Towards a Sustainable Urban Freight Transport and Urban Distribution

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***Abstract*—The objectives of this paper are to: a) develop a comprehensive sustainability impact assessment framework, aiming to improve the use of urban freight transportation in terms of modes, b) support showcasing of urban distribution fleet from a logistics provider and c) apply the proposed sustainability impact assessment framework for the production of outcomes regarding the sustainability performance of urban freight transportation modes. Tools are used such as Life-Cycle Analysis (LCA) for the evaluation of transportation modes, stemming from European Commission transport policy objectives, as well as efficiency and productivity targets, environmental indicators including greenhouse gas (GHG) emissions, etc. In the field of practical showcasing, there will be a case study that will represent its technologies relative to urban distribution fleet. The demonstrator is a Logistics Provider whose main activity is to distribute retail items to an urban area and its interurban agglomeration. The vehicles include two popular light-duty vehicles. As presented below, the score of diesel powered vehicle attains higher sustainability score than the LNG (liquefied natural gas) vehicle thanks to the special characteristics of this type of transportation mode.**

***Index Terms*—sustainability analysis, urban distribution, freight transportation vehicles, multi-criteria analysis**

I. Introduction

Urban areas represent special challenges for national and international freight transport both in terms of logistical performance and environmental impacts. Currently, around 74% of Europe’s population lives in urban areas [1] and the urban share is expected to increase to 84% by 2050.

In the recent white paper on transport, one goal is to “achieve essentially CO_2-free city logistics in major urban centers by 2030. The recently published by the European Commission White Paper includes objectives, actions and initiatives for the development of a more competitive and sustainable transport system till 2050, the achievement of CO_2 – free city logistics in major urban centers by 2030, and foresees initiatives for the elimination of important obstacles and bottlenecks that obstruct the improvement and cohesion in key aspects of transport, i.e. infrastructure, investments, harmonization of legal frameworks, etc. [2]. The present configuration of freight transportation systems in urban areas is reaching unsustainable levels in terms of economic efficiency and the impact on quality of life. The scientific evidence aims at presenting an increase risk of serious, irreversible impacts from climate change combined with common business paths for emissions [3].

The strong influence of transportation on the environment, economy and society strongly support the call of incorporating sustainability into transportation planning. Sustainability can be applied to any system, to describe the maintenance of a balance within the system. Initially, it was used to depict concerns mostly associated with environmental issues, and grew to include energy economy and social issues. Different points of view and desired objectives and goals pursued by every community require adjustments in sustainability definitions and approaches. There are literally dozens definitions of sustainability and sustainable development; a sample of definitions follows.

The World Commission on Environment and Development (WCED) defined sustainable development as follows [4]: “*Development that meets the needs of the present without compromising the ability of future generations to meet their own needs*”.

Sustainability has been used extensively in development and transportation due to the environmental, social and economic impacts that these sectors have on communities. Several governmental and regional agencies have applied sustainability to their transportation programs. Jeon and Amekudzi [5] studied sustainability initiatives in North America, Europe and Oceania and reported that a standard definition of transportation system sustainability is unavailable. However, the majority of these studies study common transportation system pillars such as the mobility of people and goods, accessibility and safety within environmental limits.

To this end, the scope of this paper is to investigate the sustainability outlook of trucks that carry out urban

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deliveries of a logistics service provider. These modes are evaluated according to their sustainability performance which is presented with in-depth detail by quantifying and thus comparing criteria and indicators as shown below.

At first, a targeted impact assessment framework is introduced, basically in terms of transportation modes which will perform an operational life cycle assessment of two different commercial vehicles that are used in urban distribution activities of a logistics service provider. The criteria which characterize the framework are energy, environmental, economy and generally concerning technological aspects. This framework uses Key Performance Indicators (KPIs) to measure operational aspects of transportation modes.

KPIs are quantified and compared to each other reflecting the most sustainable mode between the two of them. These vehicles are: a Fiat Doblo 1, 4 with liquefied natural gas engine and a diesel powered Ford Transit.

The raw data that govern the framework are being processed through their quantification. Using simple normalizing methods of indicators' values, a sound outcome is produced which by utilizing mathematical tools justifies the sustainability evaluation of the urban freight transportation modes. Finally conclusions are being made along with the analysis of the results of the evaluation process indicating also further needs for research, i.e. alternative and renewable sources of energy of transport modes or deeper analysis of the activities of logistics service provider through the assessment of operational aspects using tools such as Multi Criteria Analysis, etc.

II. Multi-criteria Analysis and Life-cycle Assessment as Part of Transportation Sustainability Assessment

The evaluation of logistics activities are subject to a throughout evaluation that includes the use of KPIs. These types of indicators are basically part of a generic framework that will assess whether objectives of a scenario are fully, partially or not at all accomplished. These objectives are then translated into criteria. Weights may need to be assigned to the different criteria in order to know how important these objectives are (i.e. for the stakeholders). The next step attempts to couple one or more measurable indicators to each criterion. These indicators allow evaluating each alternative with regards to a given criterion. These indicators can be either quantitative or qualitative, depending on the criterion. Afterwards, aggregation of the information of the previous steps is performed. The actual results are given and are generated by using a Multi Criteria Analysis (MCA). MCA describes any structured approach used to determine overall preferences among alternative options, where the options accomplish several objectives. In MCA, desirable objectives are specified and corresponding attributes or indicators are identified and MCA has the ability to evaluate several alternatives with regards to multiple criteria.

The actual measurement of indicators need not be in monetary terms, but are often based on the quantitative analysis (through scoring, ranking and weighting) of a wide range of qualitative impact categories and criteria. Explicit recognition is given to the fact that a variety of both monetary and nonmonetary objectives may influence policy decisions. MCA provides techniques for comparing and ranking different outcomes, even though a variety of indictors are used. MCA includes a range of related techniques, some of which follow this entry [6].

Multi-criteria analysis or multi-objective decision making is a type of decision analysis tool that is particularly applicable to cases where a single-criterion approach (such as cost-benefit analysis) falls short, especially where significant environmental and social impacts cannot be assigned monetary values. MCA allows decision makers to include a full range of social, environmental, technical, economic, and financial criteria [6]. The framework will be applicable to any measure within the urban-interurban context, embedding a Life-Cycle Assessment method (LCA) specifically for the assessment of transport modes and other technological solutions.

LCA has been used in many different fields such as water technologies, domestic product production, energy production, and transportation to estimate energy requirements and emissions generation. The term "life cycle" refers to the most energy and emissions intense activities in a product's lifetime from the extraction and collection of raw materials for its manufacture, use, and maintenance, to its final disposal or recycling. LCA can be implemented in sustainability assessment as it can provide detailed measures to assess partially the environmental dimension (emissions, energy) of sustainability. In the transportation sector, studies that have used the LCA methodology to analyze the environmental impacts of transportation components include the life cycle assessment for passenger car tires, lithium-ion batteries, electric vehicles, and fuel types.

A conceptual sustainability framework is suggested here, referring to analyzing and assessing urban transportation modes in terms of sustainability aspects [7]:

…The proposed sustainability framework consists of four fundamental layers and three controllers that manage the deployment of a system.

The four layers are: environment, technology, energy and economy and the three controllers are: users (and other stakeholders), legal framework and local restrictions.

According to the proposed framework, a prism is used (Fig. 1) as a visual representation of the hierarchy of the four layers that structure the system to depict the dependence that each category exerts on the next one. The four layers represent the essential components for the development of a system. The three sides of the prism represent the three controllers that restrict the system's creation, implementation and acceptance. These controllers are imposed by the community.

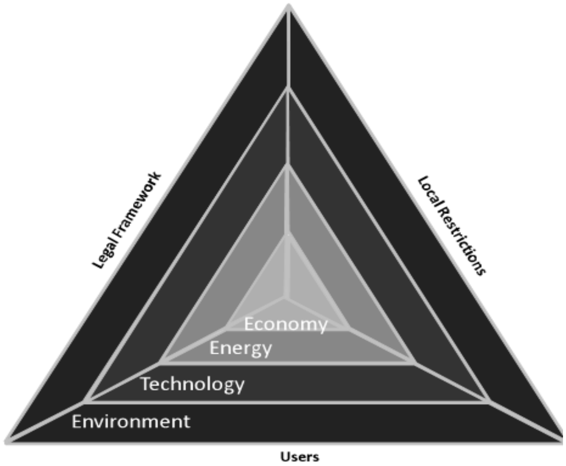

Figure 1. Sustainability decomposition prism [7]

The proposed framework can act as a theoretical basis of a life-cycle assessment of urban transportation modes in terms of environment, technology, energy and economy taking also into account users' aspect.

III. Methodological Framework for Incorporating Sustainability Assessment into Urban Freight Transportation Modes

In order to examine a transportation mode, criteria are developed for each combination of sustainability category and attribute for vehicles. For each criterion a list of indicators is developed that enables quantification of sustainability performance according to each criterion. The criteria and indicators of the proposed framework as discussed in the next section.

A. *Sustainability Categories, Criteria and Indicators*

Environment

- Green House Gas (GHG) emissions are an outcome of the operation of the vehicles within their lifetime. They have a direct impact on the environment. Carbon Dioxide (CO_2) - Creates greenhouse gas which contributes to the global climate change.
- Air quality emissions. The criteria pollutants are carbon monoxide (CO), lead (Pb), nitrogen dioxide (NO_2), ozone (O_3), particulate matter (PM), and sulfur dioxide (SO_2) [8]. Carbon monoxide (CO) at low concentrations causes fatigue, chest pain in people. At higher concentrations it causes impaired vision and coordination, headaches, dizziness, confusion and nausea.

Energy

- Consumption refers to the energy a vehicle (propulsion) needs to operate.

Economy

Cost refers to the cost of all attributes that can be interpreted in monetary terms:

- Purchase cost is the lump sum monetary value which provided in order to own the transportation mode.
- Maintenance cost is the total annual cost which includes: general expenses, insurance costs, road service, taxes and maintenance costs).
- Fueling costs is the total annual cost that meets the fueling needs of the mode.

Other data basically depicting technological and operational criteria

- Life expectancy refers to the expected lifetime of vehicle.
- Distance covered. The total distance in kilometers covered by transportation modes. The longer the distance covered, the more positive impact has to sustainability outlook of this mode.

B. *Data Collection, Processing and Evaluation*

The collection of data pinpointed came as a result of data assembly after a long-time visit at the facilities of Mama Products SA, a logistics service provider (LSP) which services retail shops in urban and interurban agglomeration outside a Thessaloniki, Greece. Combined with that data, a web searching took place tailored for evaluating operational lifecycle of two different types of vehicles that the LSP uses for distributing merchandise within urban context. The data [9] provided by Mama Products SA should have been quantified in order to act as practical showcasing and applied framework of the indicators used to develop it.

Data processing involved assumptions and mathematical equations in order to compile a matrix of raw data for further quantification. Data processing and evaluation relied on the following simple models:

- $e = Ey/TK$, e = total amount of energy per tonne-kilometers, E = amount of energy in joules per year, y = total expected lifetime of the vehicle and TK refers to tonne-kilometers covered in a year
- n = Noise in dB
- $g = GKy/TK$, g indicates total amount of GHG emissions per TK, K is for kilometers per year and G is GHG emissions in gr/km
- $a = AKy/TK$, a indicates total amount of air emissions per TK, and A refers to air emissions in gr/km
- $pc = PC/TK$, where pc is the purchase cost of the vehicle per TK and the PC the initial purchase cost in €
- $mc = MCy/TK$, where mc is the maintenance cost per TK and MC is the total annual maintenance cost in €
- $fc = FCy/TK$, is the fuel cost per TK and FC refers to the annual fueling cost in €.

The data E, y, tones and kilometers per vehicle (T, K), MC and FC are directly reaped by the logistics service provider achieve files. Purchase costs were identified on Ford and Fiat websites (www.ford.com, www.fiat.com).

In addition, due to the fact that there was no emissions data for LNG vehicles that were involved in our research, it was taken as granted that vehicles that use LNG vehicles exhaust around 25% less CO and about equal amount of NOx as the conventional energy source vehicles [10].

Table 1 presents the quantified life cycle sustainability indicators applied to each vehicle type. The proposed sustainability indicators are first distinguished into indicators with positive (+) impact, and indicators with negative (-) impact. Aggregation of indicators into a unique sustainability category index can be achieved by normalizing the value of each indicator for each vehicle type by using equations 1a and 1b and then by assigning weights [11]:

$$N_{ij}^{+} = \frac{I_{ij}^{+} - I_{\min,j}^{+}}{I_{\max,j}^{+} - I_{\min,j}^{+}} \tag{1a}$$

$$N_{ij}^{-} = \frac{I_{\min,j}^{-} - I_{ij}^{-}}{I_{\min,j}^{-} - I_{\max,j}^{-}} \tag{1b}$$

TABLE I: SUSTAINABILITY CATEGORIES WITH SELECTED SUSTAINABILITY CRITERIA, INDICATORS AND THEIR VALUES

Categories	Criteria	Indicators		Units	*FIAT Doblo*	*Ford Transit*
Environment	GHG	CO2	-	gr/TK	1509.52	1811.85
	Air quality	CO	-	gr/TK	5.02	5.79
		N0x	-	gr/TK		
Environmental sustainability index/ vehicle type					*0*	*1*
Energy	Energy consumption	Fuel energy	-	Joule/ TK	117.3	86.2
Energy sustainability index per vehicle type					*1*	*0*
Economy	Cost	Purchase cost	-	€/TK	0.753	0.518
		Maintenance cost	-	€/TK	0.402	0.706
		Fuel cost	-	€/TK	0.776	1.03
Economy sustainability index per vehicle type					*0.33*	*0.66*
Other data	Technology	Lifespan	+	years	7	10
		Annual distance covered	+	kms	48000	32000
Other data' sustainability index per vehicle type					*0.5*	*0.5*
Overall sustainability index per vehicle type					**0.46**	**0.54**

where N_{ij}^{+} , is the normalized indicator with positive impact achieved by the ith alternative regarding the jth indicator of sustainability. I_{ij}^{+} is the indicator achieved by the ith alternative when evaluated based on the jth indicator. $I_{\min,j}^{+}$ is the indicator with the 'worst' value achieved by the jth indicator of sustainability and $I_{\max,j}^{+}$ is the optimal value of jth indicator of sustainability level obtained. The normalized values are dimensionless and vary from 0 to 1, therefore the greater the absolute value of the normalized indicator, the more sustainable it is. Hence, on a relative scale, the most sustainable vector for each vehicle type is $I_{\max} = (1,...1)$ and the least sustainable vector is $I_{\min} = (0,...0)$ where its components equal the number of the sustainability categories.

Aggregation of normalized indicators into a single sustainability category and overall sustainability indices per vehicle type is performed by using the weighted sum method (WSM) [12]. The value of alternative Ai with assigned weight w_j for each indicator j can be mathematically expressed as:

$$V_i = \sum_{j=1}^{n} w_j N_{ij} \qquad i = 1,...,m \tag{2}$$

In this analysis equal weights were assigned to each indicator and sustainability category. Table I presents the sustainability category index and the overall sustainability index per vehicle type.

IV. ANALYSIS OF THE RESULTS

The selected indicators that are quantified extensively in this study provide comprehensive comparable estimations for the two different types of light-duty vehicles, Fiat Doblo and Ford Transit. Criteria and indicators are identified for the four sustainability categories, including: environment, technology, energy and economy.

The quantified indicators and their units are shown in Table I for each sustainability category. The four sustainability categories are the goals for urban transportation vehicles which guide decision makers in enhancing sustainability performance. The overall sustainability index for each vehicle is used to compare the two vehicle types. Plus and minus signs show the positive and negative utility for the corresponding sustainability indicator (i.e., the greater the absolute value of the indicator the more positive or negative impact it has).

Based on the sustainability category indices, in the categories of environment and economy Ford Transit (diesel) was ranked first with scores equal to 100% and 66%, respectively. In the sustainability category energy, Fiat Doblo was ranked first with a score equal to 100%, as perhaps expected. In the sustainability category 'Other – Technology', case study vehicles were equally ranked first with a score to 50%.

When these four sustainability categories are used with the proposed criteria, equal weights for each sustainability indicator and category and when indicator values are weighted for tonne-kilometers to develop an overall sustainability index, then the most sustainable transportation mode is found to be the Ford Transit. The Ford Transit attained sustainability up to 54% whereas Fiat Doblo, even considered as a 'cleaner' vehicle, reached a sustainability index of 46%.

Whereas it may be unexpected that Fiat Doblo should have been more 'sustainable' as it uses liquefied natural gas, Ford Transit scores higher due to the fact that analysis is being carried out under the framework of tonne-kilometers. The annual distance covered by Ford Transit is 32000 km whereas the Fiat Doblo reaches 48000 kilometers. The covered tonne-kilometers are presented inversely proportional and thus the final outputs are justified mainly by the term 'per tonne-km'. Lifespan looks shorter for natural gas vehicle because converting a conventional engine into LNG reduces lifetime of a former conventional engine.

V. Discussion and Conclusions

Urban areas represent special challenges for national and international freight transport both in terms of logistical performance and environmental impacts. Congestion on European roads is a major cause of pollution, wastes time and energy, and is a threat to public health [13].

Public concerns should be expressed by indicators that are easily understood, to make possible their use by decision-makers and their long-term monitoring by agencies and stakeholders [7]. Transportation agencies may support their decisions on the sustainability framework for the introduction of a new mode that aims to alleviate transportation problems on a corridor or an area by comparing sustainability indicators which assist in prioritizing and influencing choices.

Our sustainability analysis showed that the diesel van ranked first, achieving an overall sustainability index of 54% whereas the natural gas vehicle follows by 46%. Ford Transit (diesel) precedes Fiat Doblo when assessed in economy sustainability index and the environmental one. In contrast, LNG vehicle scores better under energy sustainability evaluation framework and the analysis reveals a tie between the two of them when assessing in terms of lifetime and distance covered indicators. It is crystal clear that at first, we could have expected LNG vehicle to achieve higher sustainability index. However, the fact that all outputs appear as x/TK measurement unit leads to the result that, tone-kilometers characteristics of each vehicle (as well as annual distance covered) play a vital role to the final outcome. Indeed, estimations show that the synthesis of all these attributes reveals that diesel vehicle goes ahead of LNG vehicle by 8% in terms of overall sustainability performance.

The primary contribution of this research is the representation of a sustainability framework within which attributes of a transportation mode can be studied. Criteria and indicators can be integrated into a tool that is able to appraise transportation modes in a sustainability context. Assembling sustainability indicators into a simple and explicit overall sustainability index is achieved by normalizing indicator values to assess competing transportation modes.

This tool can be utilized by policy makers and transportation agencies to study changes in the sustainability of a corridor, of origin-destination trips or of networks by altering the percentages of vehicles in the local fleet. These outcomes could also be valuable to MAMA Products SA staff to acknowledge the sustainability level of their fleet. Moreover, further research could be applied on the evaluation of logistics measures performed by logistics service providers. Thus, a robust and generic impact assessment framework could be developed for sustainability evaluation of city logistics transportation concepts.

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