

Framework for LCI Modelling towards Green Logistic Systems

Trakarn Prapasongsa^{1,2*}, and Søren Løkke²

¹ Department of Civil and Environmental Engineering, Mahidol University
999 Puttamonthon, Nakorn Pathom 73170 Thailand

² The Danish Centre for Environmental Assessment, Aalborg University, Vestre Havnepromenade 9,
Aalborg 9000 Denmark

Abstract

In order to establish green logistic systems, life cycle assessment (LCA) is an important tool for evaluating and comparing overall environmental impacts from various options. Most LCA studies rely on readily available secondary databases on transport services such as Ecoinvent database and scientific publications. The most widely applied Ecoinvent database on transport services is aggregated with specific transport variables and statistics based on European and Swiss average data. To modify the life cycle inventory (LCI) database with specific variables (e.g. load factors, driving speed, etc.) is very complicated and may not be possible. Such studies are still lacking due to complexity and resource limitations. This study aims to provide a framework for LCI modelling to conduct LCAs of European freight transport with up-to-date LCI data in terms of emissions and transport variables. The framework comprises of a conceptual transport model, important transport variables and data sources for freight transport by road and by rail in Europe. The data collection was carried out by literature studies and interviews with relevant experts. The framework is useful for LCA practitioners, researchers and industries to include specific transport variables and to adequately assess the environmental impacts from transport activities by road and by rail.

Key words: Green logistics/ LCI modelling framework/ Emission model/ European freight transport.

1. Introduction

Global trading and logistics of goods have been developed and intensified to fulfil rapidly increased demand for food, energy and materials. Transport operations consume considerable amount of fuels and significantly emit various pollutants resulting in adverse impacts on climate, resource, human health and ecosystem (based on IPCC, 2007; Heinrich et al., 2005; Wash, 2011). In order to design green logistic systems with less environmental impacts, life cycle assessment (LCA) has been widely used as a tool for impact assessment and comparison (Facanha and Horvath, 2006; González-García et al., 2009). Moreover, LCA aims to evaluate the overall environmental impacts of a product from a whole life cycle including raw material

extraction to final disposal. Hence, transport is generally included in LCA studies. Most LCA studies in Europe rely on the readily available secondary database on transport services such as Ecoinvent database and scientific publications (González-García et al., 2011; Prapasongsa et al., 2010). The most widely applied Ecoinvent database on transport services (Spielmann et al., 2007) is aggregated with specific transport variables and statistics based on European and Swiss average data. Modification with specific variables is very complicated and may not be possible. Furthermore, primary data collection requires a lot of resources, which are rather used for the main production processes of the products. In the meanwhile, research on transport in Europe has been carried out at individual, national and European level. There are

*Corresponding author:

E-mail: Trakarn.pra@mahidol.ac.th,
Tel. +662 889 6378

several existing emission models or guidebooks which are updated periodically such as EMEP/EEA air pollutant emission inventory guidebook 2009 (EEA, 2009a), Handbuch (Hausberger et al., 2009), TREMOVE (De Ceuster et al., 2007), and COPERT (Ntziachristos et al., 2009a). The application of European transport emission models in combination with existing LCI databases on LCA studies can improve the data quality. Such studies are still lacking due to the complexity and resource limitations. Therefore, this study aims to provide framework for LCI modelling to conduct LCAs of European freight transport with up-to-date LCI data in terms of emissions and transport variables by utilising the integrated European models and databases. The framework includes a simplified conceptual transport model, important transport variables and data sources for freight transport by road and by rail in Europe.

2. Methodology for LCI Modelling

2.1 Goal and scope of the LCI

The goal of the LCI modelling is to provide a tool for researchers, industries and practitioners to carry out LCAs with the most up to date and relevant LCI data on European freight transport services. Sources of data on fuel and material consumption and related emissions from freight transport are identified. The functional unit (FU) of the complete LCI modelling is one tonne-kilometre (tkm) referring to the weight of goods transported by a certain mean over one kilometre. The system boundary considers only inland freight transport in EU-27. The transport modes included in this study are only road and rail contributing to 74% and 16% of total inland freight transport in EU-27 in 2009, respectively (European Union, 2011). This conceptual framework is only part of LCI analysis phase. The complete LCI data with the specified FU are not included. Only

framework to support how to model/gather data is presented. The actual application of this framework is recommended to consider all requirements in the ISO 14040 and 14044 standards (ISO 14040, 2006; ISO 14044, 2006).

2.2. Framework development and data collection

The conceptual framework is developed on the basis of the transport model structure in Ecoinvent database (Spielmann and Scholz, 2005; Spielmann et al., 2007). The transport emission model analysis and data collection were carried out by various methods including literature studies and interviews with experts from European Environmental Agency, and Volvo Truck Corporation.

3. Framework for LCI Modelling of Freight Transport by Road and by Rail

3.1 European transport emission models

Transport emission models such as COPERT, ARTEMIS, Handbuch, VERSIT+, etc. have been developed for application at regional, national, city and street levels (Hausberger et al., 2009; Ntziachristos et al., 2009a; Smit et al., 2007; Ntziachristos et al., 2009b). Selection of the emission models depends on data availability and purposes of the model application. If the transport activity data are available at disaggregated level, the detailed emission models for application at street or city level such as VERSIT+ are preferable (Jensen, P. and Adam, M., personal communication, November 18, 2010). In this study, COPERT—a European road transport emission inventory model - is chosen as a part of the LCI modelling framework since the goal of LCI modelling defined in this work focuses at European level applying easily accessible data. Moreover, COPERT has been used to calculate emissions (GHG and other air pollutants) reported in national

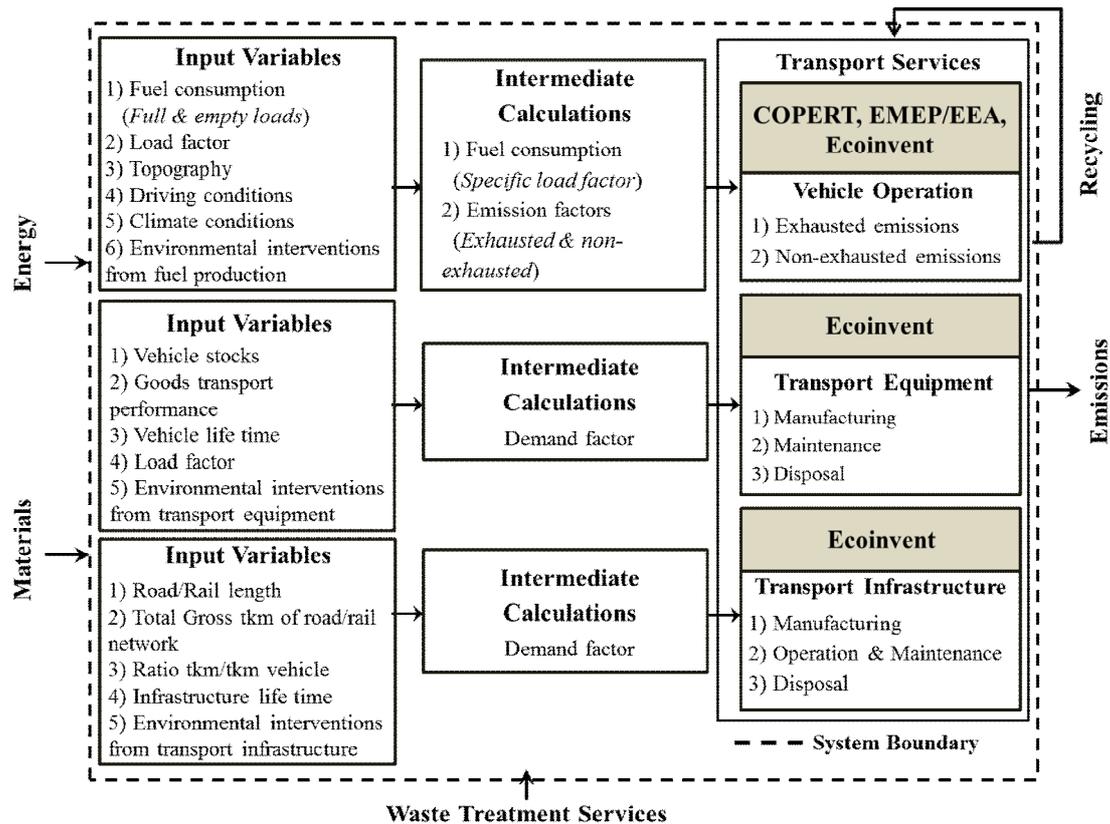


Figure 1 Conceptual framework for LCI modelling of European freight transport (Developed from Ntziachristos et al., 2009a; Ong et al., 2011; Spielmann and Scholz, 2005).

inventories of 22 EU member states (Ntziachristos et al., 2009a).

This model is also applicable worldwide and updated on a yearly basis. The COPERT methodology has been applied as the algorithm in (EEA, 2009a) to calculate emissions from road transport (Ntziachristos et al., 2009a). The methodology provided in the EMEP/EEA guidebook 2009 is also selected as part of the emission model for freight train transport as it has also been widely used in Europe (Uherek et al., 2010).

3.2 Framework for LCI modelling

The conceptual framework/model for LCI modelling is illustrated in Figure 1. The figure illustrates the three transport modules for the European freight transport by road and by rail with an indication for transport models, main input variables and intermediate calculations. Detailed components of this

framework including general description, intermediate calculations, and input variables with some examples are also presented below.

Firstly, The conceptual transport model (framework) is mainly based on the Ecoinvent database categorising road and rail transport services into three modules of vehicle operations, transport equipment and transport infrastructure (Spielmann et al., 2007; Spielmann and Scholz, 2005). Secondly, Vehicle operations include exhausted and non-exhausted emissions while transporting goods by road or by rail over one kilometre. The main input variables, intermediate calculations and overall emission calculations from this module are based on methodology in COPERT 4 software, EMEP/EEA guidebook 2009 and the ecoinvent database. Thirdly, Transport equipment covers road vehicles, locomotives and goods wagons.

The data for this transport module were gathered based on different reference units and were linked to the reference flow of “tkm” by specific demand factors.

The demand factor can be calculated from vehicle stocks, goods transport performance and vehicle life time. When multiplying the demand factors (with a unit of vehicle-km/tkm with the environmental interventions from transport equipment for manufacturing, maintenance, and disposal (with a unit of kg emissions/vkm), emissions from transport equipment per tkm can be achieved. Transport infrastructure include road and railway track. Similar to transport equipment module, the infrastructure per tkm can be estimated from the demand factor and the environmental interventions from transport infrastructure for manufacturing, operation, maintenance and disposal. Since the transport equipment and infrastructure modules are mainly based on the ecoinvent database (Spielmann et al., 2007; Spielmann and Scholz, 2005), this paper only describes the vehicle operation module in which the improvement is specifically recommended.

3.2.1 Emissions from the vehicle operations

Emissions from vehicle operations comprise of emissions from fuel production (or well-to-wheel emissions), and exhausted and non-exhausted emissions. To calculate total emissions from transport services, it requires specific activity data, emission factors and environmental interventions from fuel production. In case of electric road and rail vehicles, fuel emissions depend on the electricity production for each country/region. It is recommended to use the ecoinvent database as a background data for environmental interventions from fuel production.

Exhausted emissions can be categorised into fuel-dependent, regulated

and other emissions (Spielmann et al., 2007). Fuel-dependent emissions (CO₂, SO₂, and trace elements in fuel - heavy metals) are derived from fuel composition, fuel consumption (litre/tkm) and emission factors (kg pollutant/litre). CO, NO_x, PM and HC emissions from road vehicles are controlled under European Emission Standards (European Commission, 2012). In some European countries, emission standards for road vehicles are applied for rail transport as well. Other exhausted emissions are NH₃, N₂O and PAHs.

The emissions for road transport can be directly estimated by using the COPERT model when all relevant variables are known (e.g. vehicle populations, annual transport performance, driving conditions, climate conditions and topography, etc.). Alternatively, transport emissions can be calculated specifically from load factors, fuel consumption and emission factors. Both emission factors for road and rail transport are published in (EEA, 2009a). As mentioned earlier these numbers are widely used and regularly updated.

In addition, emission factors and fuel consumption from rail transport are also available in statistics/publications from International Union of Railways, e.g. International Union of Railways (2010). The intermediate calculations and suggested data sources for load factors and fuel consumption will be listed in the following sections.

For road non-exhausted emissions, it comprises of emissions from gasoline evaporation, road vehicle tyre and brake wear and road surface wear caused by vehicles' motion. For rail non-exhausted emissions, source includes abrasion from rail tracks, wheels, brakes, overhead contacted line (for specific rail types). It is recommended to use data and calculation methods in EEA (2009a) for road non-exhausted emissions and those in Spielmann et al., (2007) for rail non-exhausted emissions.

3.2.2 Intermediate calculations for the vehicle operations

Intermediate calculations are needed in case that the input variables cannot be directly used for estimating emissions from transport operations. For example, fuel consumption with specific load factor requires various input variables. The values can be estimated by various methods depending on available input variables. If specific variables (i.e. driving conditions, climate conditions and topography) are known, the more specific emission factors can be achieved by using the COPERT software considering both hot and cold emissions (Ntziachristos et al., 2009a). For rail transport, top-down calculations are more practicable since this mode of transport often includes both freight and passenger transport and requires additional allocation factors.

3.2.3 Input variables for the vehicle operations

Firstly, fuel consumption (with full and empty loads) and specific load factors for road transport are required for calculating the fuel consumption for specific load factors. If the actual measurements are not available for the LCA studies being conducted, the values for different road freight transport systems are available at Volvo Truck (Volvo Truck Corporations, 2010) derived from Volvo Truck's test driving cycles representing typical driving behaviours in 2009 (Kloo, H., personal communication, December 14, 2011) as shown in Table 1.

Table 1 Typical fuel consumption for road freight transport (Volvo Truck Corporations, 2010). A = Truck, distribution traffic, B = Truck, regional traffic, C = Tractor and semi-trailer, long-haul traffic, D = Truck with trailer, long-haul traffic.

	Type of road freight transport			
	A	B	C	D
Payload (tonnes)	8.5	14	26	40
Total weight (tonnes)	14	24	40	60
Fuel consumption, empty load (litres/100 km)	20-25	25-30	21-26	27-32
Fuel consumption, full load (litres/100 km)	25-30	30-40	29-35	43-53

Furthermore, the fuel consumption with full and empty loads can be directly calculated by the excel files for heavy duty vehicles available at (EEA, 2009b). Based on these data, it allows us to estimate the amount of fuel consumption per tkm.

For rail transport, the data are often available at aggregated level with typical load factors. For example, Norris *et al.* (2010) provides the amount of fuel consumption for typical railway transport per hour as shown in Table 2. Additionally, the fuel consumption per tkm of rail transport are published in International Union of Railways (2010) and Andersson et al. (2011).

Table 2 Fuel consumption for different locomotive types (Norris et al., 2010).

Category	Fuel consumption (kg/h)
Line-haul locomotives	219
Shunting locomotives	90.9
Railcars	53.5

Secondly, load factors are important variables to estimate specific fuel consumption and efficiency of the freight transport. Despite the available load factors in many studies including the European statistical database, the numbers expressed in the unit of tonnes per vehicle lead to erratic interpretations (EEA, 2010). The higher load factors in tonnes can be the results from the higher load capacity (maximum allowable laden weight) and/or from the increased efficiency in the utilization of the available capacity. The disaggregation cannot be done with the available data in the European statistical database which integrated all vehicle classes in road freight transport from different EU countries. Consequently, the load factors used in LCA studies should be estimated in a unit representing the utilization of load capacity (%) for laden trip. The factors derived from dividing the numbers of tkm by the numbers of vkm should be disregarded (EEA, 2010). The load factors (only for laden trips) in utilization of the available capacity and the percentage of empty trips for road freight transport are available at (EEA, 2010). Moreover, the overall load factors (including empty trips) can be achieved from the modelling results of TREMOVE model (TREMOVE, 2012). For rail freight transport, load factors in literature often showed the wide span of numbers in term of gross weight, load capacity and load factors (Andersson et al., 2011; Janic, 2008). Load factors for goods transport by rail for eight European countries were documented in (EEA, 2010) and clearly showed the variations from country to country.

Thirdly, topography significantly affects the amount of fuel consumption. Hilly conditions require higher fuel for road and rail transport. Driving conditions including driving speeds, acceleration rates, and stops influence on the fuel consumption as well. For climate conditions, it directly affects the emission

rates from the road transport. These variables should be specifically identified to improve data quality in emission inventory establishment.

4. Conclusion

All in all, this paper presents framework for LCI modelling by using simplified conceptual transport model based on the ecoinvent database, the COPERT model, and/or EMEP/EEA guidebook. In order to apply the most up-to-date data on emissions from transport operations in LCA studies, important data sources for input variables and emission calculations are recommended. Furthermore, the applications of this framework as a part of LCA studies will support industries for better design during product development by including green transport systems with less negative impacts on the environment and society.

5. References

- Andersson, E., Berg, M., Nelldal, B.L., and Fröidh, O. 2011. **Rail freight transport, Techno-economic analysis of energy and greenhouse gas reductions**. Stockholm, Sweden: Royal Institute of Technology (KTH).
- De Ceuster, G., Van Herbruggen, B., Ivanova, O., Carlier, K., Martino, A., and Fiorello, D. 2007. **Final report: TREMOVE**. European Commission, Directorate General (DG) Environment.
- European Commission. 2012. Transport and Environment, Road vehicles [Online]. Available: <http://ec.europa.eu/environment/air/transport/road.htm> [Accessed on 1 September 2012].
- European Environment Agency (EEA) 2009a. **EMEP/EEA air pollutant emission inventory guidebook 2009. Technical guidance to prepare national emission inventories**. EEA Technical report no.9/2009.

- Luxembourg: Office for Official Publications of the European Communities.
- EEA 2009b. EMEP/EEA emission inventory guidebook 2009. 1.A.3.b Road transport annex HDV files [Online]. Available: <http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009> [Accessed on 1 September 2012].
- EEA 2010. Load factors for freight transport [Online]. Available: <http://www.eea.europa.eu/data-and-maps/indicators/load-factors-for-freight-transport> [Accessed on 1 September 2012].
- European Commission. 2011. **Eurostat pocketbooks: Energy, transport and environmental indicators**. Luxembourg, Belgium: elemental chlorine-free bleached PaPer (ecf).
- Facanha, C. and Horvath, A. 2006. Environmental Assessment of Freight Transportation in the U.S. **International Journal of Life Cycle Assessment**. 11(4): 229–239.
- González-García, S., Berg, S., Feijoo, G., Moreira, M.T. 2009. Comparative environmental assessment of wood transport models. A case study of a Swedish pulp mill. **Science of the Total Environment**. 407: 3530–3539.
- González-García, S., Silva, F.J., Moreira, M.T., Pascual, R.C., Lozano, R.G., and Gabarrell, X. 2011. Combined application of LCA and eco-design for sustainable production of wood boxes for wine bottles storage. **International Journal of Life Cycle Assessment**. 16: 224–237.
- Hausberger, S., Rexeis, M., Zallinger, M. and Luz, R. 2009. **Emission Factors from the Model PHEM for the HBEFA Version 3**. Institute for Internal Combustion Engines and Thermodynamics, Graz University of Technology.
- Heinrich, J., Schwarze, P.E., Stilianakis, N., Momas, I., Medina, S., and Totlandsdal, A.I. 2005. Studies on health effects of transport-related air pollution. In: Krzyzanowski, M., Kuna-Dibbert, B., and Schneider, J., (eds): **Health effects of transport-related air pollution** (pp.125-165). Geneva: World Health Organization.
- International Union of Railways 2010. **Moving towards sustainable mobility: European Rail Sector Strategy 2030 and beyond**. Paris, December 2010.
- IPCC. 2007. **IPCC Fourth Assessment Report: Climate Change 2007 (AR 4)**. Cambridge: Cambridge University Press.
- ISO 14040. 2006. **Environmental Management Life Cycle Assessment Principles and Framework**. Geneva: International Organisation for Standardisation (ISO).
- ISO 14044. 2006. **Environmental Management Life Cycle Assessment Requirements and Guidelines**. Geneva: International Organisation for Standardisation (ISO).
- Janic, M. 2008. An assessment of the performance of the European long intermodal freight trains (LIFTS). **Transportation Research Part A**. 42: 1326–1339.
- Norris, J., Ntziachristos, L., Samaras, Z., and Zierock, K.-H. 2010. EMEP/EEA emission inventory guidebook 2009. 1.A.3.c Railways [Online]. Available: <http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009> [Accessed on 1 September 2012].
- Ntziachristos, L., Gkatzoflias, D., Kouridis, C., and Samaras, Z. 2009a. **COPERT: A European transport emission inventory model: Information Technologies in Environmental Engineering, Environmental Science and**

- Engineering.** Berlin Heidelberg: Springer-Verlag.
- Ntziachristos, L., Kouridis, C., Papageorgiou, T., Mellios, G., and Samaras, Z. 2009b. **Review of modelling methodology.** Laxenburg: IIASA.
- Ong, H.C., Mahlia, T.M.I., and Masjuki, H.H. 2011. A review on emissions and mitigation strategies for road transport in Malaysia. **Renewable and Sustainable Energy Reviews.** 15: 3516-3522.
- Prapasongsa, T., Christensen, P., Schmidt, J., and Thrane, M. 2010. LCA of comprehensive pig manure management incorporating integrated technology systems. **Journal of Cleaner Production.** 18(14): 1413-1422.
- Smit, R., Smokers, R., and Rabé E. 2007. A new modelling approach for road traffic emissions: VERSIT+, **Transportation Research Part D.** 12: 414-422.
- Spielmann, M. and Scholz, R.W. 2005. Life cycle inventories of transport services, Background data for freight transport. **International Journal of Life Cycle Assessment.** 10(1): 85-94.
- Spielmann, M., Bauer, C., Dones, R., and Tuchschnid, M. 2007. Transport services, Data v2.0 (2007). **Ecoinvent report no.14.** Villigen and Uster.
- TREMOVE. 2012. TREMOVE documentation [Online]. Available: <http://www.tremove.org/> [Accessed on 1 September 2012].
- Uherek, E., Halenka, T., Borken-Kleefeld, J., Balkanski, Y., Berntsen, T., and Borrego, C. 2010. Transport impacts on atmosphere and climate: Land transport. **Atmospheric Environment** 44: 4772-4816.
- Volvo Truck Corporations. 2010. Emissions from Volvo's trucks [Online]. Available: http://www.volvotrucks.com/SiteCollectionDocuments/VTC/Corporate/About%20us/Environment2012/Emis_eng_20640_10005.pdf [Accessed on 1 September 2012]
- Wash, M.P. 2011. Mobile source related air pollution: Effects on health and the environment. **Encyclopedia of Environmental Health** 5:803-809.