comparison studies. The most important novelties of the applying methodology are as follows: (i) all the impact (environmental impact, safety and security, cost, cost benefits and sustainability are analysed), (ii) the impacts are evaluated on the vehicle and might be evaluated on the transportation system levels, and (iii) generating the total impact index. This paper discusses only the differences in determining the total impact caused by using the different propulsion concepts with reference to the 4 seater aircraft.

PRELIMINARY CONSIDERATIONS

A lot of people think that, using the aircraft means wasting the energy and giving a biff to environment protection. In reality, the aviation has the best results in efficiency improvements of environmental impact reduction (Fig. 3.).

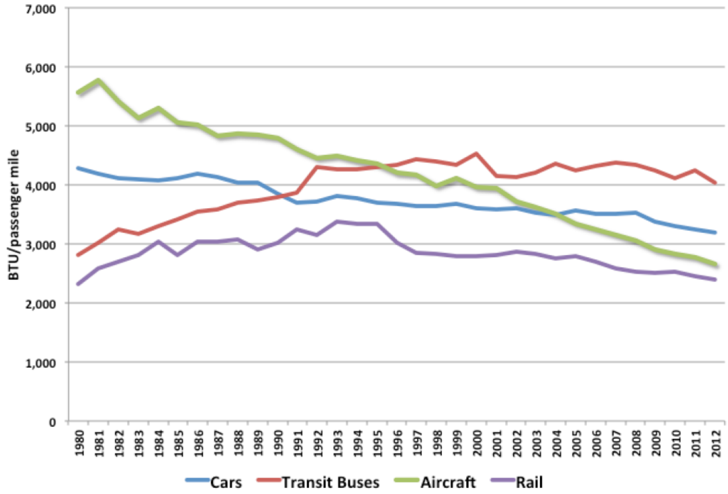

Figure 3. Vehicle Fuel efficiency based on US data [3, 4]
(BTU - British Thermal Unit equals approximately to 1.057 KJ)

The CO_2 emission from aviation piston engines far from the theoretic 3.17 kg/l because the very incomplete combustion and it can be approximated as 2 kg/l, only [5].

The Figure 4. shows that, in Europe, about half of electrical energy is generated by use of combustible fuels [5]. According to the WNA – World Nuclear Association report [6] the lifecycle greenhouse gas (GHG) emissions in case of using the combustible fuel equal to from 400 up to 1300 tons of CO_2e / GWh depending on the type of fuel (natural gas, oil, coal) and applied technologies. These emissions about 20–50 times greater than the GHG emissions in cases of generating the electricity from nuclear, hydro or wind energy. Therefore in Europe, the GHG emission of electric energy generation about 450 tons CO_2e / GWh. It means, the European energy generation emits 0.45 kg CO_2e/kWh.

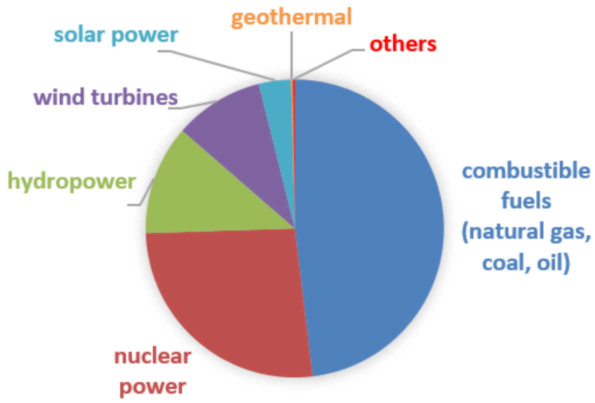

Figure 4. Net electricity generation in EU28 [5]

Let start with a very simple calculations. The typical aviation fuel applied to piston engine is the AVGAS 100, the heating value of which equals to 43.5 MJ. It is equivalent to 12.08 kWh. The aircraft piston engine has energy efficiency coefficient about 30% [7] and the propeller system efficiency is around 85% [8]. So energy total energy efficiency of aircraft piston engine propeller system is 25.65%. At the same time, the energy efficiency of electric power system nearly 100%, but taking into account the losses in energy supply chain the total energy efficiency might be defined as 95%. So, burning the 1 litre aviation fuel equals to using the 0.2565×12.083/0.95 = 3.26 kWh. (or burning 1 kg fuel equals to 3.26 kWh.) That means, the GHG, namely CO2e emission of aircraft with piston engine and with electric propulsion system equal to 2 [9] and 1,467 kg for 1 litre fuel equivalent, respectively.

Another interesting effect caused by use of accumulator banks having considerable weights comparing to the vehicle dry weight. The battery banks performance are increasing very rapidly. Why in 2009 the energy density was about 120 Wh/kg [10], by 2015 it had reached 260 Wh/kg [11]. The existing cars still use the battery of about 180 – 200 Wh/h energy density. At the same time, the electric cars are completed by battery of 80 – 100 kWh instead of 24–36 kWh used in early electric cars. This energy is enough already for 600 – 700 km driving.

The vehicle weight breakdown shows that; the engine weight reduces by 60–75 % when replaced by electro motors. However, the mass of battery banks increases the aircraft weight with 100 – 400 % depending on the accepted considerable reduction in range.

For example, in case of replacing the piston engine with electric motor in a moderate size 4 seater aircraft analogic to the Cessna 172N the mass breakdown may change as shown in Figure 5.

As it can be seen, the take-off mass increases by 70%, that increases the airframe mass to nearly 40%. The initial empty mass increases from 510 kg up to 1360 kg because the battery bank has about 800 kg, while the electric motor has about 120 kg – less mass. If it still seems acceptable, the aircraft performance must be checked, too. The initial piston engine has 120 kW power and the aircraft may use more than 200 litres of fuel flying a distance of 1290 km. If replaced with 800 kg battery mass which under normal conditions stores only 200 kWh energy, this allows aircraft to fly for 360 km distance only, at the same cruise speed.

This preliminary calculations demonstrate, the technology does not allow to make acceptable and affordable electric aircraft. Therefore, the hybrid aircraft development should be in focus.

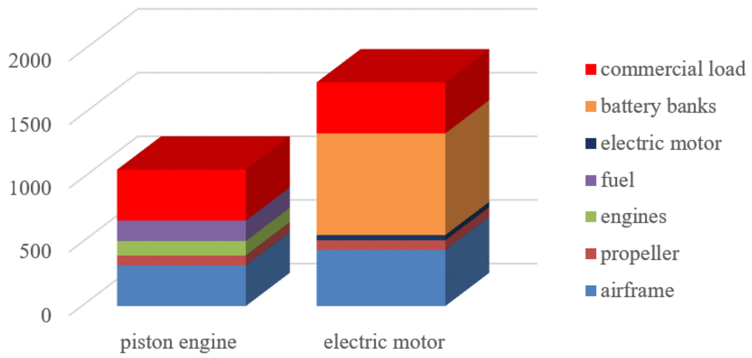

Figure 5. Take-off mass breakdown of the aircraft with conventional and with full electric propulsion system. (The performances of the aircraft are the same except the range, that is 82% less in case of full electric aircraft comparing to the conventional one).

METHODOLOGY – TOTAL IMPACT PERFORMANCE INDEX

The Department of Aeronautics, Naval Architecture and Railway Vehicles at the Budapest University of Technology and Economics has a long term research program developing methodologies for determining the environmental impacts and their application [12][13][14][15][16].

The Research program has resulted to developing a special total performance index and methodology for its calculations. The simplified and unique index evaluating the total impact is given in form of total cost induced by all life cycle effects of transportation system in form of related to unit of transport work (pkm or tkm):

$$TPI = \frac{TLCC}{TLCW} = \frac{TOLCC}{TLCW} + \frac{TILCC}{TLCW} = TOPI + TIPI\,, \tag{1}$$

where TPI is the total performance index, TOPI is the total operation performance index, TIPI total impact performance index, TLCC/TOLCC/TILCC are the total / total operational / total impact LCC (life cycle cost) and the TLCW is the total life cycle work.

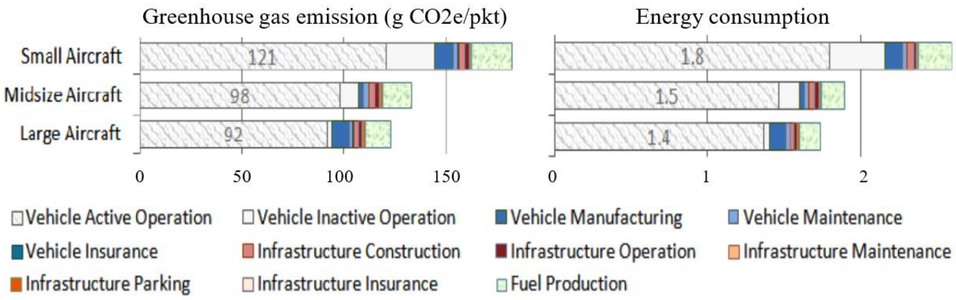

Figure 6. Total and total CO_2e emission and total energy consumption calculated for air transport [17]

The *TOPI* defining the operational cost of the given vehicle, given transportation mode is well known and applied by owners, operators, service providers. They use it in selecting the aircraft, evaluation of the mixed fleets determining the optimized transportation chain. While, principally, the *TIPI* deals with the externality. This is the index that might be used in impact assessment.

The *TIPI* summarizes all the impacts:

$$TIPI = \sum_{i=1}^{n} TIPI_i = \frac{\sum_{i=1}^{n} TILCC_i}{TLCW}$$

where $i = 1, 2, \ldots n$ define the different groups of impacts. According to the transportations systems, i = safety and security; environmental impacts; system peculiarities; system support; use of resources.

The *TIPI* for group of impacts can be determined as sum of the different effects:

$$TIPI_i = \frac{\sum_{j=1}^{m} \sum_{k=1}^{l} \sum_{q=1}^{r} N_{j,k,q}\, p_{j,k,q}\, I_{j,k,q} \sum_{v=1}^{u} o_{j,k,q,v}\, c_{j,k,q,v}}{TLCW_i} \qquad \forall i\,,$$

$$TLCW_i = \sum_{j=1}^{m} \sum_{k=1}^{l} \sum_{q=1}^{r} N_{j,k,q}\, W_{j,k,q} \tag{3}$$

where $j = 1, 2, \ldots m$ depicts the subgroups of impacts, while $k = 1, 2, \ldots l$ defines the transport means, $q = 1, 2, \ldots, r$ represents the types or groups of the given transport system, $v = 1, 2, \ldots,$

u identifies the different forms of consequences, *N* is the number of sub-sub-group elements contributors to the impact, like number of vehicles defined by *q*, *p* is the parameter of the given types or group of system elements causes the investigated effects, *I* is the impact indicator of the given system element, *o* the outcomes / consequences of impact defined by *I* or caused by the events, situations associated with the *I* indicator, *c* is the conversation coefficient for calculating the (external) cost and *W* is the work done during the investigated period defined by *p*. it means, if the p is the parameter of function given in form of average annual unit, then the *W* should related to the year, too. For example, if the *N* defines the number of vehicle and *p* is the annual average running of the vehicles, then the *W* equals to *p*.

The *p* parameter acts as weighting coefficient, or weighting function, too. Of course it depends on goals and level of studies and on the vehicle or system characteristics, parameters defined by the applied indicators. The consequences, *o*, namely function of consequences take into account the outcomes form the impact characterized by the performance indicator. The consequences might be divided into more forms harmonized with the applied impact indicators. For example, the simple accident may cause damages in (i) vehicle, (ii) transport infrastructure, (iii) buildings, (iv) cultural values, etc. and the human casualty might be classified, too, as fatality, severe and slight injury. The consequences are defined as function of outcomes, because they depend on level of economy and may change during the life cycle frame.

With taking into account the functions of parameters, impact indicators, consequences and conversation coefficients, the formula (3) can be rewritten in several other forms:

$$TIPI_i = \frac{\sum_{j=1}^{m}\sum_{k=1}^{l}\sum_{q=1}^{r} N_{j,k,q} f_{p_{j,k,q}}(p_{j,k,q}) f_{I_{j,k,q}}(I_{j,k,q}) \sum_{v=1}^{u} f_{o_{j,k,q,v}}(o_{j,k,q,v}) f_{c_{j,k,q,v}}(c_{j,k,q,v})}{TLCW_i} \quad \forall i\ , \quad (4.a)$$

$$TIPI_i == \frac{\sum_{j=1}^{m}\sum_{k=1}^{l}\sum_{q=1}^{r} N_{j,k,q} f_{p_{j,k,q}}(p_{j,k,q}) \sum_{v=1}^{u} f_I(I_{j,k,q,v}) f_{o_{j,k,q,v}}(o_{j,k,q,v}) f_{c_{j,k,q,v}}(c_{j,k,q,v})}{TLCW_i} \quad \forall i \quad (4.b)$$

These methods developed for TIPI calculations can be applied to vehicle, equivalent vehicle, fleet, or to the transportation company, transport means, transport sector, etc. Therefore, this methodology developed for calculation of the introduced total impact performance index is structured in hierarchic form and realized in a simplified excel table.

Applying the tool, it must be adapted to the real calculation by (i) definition the goals, (ii) size and (iii) level of investigation, as well as (iv) possible sources of data, (v) economic and (vi) societal conditions.

Principally all the required information might be defined, derived from the existing statistical data, references, research reports [17][18][19][20][21][22][23][24][25]. However, the data very sensitive to the real situations including the economy, culture, etc. of the region or country investigated. Therefore, this paper introduces the developing excel table for TIPI calculation and demonstrates it applicability on example e-vehicles. The describing methodology is based on formulas (4).

The developed excel table contains the following columns:

- number of rows,
- region or area of investigation (like Europe, or Hungary, or it might be a large or even small company, etc.)

- code number – completed from the indexes,
- group of impact (GI) (depicted by index "i),
- sub-group of impact (SGI) (identified by index "j"),
- transport means (TM) (indexed by "k", k = 1, 2, …; namely road, railway, water, and air transport that might be divided into more subgroups, because the road transport contains the city or urban transport highway transport, rural transport, or cars, busses, light and have vehicles, etc., here road transport conventional hybrid and electric passenger cars),
- number of studied elements or merit, i.e. value of the chosen governing parameter,
- applied general parameter describing the aspects or impact calculated,
    - applied parameters, their appellations and values (for each parameter that defines – here – the general average running distance pro year),
    - formula (using for determining the general parameter by use of defined, applied parameters) and calculated values,
- general impact indicator
    - applied indicators, their appellations and values (that defines the general impact),
    - formula (using for determining the general impact indicator) and its calculated value,
- outcomes (determined by use of same methods as it applied to general parameter and general impact indicator calculations),
- cost coefficient (determined by use of same methods as it applied to general parameter and general impact indicator calculations),
- work (two columns: dimension and value),
- results (summarized in 5 columns: $TIPI_{i,j,k,q}$, $TIPI_{i,j,k}$, $TIPI_{i,j}$, $TIPI_i$, and TIPI),
- the developing excel table can be used if the parameters, impact indicators, outcomes, etc. will be defined and calculated.

RESEARCH OF COMPARISON STUDIES

There are two major difference in calculation of the total impact performance index of the aircraft with conventional (piston engine), hybrid and electric propulsion systems, namely impact of used electrical energy instead of the impact of fuel that is used for electrical energy generation and impact induced by total using (production, operation, recycling) the electric accumulators. These impacts are considerable depending on mix in electric generation [6]. According to the available information [26][27][28] as average 586 MJ energy required for producing the each KWh accumulator capacity. By using this and data on CO_2e emission of electric energy generation, the Figure 7. shows large differences in emission of accumulator production depending on the regions.

Comparing to the production, during recycling of the butteries, the CO_2e emissions are only 1–2 kg /kWh depending on the applied technologies.

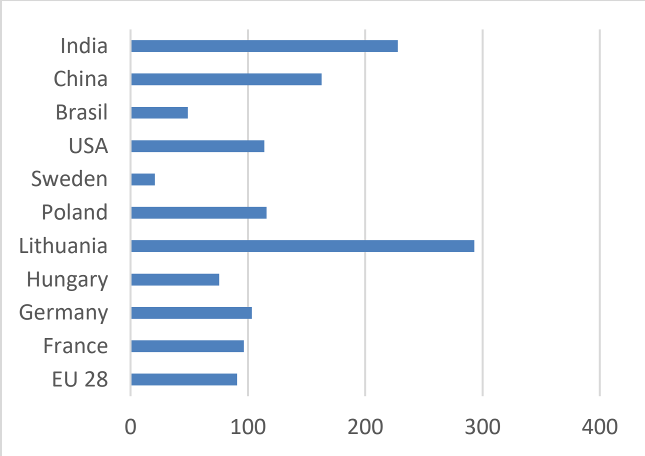

Figure 7. Battery production emission (CO_2e - kg/kWh)

In the further investigation the European average mix in electrical energy generation is used. Nowadays, the greenhouse gas emission might be accounted as one of the most important emission factor, therefore, it is used for comparison of the aircraft with different propulsion system.

For this study, five different 4 – seater aircraft were selected. The first one is the conventional small aircraft with piston engine. Two aircrafts equipped with hybrid propulsion systems, the electric sub-systems allow to fly for 15 and 45 minutes in full electric modes. And two are fully electric aircraft having accumulator banks of 200 and 400 kWh.

The Table 1. contains the mass breakdown of the investigated aircraft that had been determined from the initial aircraft analogical to the well-known Cessna 172N. The hybrid aircraft have the same flight performance as the initial aircraft. Because the battery their take-off weights increased by 13.5 and 28.5%. The battery masses were calculated from power density equals to 250 Wh/kg. The masses of sub-systems were determined from the weight balance of the developed aircraft. For example the airframe mass is increasing with increasing the mass of power plants. The fully electric aircraft cannot have flight performance analogic to the initial aircraft. The Aircraft take-off masses were increased by 61.5 and 142.5% in case of using 200 and 400 kWh capacities and the range were reduced for 72.3 and 60% respectively.

aircraft type / sub systems	conventional	hybrid 15	hybrid 45	electric 200	electric 400
airframe	320	345	380	440	510
propeller	77	77	80	87	98
engines	115	105	90	0	0
fuel	184	176	156	0	0
electric motor	0	40	42	44	50
battery banks	0	100	260	800	1600
commercial load	400	400	400	400	400
take-off mass	**1096**	**1243**	**1408**	**1771**	**2658**
performance					
wing loading (kg/m^2)	68,6	70	72	76	92
engine power (kW)	120	110	95	0	0
energy (kWh)	0	25	65	200	400
cruise speed (km/h)	226	226	226	200	200
range (km)	**1300**	**1300**	**1300**	**360**	**520**

Table 1. Mass breakdown of the investigated aircraft (kg)

So, as it can be seen, the fully electric aircraft cannot be realized yet, till the minimum power density about four times greater is achieved. Even in such case the range will be considerable reduced.

The total life cycle CO_2e emission of the investigated aircraft are shown in Figure 8.

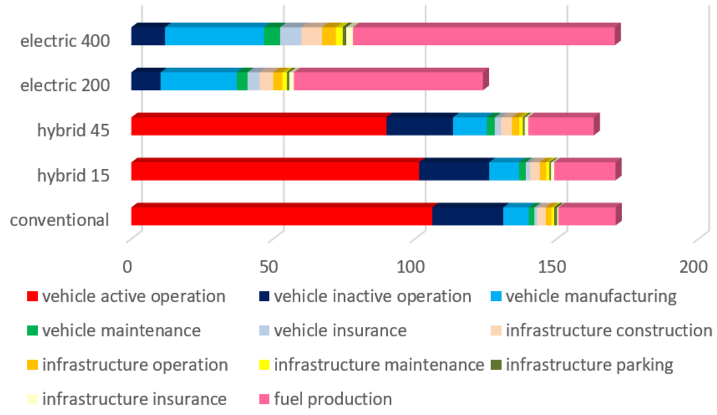

Figure 8. The greenhouse emissions of the investigated aircraft (g/pkm)

The figure 8. shows that the greenhouse emission is considerably reduced in case of radically cutting the range (electric aircraft 200). The hybrid aircraft have small reduction in greenhouse emissions, but it may really reduce the environmental impact levels in airport regions.

CONCLUSIONS

Nowadays, the environmental impact reduction and development of the small / personal aircraft transportation systems are in focus of the future aviation development. The objective of this paper was the comparison analysis of the aircraft with conventional (piston engine), hybrid and fully electric small aircraft. After some preliminary considerations on target propulsion systems of the future aircraft developments and electric generation mix, a special total life cycle impact calculation method was introduced developed at the Department of the Aeronautics, Naval Architecture and Railway Vehicles at the Budapest University of Technology and Economics. The developed methodology has a several important novelties as (i) all the impact (environmental impact, safety and security, cost, cost benefits and sustainability are analysed, (ii) the impacts are evaluated on the vehicle and maybe evaluated on the transportation system levels, and (iii) generating the total impact index.

The briefly described methodology was applied to 5 different small aircraft: a conventional aircraft, two hybrid propulsion type aircraft and two fully electric type of propulsion aircrafts. The aircrafts were preliminary designed with analogical flight performance of the initial conventional aircraft. The impact comparison was based on the total life cycle greenhouse emission determined for 1 pkm.

The following conclusions have been derived from the analysis: (i) full electric aircraft might be developed with radical decreasing in range of aircraft, while (ii) the hybrid aircraft may have smaller environmental impact generally, and (iii) their most important advance is the radical cutting of the environmental impacts (emission) in airport regions.

The total impact analysis requires some further investigations.

REFERENCES

[1] Flightpath 2050, Europe's Vision for Aviation, Maintaining Global Leadership and Serving Society's Needs, Report of the High Level Group on Aviation Research, European Commission, Directorate-General for Research and Innovation, Directorate-General for Mobility and Transport, 2011, p. 28.

[2] From air transport system 2050 vision to planning for research and innovation, EREA - Association of European Research Establishments in Aeronautics, 2012, p. 46

[3] Aviation emissions, impact and mitigation: a primer, FAA, Office of Environment and Energy, 2015, p. 42.

[4] Transportation Energy Data Book, Edition 33, July 31, 2014, http://cta.ornl.gov/data/tedb33/Edition33_Chapter02.pdf,

[5] Electricity production, consumption and market overview, EUROSTAT, Statistics Explained, http://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_production,_consumption_and_market_overview

[6] Comparison of lifecycle greenhouse gas emissions of various electricity generation sources, WNA - World Nuclear Association Report, 2011, p. 12. http://www.world-nuclear.org/uploadedFiles/org/WNA/Publications/Working_Group_Reports/comparison_of_lifecycle.pdf

[7] Epstein, A. H. Aeropropulsion for commercial aviation in the twenty-first century and research directions needed, AIAA Journal 52(5), 2014, pp. 901-911, doi:10.2514/1.J052713

[8] McCormick, B. W. Aerodynamics, aeronautics and flight mechanics. 2nd ed. New York: John Wiley and Sons., Inc; 1995. 652 p.

[9] FOCA Data Base for aircraft piston engine emission factors, Appendix 2: In-flight m4easurements, Federal Department of the Environment, Transport, Energy and Communications DETEC, Federal Office of Civil Aviation FOCA, Aviation Policy and Strategy Environmental Affairs, Swiss Confederation, Bern, ref. No. 33-05-003, 2006, p. 77.

[10] Lowe, M., Tokuoka, S., Trigg, T., Gereffi, G. Lithium-ion batteries for electric vehicles. The U.S. value chain, Center on Globalization Governance and Competitiveness, 2010, p. 76.

[11] Crabtree, G., Kics, e., Trahey, L. The energy-storage frontier: Lithium-ion batteries and beyond, MRS Bulletin, Vol. 40, issue, 12, 2015, pp. 1067 - 1076

[12] Rohács J. Emission scattering simulation for airport region, ICAS 2002, 23rd International Congress of Aeronautical Sciences, Toronto, 8 to 12 September, 2002, ICAS 2002.7.11.2. pp. 6. http://www.icas.org/ICAS_ARCHIVE/ICAS2002/PAPERS/7112.PDF

[13] Rohács, J., Simongáti, Gy. The role of inland waterway navigation in a sustainable transport system, „Transport Research" Journal of Vilnius Geodiminas Technical University and Lithuanian Academy of Sciences, Vol. XXII. No. 3, 2007, pp 148 – 153. printed version, ISSN1648-4142,

[14] Rigo. N., Hekkenberg, R., Ndiaye, A. B., Hargitai, L. Cs., Hadházi, D., Simongáti, Gy. Performance assessment of intermodal chains, European Journal of Transport and Infrastructure Research: Quarterly:(4) 2007pp. 283-300.

[15] Bicsák, Gy., Hornyák, A., Veress, Á. Numerical Simulation of Combustion Processes in a Gas Turbine In: ICNPAA 2012 World Congress: 9th International Conference on Mathematical Problems in Engineering, Aerospace and Sciences., AIP (American Institute of Physics) Conference Proceedings, Vol. 1493, pp. 89-97. (2010)

[16] Rohacs, D., (et al. 2013) Voskuijl, M., Rohacs, J. Schoustra, R.-J. Preliminary evaluation of the environmental impact related to aircraft take-off and landings supported with ground based (MAGLEV) power, Journal of Aerospace Operations, OS Press, Vo.l. 2., No. 3.-4., 2013, pp. 161-180. ISSN 2211-002X (Print), 2211-0038

[17] Chester, M. V., Horvath, A. Environmental assessment of passenger transportation should include infrastructure and supply chains, Environmental Research Letters, Vol. 4. No. 2. 4, 2009, [024008]. DOI: 10.1088/1748-9326/4/2/024008

[18] Bickel, P., Friedrich, R., Burgess, A, Fagiani, P., Hunt, A., De Jong, G., Laird, J., Lieb, C., Lindberg, G., Mackie, P., Navrud, S. Developing harmonised European approaches for transport costing and project assessment (HEATCO). Deliverable D6: Case Study Results: IER, University of Stuttgart. 2006.

[19] HEATCO - Developing Harmonised European Approaches for Transport Costing and Project Assessment, Deliverable 5. Proposal for Harmonised Guidelines, IER, Germany, 2006

[20] Mailbach, M., Schreyer, C., Sutter, D., van Essen, H. P., Boon, B. H., Smokers, R., Schroten, A., Doll, C., Pawlowska, B., Bak., M. Handbook on estimation of external costs in the transport sector, Produced within the study Internalization Measures and Policies for All external Cost of Transport (IMPACT), Delft, 2008., p. 336.

[21] Van Essen, H., Scroten, A., Otten, M., Sutter, D., Schreyer, C., Zandonella, R., Maibach, M., Doll, C. External costs of transport in Europe, Update study for 2008, CE Delft.,2011, p. 163., http://www.cer.be/sites/default/files/publication/2312_External_Costs_update_study_FINAL.pdf (downloaded at April 6, 2017)

[22] IPCC Climate Change 2014: Mitigation of Climate Change. Intergovernmental Panel on Climate Change (IPCC), Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA., p. 1454., https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_full.pdf

[23] Korzhenevych, A., Dehnen, N., Bröcker, J., Holtkamp, M., Meier, H., Gibson, G., Varma, A., Cox, V. Update of the Handbook on External Costs of Transport, Final report, Ricardo-AEA/R/ ED57769 Issue Number 1, 8th January, 2014, p. 139., https://ec.europa.eu/transport/sites/transport/files/themes/sustainable/studies/doc/2014-handbook-external-costs-transport.pdf (accessed at 24 of August, 2017)

[24] WRI - World Resources Institute: Climate Analysis Indicators Tool (CAIT) 2.0: WRI's climate data explorer, http://cait.wri.org/, May 2014. (accessed, April 5, 2017)

[25] Statistical pocketbook 2016, EU transport in figure, European Commission, European Union, 2016, p. 160

[26] Ellingsen, L. A.-W., (et al., 2014), Majeau-Bettez, G., Singh, B., Srivastava, A. K., Valøen, L. O., Strømman, A. H. Life Cycle Assessment of a Lithium-Ion Battery Vehicle Pack, Journal of Industrial Ecology, Vol. 18., No. 1., pp. 113 - 124.

[27] Peters, J. F., Baumann, M., Zimmermann, B., Braun, J., Weil, M. The environmental impact of Li-Ion batteries and the role of key parameters--A review. Renewable and Sustainable Energy Reviews, 2017, pp. 491-506.

[28] Romare, M., Dahllöf, L. The Life Cycle Energy Consumption and Greenhouse Gas Emissions from Lithium-Ion Batteries. A Study with Focus on Current Technology and Batteries for light-duty vehicles, IVL Swedish Environmental Research Institute, Report Number C 243, 2017, p. 58., http://www.ivl.se/download/18.5922281715bdaebede9559/1496046218976/C243+The+life+cycle+energy+consumption+and+CO2+emissions+from+lithium+ion+batteries+.pdf (downloaded at 22 of August, 2017)

KÜLÖNBÖZŐ PROPULZIÓS RENDSZEREKKEL HAJTOTT REPÜLŐGÉPEK TELJES ÉLETTARTAM CIKLUS EMISSZIÓ ÖSSZEHASONLÍTÓ VIZSGÁLATA

Ez a cikk röviden bemutatja a járművek és közlekedési rendszerek teljes hatásának az értékelésére kidogozott új eljárást és alkalmazását a hagyományos, hibrid és villamos hajtású repülőgépek emisszió összehasonlító vizsgálatára. Az alkalmazott eljárás legfontosabb sajátosságai: (i) az összes hatást (környezetterhelés, biztonság, védelem, költség, költség-haszon, fenntarthatóság) vizsgálja, (ii) a hatások a járművek és a közlekedési rendszerek szintjén is értékelhető, (iii) teljes hatás indexet számol. Ez a cikk csak a különböző propulziós rendszerek hatásaival számol.

***Kulcsszavak**: teljes hatás, hagyományos, hybrid, villamos hajtás, e-mobilitás*

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