THE APPLICATION OF ENVIRONMENTAL LIFE CYCLE COSTING TO THE ECO-EFFICIENCY ANALYSIS OF TRANSPORT MODES

JANIK Agnieszka

Silesian University of Technology, Poland, EU, agnieszka.janik@polsl.pl

Abstract

This paper presents an analysis of the applicability of environmental life cycle cost to the eco-efficiency analysis of transport modes. For calculating such costs, the method based on LCA results converted into monetary values was proposed. It allows taking into account all externalities generated by transport in the life cycle. The proposed solution complements earlier research work undertaken in this area, because the existing methods often focus on valuation of damages generated only during usage of transport modes and often take into account only the valuation of the damages resulting from the emission of substances contained in exhaust gases. It all makes, that the value of the environmental effects determined in this way is undervalued and relatively small compared with financial costs incurred throughout the life cycle of a transport modes. Thus, it has a little importance in the decision-making process. For that reason it is very important to develop the solutions which allow assessing impact of the transport mode in entire life cycle and which allow expressing the externalities in monetary terms.

Keywords: Environmental life cycle costing, eco-efficiency, transport modes

1. INTRODUCTION

Transport underpins modern economy and society. Its role is important not only in transfers of goods and services, but also in ensuring the mobility of people. It has, however, a negative impact on the environment causing air pollution, natural resource depletion and other damages in the environment and in human health.

The volume of transport modes is still growing, which undoubtedly will result in further deterioration of the environment quality. Therefore, to prevent this situation, the European Union proposes solutions aiming at „greening" the transport modes. The White Paper on Transport [1] is an example of document, which indicates possibilities of transition of transport system to a more environmentally friendly. It includes the Roadmap towards a competitive and resource efficient transport system significantly reducing greenhouse gas emissions. The implementation of actions indicated in the White Paper should allow such organization of the transport system to reach maximum economic efficiency with the least environmental impact. For this reason when the transport modes are chosen, it is essential to take into account the financial aspects, as well as the environmental aspects and assess the eco-efficiency of each of them.

There are some methods described in the literature, which can be used to assess the eco-efficiency of transport modes. A lot of them take into account only the most important environmental impact factors caused by the transport modes during the phase of their usage like: global warming (mainly through emission of CO_2), air pollution (e.g., particulates and nitrogen oxides) and noise nuisance. Only few of them include also impacts generated in the fuel production phase. These methods generally express damages in various units of measurement making difficult the assessment of the eco-efficiency. It seems therefore that seeking for solutions which allow assessing impact of the transport mode in entire life cycle and which allow expressing the externalities in monetary terms is required.

This paper presents an analysis of the applicability of environmental life cycle costing to the eco-efficiency analysis of transport modes. For calculating such costs, the method based on LCA results converted into monetary values was proposed. Such a solution allows taking into account all externalities generated by transport in the life cycle and allows to express the eco-efficiency ratio in monetary terms.

2. THE CONCEPT OF THE ECO-EFFICIENCY

Eco-efficiency is an instrument for sustainability analysis, which shows an impact of economic activities on the environment and human health. The concept of eco-efficiency was popularized by the World Business Council for Sustainable Development (WBCSD) as a key concept, which can help companies, individuals, governments or other organizations to become more sustainable. According to WBCSD, eco-efficiency can be achieved through the delivery of competitively-priced goods and services that satisfy human needs and bring quality of life, while at the same time reducing ecological impacts and resource intensity throughout the life-cycle [2]. The European Environmental Agency (EEA) defines the eco-efficiency as “a concept and strategy enabling sufficient linking of the use of nature from economic activity, needed to meet human needs, to keep it within carrying capacities and to allow equitable access to, and use of the environment, by current and future generations” [3]. OECD assumes that eco-efficiency is “the efficiency with which ecological resources are used to meet human needs” and defines it as a ratio of an output (the value of products and services produced by a firm, sector or economy as a whole) divided by the input (the sum of environmental pressures generated by the firm, the sector or the economy) [4]. The term of eco-efficiency is also defined in ISO 14045 as an aspect of sustainability relating the environmental performance of a product system to its product system value [5].

As appears from the definitions presented above, the measure of eco-efficiency is a function determining the relation between two types of indicators: economic and environmental. Economic indicators are related to the value of product system for a stakeholder. According to ISO 14045 the value of the product system may be chosen to reflect its resource, production, delivery or use efficiency, or a combination of these. This value may be expressed in monetary terms or other value aspects [5]. Generally applicable indicators for value of product system can be divided in three group: (1) describing a quantitive value of product system - units of goods or services produced, mass of goods or services sold, (2) describing a monetary value of product system - net sales, gross margin, value added, income, net present value (NPV), conventional Life Cycle Costing (LCC), the Dynamic Generation Cost (DGC), (3) describing the functional value of a product system to the end-user - transport capacity (e.g. ton-kilometers, passenger-kilometers), product performance (e.g. laundry loads washed), product durability / lifetime.

The impact of system product on the environment might be determined by environmental indicators. These indicators are expressed as single indicator describing the influence on the individual elements of environment (e.g. emission of VOC, SO_2, NO_x, emission of wastewater, amount of packaging waste) or identifying the volume of energy, water, natural resources or materials consumed. They can also be expressed in aggregated form as a sum of the indicators for different pollutant contributing to the same environmental burden (e.g. Global Warming Potential, eutrophication, human toxicity). Most indicators describe the influence generated in a selected phase of life cycle (e.g. product creation or product use) but some of them cover the entire product life cycle. It should be stated, that in accordance with ISO 14045, the environmental impacts should be evaluated using Life Cycle Assessment (LCA) [6]).

The measurement of eco-efficiency requires the determination of the relation between economic and environmental indicators applied by the organization. Depending on the aim of eco-efficiency measurement, this relation is described as:

- the ratio of economic indicator to environmental indicator, if the organization wants to know, what is its environmental productivity or what is the cost of environmental improvements,
- the ratio of the environmental indicator to the economic indicator, if the organization wants to know, what is its environmental intensity or environmental cost-effectiveness.

Due to the desire to determine which transport mode is the most efficient in terms of both aspects economic and ecological, in this article the first formula was chosen as appropriate for eco-efficiency assessment of transport modes.

3. THE TOOLS USED TO THE ECO-EFFICIENCY ASSESSMENT OF TRANSPORT MODES

There are few examples of eco-efficiency assessment of transport modes in the literature. Most of them use commonly applicable methods to assess the efficiency adapting them to the needs of assessment of transport modes [e.g. 7, 8]. There are also several tools, which are dedicated specially for eco-efficiency assessment of transport modes. Their short description was presented in **Table 1**.

Table 1 Selected examples of tools used for eco-efficiency assessment of transport modes [9, 10, 11, 12]

Name of tool	Tool description
Intermodal Terminal Eco-Efficiency Calculator (ITEC)	• developed by HaCon, KombiConsult and Thinkstep within the scope of the EcoHubs project co-funded by the EU; • can be used for calculation of environmental impact of intermodal terminal including impact of used transport modes; • calculates: (1) the greenhouse gas (GHG) emission, (2) the fuel consumption, (3) the energy consumption of intermodal terminals including all relevant operations; • identifies the terminal's "hot spots", i.e. the main energy consumers and processes; • points out the impact of "greening measures" already implemented and anticipates effects of planned measures; • does not take into account the economic indicators to calculate eco-efficiency; • includes only the tank-to wheels analysis, which takes into account the emission caused by use of transport modes.
EcoTransIT World	• developed by The Institute for Energy and Environmental Research (ifeu) Heidelberg, the Öko-Institut Berlin and the Rail Management Consultants GmbH (RMCon/IVE mbH) Hanover; • can be used for assessing the environmental impact of transporting freight by various transport modes; • calculates: (1) the primary energy consumption, (2) the greenhouse gas emissions, (3) NO_x emission, (4) SO_2 emission,(5) NMHC emission (6) PM emission; • does not take into account the economic indicators; • includes the well-to-wheels analysis, which takes into account the emission from production and distribution of the fuel and from use of transport mode; • excludes the emissions associated with the production of the vehicle and the recycling or after use-processing.
Ecoscore	• developed by the Vrije Universiteit Brussel (VUB), VITO and ULB; • can be used for evaluation of the environmental performance of passenger vehicles; • identifies the impact of environment taking into account: (1) emissions with impacts on global warming (CO_2, CH_4, N_2O), (2) emissions with impacts on air pollution (NO_x, SO_2, CO, HC, PM) and (3) noise emission; • expresses the different impacts on the environment in one single indicator - as a value between 0 and 100 (the higher the score, the more environmentally friendly vehicle); • does not take into account the economic indicators; • includes the well-to-wheels analysis, which takes into consideration the emission from production and distribution of the fuel (fuel cycle emission) and from use of transport mode (exhaust emissions); • excludes the emissions associated with the production of the vehicle and the recycling or after use-processing.
Clean Fleets Life Cycle Cost (LCC) Calculator	• developed within the scope of the Project Clean Fleets funded by the EU; • is an operational instrument under the European Commission Directive 2009/33/EC on the promotion of clean and energy-efficient road transport vehicles; • can be used only for evaluation of eco-efficiency of different type of road vehicles (cars, vans and Heavy duty vehicles); • calculates the Life Cycle Costs of vehicles, which include: (1) costs of acquisition, (2) operation costs (3) maintenance costs (4) tax and other cost (5) emission costs (Operational Lifetime Cost -OLC), (6) end-of-life costs; • converts the impacts on the environment to monetary terms and calculates the Operational Life Costs, which are consist of: the lifetime costs for energy consumption, CO_2 and pollutant emissions (NOx, PM and NMHC); • includes only the tank-to-wheels analysis.

Analysing the tools shown in **Table 1** it can be said that most of them focus on the assessment of selected environmental aspects generated by the transport modes ignoring the assessment of economic aspects. Therefore, these tools do not assess the eco-efficiency but indicate which transport modes is more environmentally friendly. The Clean Fleets LCC Calculator is the only tool which takes into account both economic and environmental effects thereby allowing the determination of eco-efficiency indicator.

A part of the tools listed in **Table 1** takes into consideration only the impacts generated during use phase of transport modes applying the tank-to-wheels approach (ITEC and Clean Fleets LCC Calculator). Part of them extends the analysis and assess also the impacts generated in the phase of fuel production and distribution using the well-to-wheels approach (Ecoscore or EcoTransIT World). None of the presented tools takes into consideration damages caused in the phase of extraction and processing of raw materials needed for the production of transport modes, in the manufacturing phase and in the end-of-life phase. It means that neither of them assesses the eco-efficiency of the transport modes throughout the life cycle. In addition, most of these tools evaluate only the emissions of greenhouse gases, exhaust emissions and fuel consumption. The Ecoscore is the exception, because the emissions generated by transport mode are divided here into three impact categories: emissions with impacts on global warming, emissions with impacts on air quality (which are divided into impacts on human health and impacts on ecosystems) and noise emissions from engine.

In the most of eco-efficiency studies presented in literature the environmental impacts are expressed in incommensurable units. For that reason their aggregation is complicated because there usually are no unambiguous value-weights for these impacts. As a consequence, many eco-efficiency studies present each category of environmental impact separately or they apply ad hoc summation of different criteria, disregarding their relative importance. In the case of tools presented in **Table 1**, the different categories of environmental influence are aggregated in one indicator in Ecoscore and Clean Fleets LCC Calculator. In Ecoscore environmental effects are expressed in a single value between 0 to 100, while in Clean Fleets LCC Calculator are converted into monetary value on the basis of the value of external effects included in Directive 2009/33/EC [13]. Both of these methods could be therefore considered appropriate to calculate the eco-efficiency of transport modes, but none of them takes into account the impact on the environment throughout the life cycle, which is recommended by ISO 14045. In addition, Ecoscore allows to determine only the environmental impacts, without taking into account economic aspects. The advantage of Clean Fleets LCC Calculator is expressing economic and ecological indicator in the same unit, i.e. in monetary values, which undoubtedly makes it easier to understand the results of the analysis. Unfortunately, despite that an economic indicator is expressed as Life Cycle Costs (LCC), the environmental indicator focuses only on the value of effects generated during the use of the transport modes. Therefore, in order to identify the transport modes characterized by the highest eco-efficiency throughout the life cycle, all environmental effects generated throughout the life cycle should be monetised. It is possible by application of the Environmental Life Cycle Costing.

4. THE ROLE OF ENVIRONEMNTAL LIFE CYCLE COSTING IN THE ECO-EFFICIENCY ASSESSMENT OF TRANSPORT MODES

Life cycle costing (LCC) is a methodology for the systematic economic evaluation of life cycle costs over a period of analysis. Environmental life cycle costs are one of the type of life cycle costs. They include monetary value of externalities resulting in different phases of the product life cycle, which can be internalized in the account of polluters. The concept of environmental LCC was developed for combining the results of Life Cycle Assessment (LCA) with conventional LCC, which includes all financial costs (acquisition costs, ownership costs and end-of-life disposal costs) directly covered by the main producer or user in the product life cycle. Accordance with SETAC, environmental LCC contains conventional LCC and the monetary value of externalities (positive or negative) generated in life cycle [14].

Calculating the value of environmental LCC is not easy, because it requests to express in monetary terms environmental effects which don't have a market value in most cases. Nevertheless, there are non-market methods valuing this kind of effects. These methods include stated preference methods (e.g. contingent valuation method and choice experience) and revealed preference methods (e.g. hedonic price method, travel cost methods, opportunity costs or restitution costs method). These methods are used to determine the value of different types of environmental effects. There are examples of studies in literature, where the results of LCA (expressed in midpoints or endpoints) have been converted into monetary value [15]. There are also some examples, in which the valuation of externalities generated by the transport mode was done. [16].

The calculation of the environmental life cycle costs allows to express the environmental indicator in monetary values and thus allows the calculation of eco-efficiency indicator for transport modes. It is therefore proposed to accept conventional LCC as an economic indicator and LCA results converted into monetary value as an environmental indicator. Determining the eco-efficiency indicator would be based on the following formula:

$$eco-efficiency\ indicatior = \frac{Conventional\ LCC}{Economic\ value\ of\ LCA\ results} \quad (1)$$

On the basis of the earlier studies [17], it can be stated that the calculation of eco-efficiency indicator may be not sufficient for the determination of the eco-efficiency of transport modes. There may be a situation when two different transport modes have the same value of eco-efficiency indicator at different levels of conventional LCC and values of LCA. In such case, the mentioned above formula takes the following form:

$$eco-efficiency\ indicator = \frac{Conventional\ LCC}{Economic\ value\ of\ LCA\ results} \wedge Environmental\ LCC \rightarrow min \quad (2)$$

5. CONCLUSION

The solution proposed in this article allows the assessment of eco-efficiency of transport modes in life cycle through expressing the environmental indicator in monetary value. Undoubtedly, it facilitates interpretation of the results of such analysis. Although the execution of LCA requires the identification of all environmental influence generated in life cycle and for that reason it is not easy task, the availability of databases facilitating the execution of LCA (e.g. IDEMAT, Ecoivent, GaBi LCA Databases) increases with each year. Similarly there are more and more examples of environmental damage valuations that can be transferred to determine the economic values of environmental effects generated by transport modes.

The implementation of the ambitious targets set out in the White Paper on Transport requires the introduction of diverse eco-innovations and development of various forms of interorganizational cooperation [18] in the transport area. In practice, these activities must be supported by IT tools [19]. The proposed solution allows to extend the functionality of existing IT tools giving the opportunity to take into account the environmental effects generated throughout the life cycle.

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REFERENCES

[1] THE WHITE PAPER - Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system, COM/2011/0144 final, Brussels 2011.

[2] VERFAILLIE H.A, BIDWELL R., Eco-efficiency measuring. A guide to reporting company performance. World Business Council for Sustainable Development Report, London, 2000.

[3] THE EUROPEAN ENVIRONMENT AGENCY, Making sustainability accountable: Eco-efficiency, resource productivity and innovation. Topic report No 11., Copenhagen, 1999.

[4] OECD, Eco-Efficiency. OECD Publication. Paris, 1998.

[5] ISO 14045:2012 Environmental management - Eco-efficiency assessment of product systems - Principles, requirements and guidelines.

[6] BARAN J. Redesign of steam turbine rotor blades and rotor packages - Environmental analysis within systematic eco-design approach, Energy Conversion and Management, Vol. 116, 2016, pp. 18-31.

[7] LEAL I.C. JR., DE ALMADA GARCIA P.A., DE ALMEIDA D'AGOSTO M., A data envelopment analysis approach to choose transport modes based on eco-efficiency. Environment, Development and Sustainability, Vol. 14, 2012, pp. 767-781.

[8] MEYRICK S., Urban freight transport eco-efficiency and sustainability: policies and indicators. Transport and Communications Bulletin for Asia and the Pacific. Vol. 80, 2011, pp. 20-43.

[9] Intermodal Terminal Eco-Efficiency Calculator (ITEC). Available: [http://www.intermodal-terminals.eu].

[10] EcoTransIT World. Ecological Transport Information Tool for Worldwide Transports. Ifeu Heidelberg, INFRAS Berne, IVE Hannover, 2016. Available: [http://www.ecotransit.org].

[11] EcoScore. Available: [http://www.ecoscore.be/info/ecoscore/calculation-method].

[12] CLEMENT S., EVANS N., Procuring clean and efficient road vehicles. Clean fleets guide. November 2014. Available: [http://www.clean-fleets.eu/home/].

[13] Directive 2009/33/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of clean and energy-efficient road transport vehicles (OJ L 120, 15.5.2009, p. 5-12).

[14] HUNKELER D., LICHTENVORT K., REBITZER G. Environmental life cycle costing. SETAC-CRC Press: London-New York, 2008, pp. 1-54.

[15] JANIK A., Valuation of Environmental Life Cycle Cost of steel production - case study. METAL 2015. 24th International Conference on Metallurgy and Materials, Brno, Czech Republic, June 3rd-5th, 2015. Conference proceedings. Ostrava Tanger, 2015, pp. 1951-1957.

[16] RICARDO-AEA, Update of the Handbook on External Costs of Transport. Report for the European Commission DG MOVE. January 2014.

[17] BARAN J., JANIK A., RYSZKO A., SZAFRANIEC M., Making eco-innovation measurable - are we moving towards diversity or uniformity of tools and indicators? 2nd International Multidisciplinary Scientific Conference on Social Sciences and Arts SGEM2015, SGEM2015 Conference Proceedings, Book 2, Vol. 2, Albena, Bulgaria, 2015, pp. 787-798.

[18] RYSZKO A., Interorganizational cooperation, knowledge sharing, and technological eco-innovation: The role of proactive environmental strategy - empirical evidence from Poland, Polish Journal of Environmental Studies, Vol. 25, No. 2, 2016, pp. 753-764.

[19] SZAFRANIEC M. Selected issues of supporting environmental decision-making processes in company, 15th International Multidisciplinary Scientific GeoConference SGEM2015, SGEM2015 Conference Proceedings, Book 5, Vol. 3, Albena, Bulgaria 2015, pp. 553-560.