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Sustainability Framework for Assessing Urban Freight Transportation Measures

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***Abstract*— The salient scope of this paper is to enable the knowledge and understanding of urban freight transportation and provide guidance for implementing sustainable policies and measures in a city. To achieve this goal, an evaluation framework for city logistics policies and measures is developed, which demonstrates the complexity of urban freight transportation systems, through selected performance indicators, taking into account divergent stakeholders' interests, conflicting business models and operations. Evaluation follows a hierarchical process; sustainability disciplines (economy and energy, environment, transportation and mobility, society), applicability enablers (policy and measure maturity, social acceptance and users' uptake), multiple criteria and indicators, capturing the lifecycle impact of policies and measures and multiple stakeholders. Apart from the multicriteria context, the framework embeds methodologies, including, Impact Assessment, Social Cost Benefit Analysis, Transferability and Adaptability, and Risk Analysis. To demonstrate its applicability a case study is set for the City of Graz assessing the establishment of an Urban Consolidation Center. Results show that there is an overall improvement of 2.2% in the Logistics Sustainability Index when comparing before and after implementation cases of the Urban Consolidation Center.**

***Index Terms*—Framework, Logistics assessment, Sustainability, Urban logistics.**

I. Introduction

During the last two decades, the booming increase of passenger and freight transportation in both interurban and urban context has resulted in deep impacts in human and natural environment [1]. Urban areas represent the greatest challenges for freight transportation and service trips, in terms of not only goods distribution and service allocation performance, but also pertaining to traffic congestion, excessive energy use, environmental and safety impacts. A glance to the stage of play, related to the increasing burdening of the urban environment over time, is highlighted in the following:

- Over 50% of the world population lives in cities [1];
- More than 100 million people have migrated to cities globally since the beginning of this decade [2];
- By 2050, at least 70% of the world population will live in cities [2];
- In Europe, around 75% of the population lives in urban areas [3];
- Urban mobility accounts for 40% of carbon dioxide (CO_2)and up to 70% of other pollutant emissions of road transportation [4, 5, 6];
- Urban freight vehicles account for 6 -18% of total urban travel [7] and 19% of energy use and 21% of CO_2 emissions in Europe [8];
- Annually, approximately 1% of the Gross Domestic Product of the European economy is lost due to congestion [9].

The technological, economic and social transformations and reclassifications in the urban land uses, as well as the environmental consequences of road based transportation systems, have caused significant changes in the patterns of freight movements, increasing the interest and attention to freight transportation within urban areas [8].

City logistics have been introduced as an efficient concept to address the intricate needs arising from the multidimensional character of urban areas, formulated by consumer habits, environmental considerations, economic growth, new and smart technologies, legal and institutional frameworks, but also by congestion, air pollution, noise, crashes and reduced accessibility due to obsolete infrastructure or environmental and traffic restrictions. On this direction, Taniguchi et al. [10] have set three basic pillars as guiding principles for city logistics: mobility, sustainability and livability. Promoting sustainable urban mobility, the latest Transport White Papers of the European Commission set the goal of achieving CO_2-free city logistics by 2030 [11], aiming towards an overall reduction of 60% in Greenhouse Gas (GHG) emissions. The performance of Urban Freight Transportation (UFT) has direct implications for the congestion, emissions and quality of life, economic development of the city and competitiveness of the business stakeholders. However, decisions such as land use and zoning restrictions on delivery time, routes followed and parking locations are often made without a full understanding or consideration of urban goods movement by commercial vehicles [12].

Achieving sustainable urban mobility requires raising knowledge and understanding, however, very few cases exist, where city authorities undertake sound analysis of possible city logistics measures and impacts and use the results to build long term policies and synergies with other stakeholders (supply chain, society) [13]. Provided knowledge and understanding rely on experiences obtained from other cities' applications, which may not fit each city's specificities; whereas, there is still a gap in the consolidation of the stakeholders in a common decision-making context. As a response to the need for enabling balanced decision-making with the mutual participation of all city stakeholders in city logistics, the salient scope of this paper is to enable the knowledge and understanding of UFT and provide guidance for implementing effective and sustainable policies and measures (measures from here onwards). Towards this direction, an evaluation framework for city logistics measures is developed, which assesses the complexity of UFT systems, through selected performance indicators, divergent stakeholders' interests, conflicting business models and operations. The framework is adjustable and flexible, thus applicable to any city and measure, regardless of its nature (technological, legal, cooperative, etc.).

II. State of the Art

Evaluation is a technique that critically examines a process, program or project. It involves collecting and analyzing information about activities, context and results. Its purpose is to enable judgments on effectiveness and efficiency and lead to the improvement of a process, program or project, through facilitating decisions for corrective actions [14].

In city logistics, the selection and implementation of the appropriate measure(s) should rely on a well-structured evaluation process, which examines the expected impacts of the measure(s) in the specific city and facilitates decision-making. Over the last years, tendencies for adoption of a uniform evaluation method in UFT exist; however, there is not yet a uniform and robust evaluation method [15].

In Europe, there are several research projects that have dealt with city logistics and how improvements can be achieved through the implementation of "smart" measures. Some representative projects are described, here. A general assessment framework was developed and implemented in the STRAIGHTSOL project, which combined social cost benefit, business model and multi actor multi criteria analyses [16]. A design and monitoring framework was adopted in 'before' and 'after' analysis of UFT measures in SMARTFUSION project, considering costs in respect to logistics and society [16]. Vehicle design concepts combined with structural urban development models were studied in CITYLOG project, raising the issue of sustainability and efficiency [17].

Several measures were adopted by the cities that participated in ENCLOSE project [18] and were assessed by using six criteria. CIVITAS-MIRACLES project defined a set of indicators to evaluate different legislative and technological measures, using multi criteria analysis [19]. BESTUFS project incorporated a Strengths Weaknesses Opportunities Threats (SWOT) analysis in order to evaluate more specific strategic and operational measures [20]. In order to enhance and disseminate best practices concerning UFT evaluation methods, BESTFACT project developed an evaluation cost-benefit based tool to examine the appropriateness of a specific measure [21].

Multi-stage impact chain analysis was followed in C-LIEGE project [22]. The aim of the analysis was to pinpoint the pathway from the implementation of a measure up to its realized effects. A second component concerned comparison with reference cities that had already implemented specific measures. Lastly, a scenario-based impact assessment was conducted. Identification of research questions and hypotheses were used in FREILOT project for the definition and estimation of performance indicators [23]. Transferability constituted a primary objective of the CITYLAB project and was addressed through an evaluation methodology comprising adoption, process, context and impacts analyses [24].

Most of the above studies treated sustainability in terms of economy, environment, society, mobility, during the examined measures' operation, however none of them considered the lifecycle of the measures. Lifecycle analysis for sustainability performance has been used in transportation, mostly related to the use of urban transportation modes, in general [25, 26] and freight vehicles, in particular [27]. However, no methodology has yet addressed the lifecycle of processes, which best depict the city logistics measures, as they are not necessarily related to vehicles and products. To fill the identified gap in the area of assessment frameworks [28], the present research addresses the issue of sustainability of city logistics measures, by adopting a lifecycle analysis approach.

III. EVALUATION FRAMEWORK

The aim of the developed evaluation framework is to assess the performance of urban logistics measures, portraying the complexity of UFT systems in terms of divergent stakeholders' interests, conflicting business models and unsustainable operations. The framework embraces a transparent decision-making model, expanded through the components of LifeCycle Sustainability Assessment (LCSA), and structured as a multi-stakeholder multi-criteria decision-making tool. The structure of the overall framework is presented in Fig. 1 and explained in the following sections.

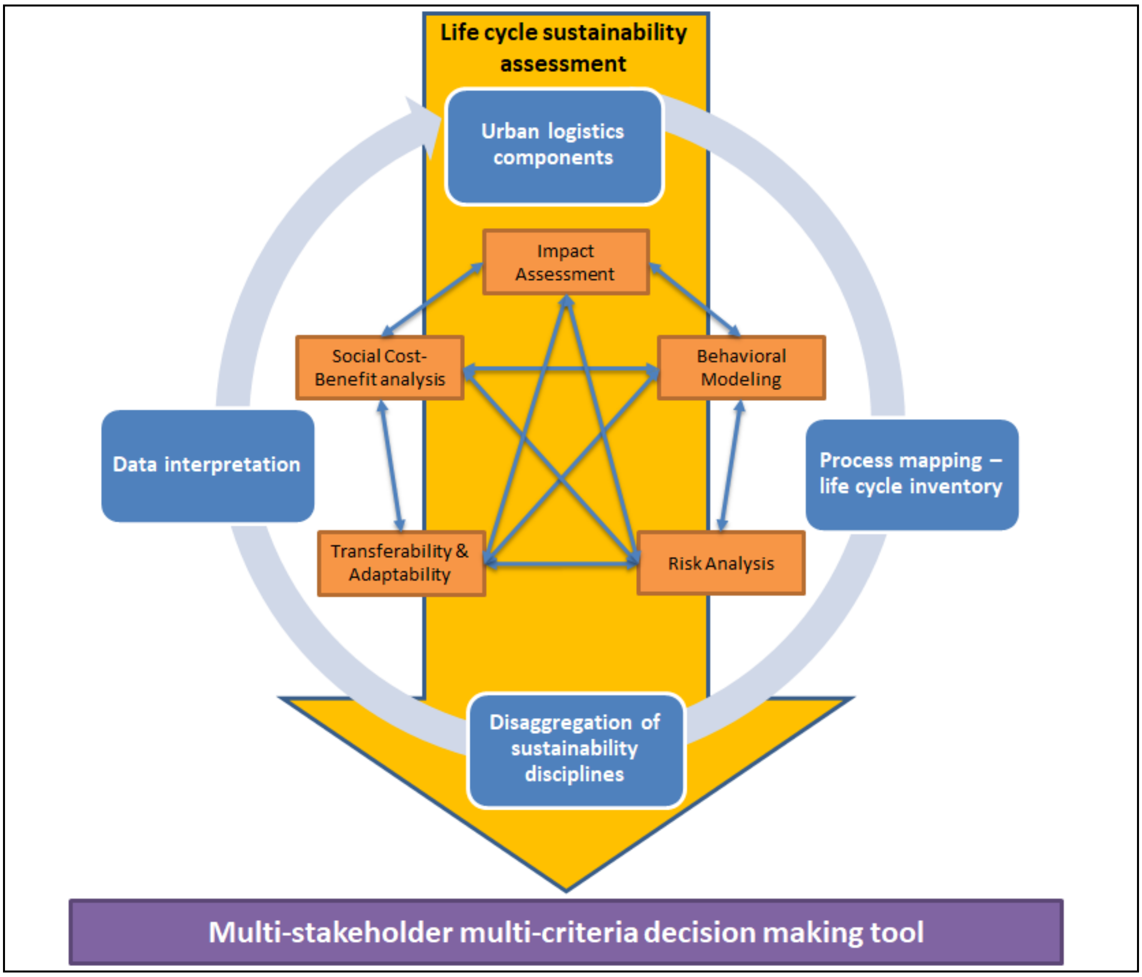

Fig.1. Evaluation framework structure

A. *Lifecycle Sustainability Assessment*

The optimization of UFT and the introduction of new sustainable logistics measures can significantly contribute to the increase of the sustainability and livability level of cities, through the limitation of the emissions and noise impacts, and the alleviation of traffic congestion [29].

Life Cycle Analysis (LCA) is a decision-making tool, which takes into account the emerging environmental concerns and is capable of measuring potential environmental impacts, throughout the entire lifecycle of a process, system or product, avoiding the crucial errors caused by limited scope work [30]. Through LCA, the environmental impacts of product's lifecycle are quantified from cradle to grave, divided into five phases: raw material extraction, manufacturing, transportation, use, and end-of-life [31]. Initially, the lifecycle analysis process was introduced in Europe and the United States of America in the late 1960's, and since then it has been mainly applied to the estimation of energy requirements and environmental impacts of various products. Extending their research focus, a number of studies have included social and economic concerns in lifecycle analysis, in addition to environmental aspects [32]. The extended quantification of environmental, economic and social impacts has resulted to Life Cycle Sustainability Assessment (LCSA) initially formulated by Klöpffer [33], followed by Finkbeiner et al., [34], and Onat et al., [35]. The LCSA process has been used in transportation for the assessment of vehicles by using indicators representing lifecycle impacts for different vehicle types [26].

Based on the four lifecycle stages (Creation – construction, Operation, Maintenance, and Closure – disposal), LCSA acts as the umbrella of the overall framework, realized in four discrete steps (Fig. 1).

Step 1: Identification of Urban Logistics Components

Key influencing factors and measures lead to the formulation of logistics scenarios or alternatives, and the latter leads to the estimation of freight trip activities. Five main categories of key influencing factors have been identified [36]:

1. Economy and demographics: GDP per city inhabitant, fuel cost, urban population share, city's population share of over 65, household size, retail establishment size.
2. Ecology and social responsibility: demand for environmentally-friendly products, demand for ethical sourcing, demand for local sourcing, demand for reduced waste.
3. Logistics solutions: green delivery solutions, collaborative delivery solutions, new business models.
4. New technologies: mobile/wearable technology and Internet of Things, big data and advanced analytics, driverless cars, augmented reality.
5. Consumer requirements: same day (or next hour) delivery, provision of relevant information, knowledge of what happens to the digital data they provide, information about products, and their social and environmental impact.

As the domain of UFT is multidisciplinary, involved stakeholders are grouped in three categories:

1. Supply chain stakeholders, including freight forwarders, transportation operators, shippers, major retail chains, and shop owners.
2. Public authorities, comprising local government, national government.
3. Other stakeholders, composed mainly of industry and commerce associations, consumers associations, research and academia.

Each category defines their own objectives, which affect the formulation of the criteria (in step 3) against which the performance of the city logistics measure is assessed.

Step 2: Process Mapping - Lifecycle Inventory

Processes for each measure are described analytically under each of the four lifecycle stages (from cradle to grave): Creation-construction, Operation, Maintenance and Closure. Where equipment is included, its development from creation to disposal (back logistics) is also detailed.

Step 3: Disaggregation of Sustainability Disciplines and Applicability Enablers

This step includes the identification and disaggregation of the impact areas; thus, the four sustainability disciplines: Economy and energy, Environment, Transportation and mobility, and Society; and the three applicability enablers: Policy and measure maturity, Social acceptance and

Users' uptake. For each sustainability discipline and applicability enabler, the relevant criteria are indicated, and then, for each criterion, respective basic and combined indicators are defined, and associated to stakeholder categories.

Step 4: Data Interpretation

Data interpretation comprises the estimation of the Logistics Sustainability Index (LSI). Evaluation incorporates a multiple weighting scheme and ranking techniques for the facilitation of "shared" decision-making, taking into account the participation and contribution of all involved stakeholders to the conformation of the final decision made on the measures.

IV. Multi-Stakeholder Multi-Criteria Evaluation

Evaluation follows the formulation of multi-stakeholder multi-criteria analysis. Function 1 in Fig. 2 includes the definition of the involved stakeholders, while the determination of specific objectives per stakeholder category is part of function 2. In parallel, alternatives in terms of different scenarios are built (function 3). Depending on the anticipated measure, each scenario is tested against a number of representative performance criteria (grouped in impact areas) and indicators, which are established and associated with the stakeholders' objectives (function 4). A commensurate scale is developed for the valuation of the indicators through normalization or utility function (function 5). In parallel, weights per impact area, criterion and indicator are defined, following specific processes, e.g. analytic hierarchy processes, budget allocation processes, conjoint analyses, etc. (function 6). Based on the actual indicator values and the commensurate scale, comparative impacts are estimated (function 7). In function 8, weights and comparative impacts are used together for the calculation of the combined impact of each alternative, which comprises the LSI of the scenario for the stakeholder category (function 8). Ranking of alternatives and selection is done in function 9.

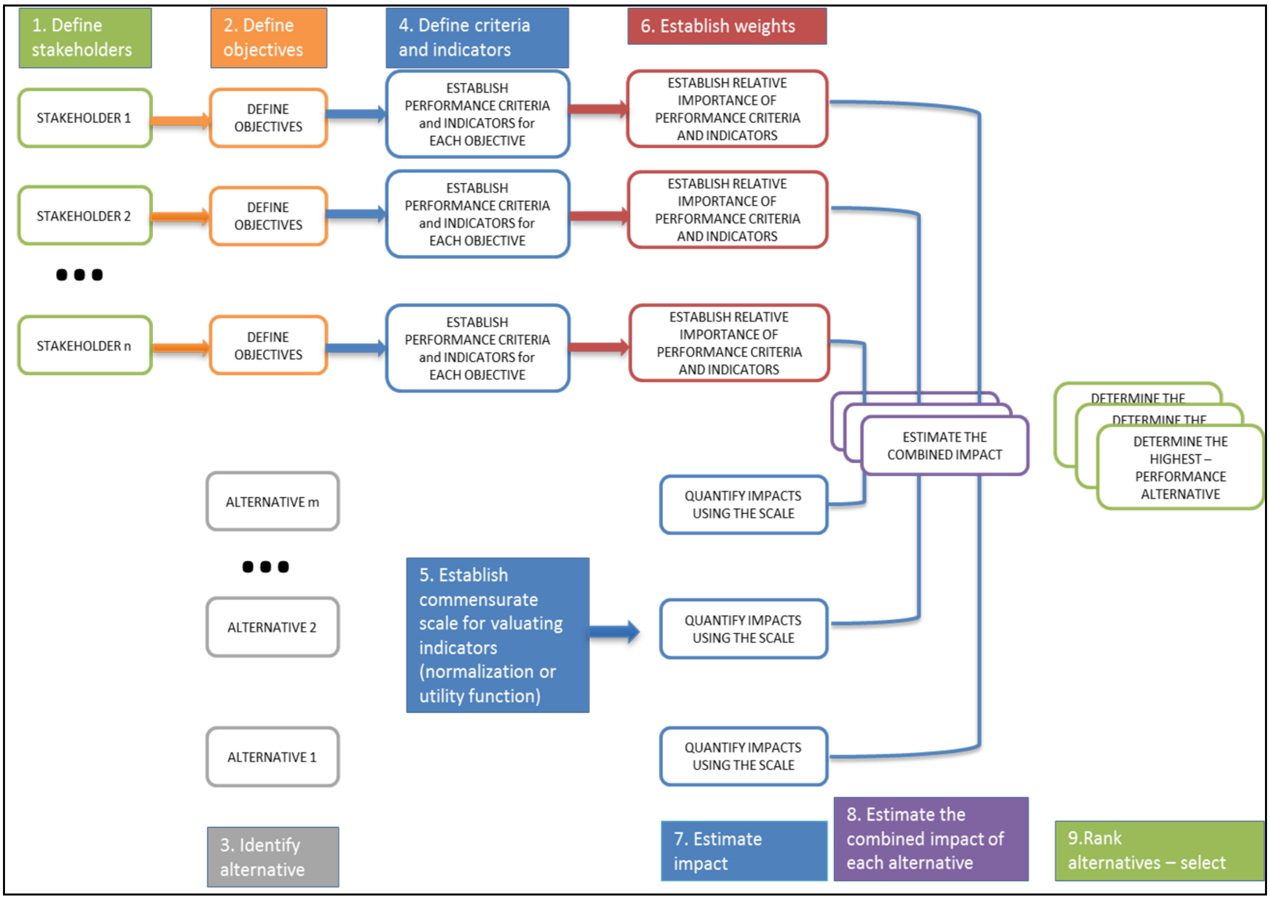

Fig. 2. Evaluation methodology [29]

When all relevant stakeholders participate in the process supported by the framework, the evaluation results reflect to the city. Individual results, thus concerning each stakeholder category may be easily isolated and considered separately, if so desired. The LCSA framework enables the incorporation of lifecycle inventory in the respective functions, where appropriate, so that each combination of the above input data is mapped from creation, through operation and maintenance to closure.

A. *Evaluation Components*

The definition of the hierarchical order of the evaluation components is of significant importance in the framework. Objectives, which lead ultimately to the optimization of UFT in a city through a measure implementation, are clearly defined. These are associated to a set of impact areas, criteria and indicators to quantify the impacts. The choice of the evaluation components depends on the stakeholder category, the selected measure and the lifecycle stage. The seven impact areas are:

Economy and energy. Energy is a major field that is directly connected with economy in modern communities. Energy availability, demand, price and actual consumption have short term and long term impacts on lifestyles. The creation of a sustainable economy requires partial utilization of energy and development within environmental limits. Continuous utilization of nonrenewable energy sources results in depleted energy sources and increased energy pricing, therefore unsustainable communities.

Environment. The environment refers to the preservation of natural resources and the limits within which activities should take place without depleting non-renewable resources. The environmental impact of logistics is addressed through emissions, air quality and noise impacts on communities.

Transportation and Mobility. Transportation and mobility are two concepts that are becoming more and more popular at local, national and European level. The continuous pursuit of improving transportation of goods and mobility of people is usually translated into terms of attractiveness, accessibility, level of service, safety as well as availability of infrastructure.

Society. Ultimate aim of the implementation of UFT measures is the positive impact of them to the society. Society is defined as different groups of people that interact with other people in a community. Societal impacts of logistics can be described adequately with respect to sustainability, convenience and living standards of the community.

Policy and measure maturity. The policy and measure maturity impact area express mainly the involvement of stakeholders into the implementation of a proposed UFT measure. More specifically, it is related with the awareness of stakeholders towards the measure, their managerial skills as well as their related knowledge, experience and willingness to adopt it.

Social acceptance. The social acceptance impact area can be discerned into two levels; the social approval level, i.e. the extend that a measure is welcomed and respected by the society, regulations' compliance and measure enforcement.

User Uptake. This impact area checks the adaptability, flexibility, transferability and success of the implementation of a UFT measure, taking into consideration stakeholders' opinions, agreements and acceptance.

The seven impact areas as they apply to all UFT measures, with the respective number of 26 criteria and 140 indicators are presented in Tables 1 to 4. The user may choose to evaluate a UFT measure by selecting impact areas, criteria and indicators; in this case the evaluation is based on the Logistic Sustainability Index that is generated for each measure following the process in Fig. 2. The user may also use either supplementary or independently one or more of the five modules (as described in section 5) to perform an evaluation of UFT measures.

Table 1. Impact areas, criteria and indicators – Part 1

	Criterion	**Indicators**	**Explanation**
Economy and energy	**Energy**	Energy consumption	Energy consumed (non-renewable energy sources).
	Develop-ment	Working potential	Direct employment positions related to UFT.
		Business development	Indirect employment positions related to UFT.
		Local development	Effect on local/regional socioeconomic life activities and wealth, e.g. GDP/capita.
	Benefits	Income generated	Total income generated.
		Diversification of local economy	Change of dynamics in the domain of economy in the mean of increasing potential for growth increase in the future.
	Costs	Planning and managerial costs	Costs related to planning process; include the managerial costs that occur during the planning and designing phase.
		Investment costs	Total additional capital costs for setting up an initiative, demonstration, action or measure.

	Criterion	Indicators	Explanation
		Management	Cumulative amount of money spent on management.
		Wages	Cumulative amount of money spent on wages.
		Fuels	Cumulative amount of money spent for fuel.
		Warehousing/handling	Cumulative amount of money spent for warehousing and / or cargo handling.
		Transshipment	Cumulative amount of money spent for cargo transshipment.
		Depreciation of infra.	Cumulative amount of money associated with infrastructure depreciation.
		Depreciation/equip	Cumulative amount of money associated with equipment depreciation.
		Training	Cumulative amount of money spent on staff / personnel training.
		Personnel	Cumulative amount of money spent on staff for maintenance activities.
		Equipment/infrastructure	Cumulative amount of money spent on equipment and infrastructure for maintenance.
		Consumer cost	Product cost charged to the end customers (final consumer) incl. delivery cost.
		Enforcement cost	Total cost usually spent by the local authority for enforcing regulations/policies.
		Shipper/receiver costs	Amount of money paid by the shipper/receiver for shipping/receiving a product.
		End of life costs (infra)	Amount of money needed for rehabilitation/demolition of related infrastructure.
		End of life costs (equip)	Amount of money needed for the withdrawal of obsolete equipment, hardware.
	Economic and financial risks	Tax changes	The level of tax changes (mainly increase) which influence the budget of UFT.
		Inflation	The level of influence of changes in inflation rate on UFT.
		Economic situation	The level of influence of unstable economic situation on UFT activity's implementation.
		Rising costs	The level of influence of the rising cost of fuel, machines and materials on the budget of implementing UFT activities.
		Payroll and tax increase	The level of influence of the increase in payrolls and tax payments on the budget of implementing UFT activities.
		Reduction of the foreseen capacity	The level of changes in the budget of the UFT activities caused by a reduction of the foreseen capacity of the freight transportation system.
		Maintenance costs of a UFT activity	The level of cost increase in the budget of a UFT activity caused by unexpected higher maintenance costs.
		Inadequate budget	The level of differences between planned and executed budget.
		Financial status actors	The number (in percentage) of actors and stakeholders with financial problems.
		Funds in the budget	The level of shortfall of funds in the budget in comparison to the planned budget.
		Delayed receipt of fund	The range of delays in funds being received in relation to the schedule.
		UFT economic aging	The duration (in years) of the economic aging of UFT activities.
		Funding opportunities	The range of opportunities for funds while planning/implementing UFT activities.
Environment	**Air quality**	CO concentration	The maximum daily 8 hour mean CO concentration.
		SO_x concentration	The averaging SO_X concentration for a 24h period.
		NO_x concentration	The averaging NO_X concentration for a period of 1 year.
		VOC concentration	The averaging VOC concentration for a period of 1 year.
		NH_3 concentration	The averaging NH_3 concentration for a period of 1 year.
		PM_{10} concentration	The averaging PM_{10} concentration for a period of 1 year.
	GHG emissions	CO_2	Total CO_2 emissions produced.
		CH_4	Total CH_4 emissions produced.
		N_2O	Total N_2O emissions produced.
	Noise	Noise level	Average noise level during the day.

Table 2. Impact areas, criteria and indicators – Part 2

	Criterion	Indicators	Explanation
Transportation & mobility	**Level of service**	Punctuality	Proportion of deliveries and pick-ups made in the right time slot.
		Quantity	Proportion of deliveries and pick-ups made in the right quantity (no loss or theft).
		Quality	Proportion of deliveries and pick-ups made in the right form (i.e. not damaged).
		Market response	The proportion of times that products were available at the receiver.
		Customer satisfaction	The perceived customer satisfaction stated by customers based on experience.
		Supply chain visibility	Information accessible updated and visible by all interested actors via internet.
	Safety and security	Accidents	Number of accidents on site and en route covered by UFT activities' vehicles.
		Fatalities	Number of fatalities on site and en-route covered by UFT activities' vehicles.
		Injuries	Number of injuries on site and en-route per total vehicle km (UFT activities'

			vehicles).
		Damages	Number of damages (property damage) in accidents on site (e.g. UFT facility) and en-route covered by UFT activities.
		Crime / Theft events	Number of incidents involving crime / theft in facilities or en route over total number of shipments.
		Vandalism	Number of incidents involving vandalism in facilities or en route over total number of shipments.
	Transpor-tation system	Delays	Total delays in traffic.
		Violations	Number of violations over the total number of entries in restricted areas (e.g. LTZs or pedestrian zones).
	UFT vehicles	Traffic throughput	Number of veh-kms.
		Load factor	Average load factor of a vehicle during deliveries and pickups.
		Vehicle utilisation factor	Hours that vehicles are in service, e.g. deliveries, pickups, transporting, weighting, loading/unloading over 24 hours.
	IT, infrastru-cture and techno-logy	Underdeveloped transportation infrastructure	Level of changes in the schedule and cost of a UFT activity's implementation caused by underdeveloped transportation infrastructure.
		Low quality of infrastructure	Level of changes in the schedule and cost of a UFT activity's implementation caused by low quality of infrastructure.
		Limitations at infrastructure	The level of changes in the schedule and cost of a UFT activity's implementation caused by limitation at existing infrastructure.
		Limited access to modern technologies	The level of changes in the schedule and cost of a UFT activity's implementation caused by lack or limited access to technologies.
		Lack of information technologies (IT)	Actors and stakeholders who do not have IT dedicated to freight transportation or/and IT infrastructure is obsolete to commence a UFT activity's implementation.
		Development of IT prototype	Percentage of actors and stakeholders whose needs weren't taken into account while developing an IT prototype.
		Failures of IT systems/ technologies	The duration (in days) of disruption of a UFT activity's implementation caused by failures of IT systems and other modern technologies.
		Conflicting interfaces of work	Number of actors and stakeholders who have conflicting interfaces of work items while implementing UFT activities.
		Hacker disturbance	The duration of disturbance of UFT activities' implementation caused by problems with IT hacking.
		Network barriers	Evaluation of accessibility level pertaining the seamless movement of freight vehicles as a result of infrastructure and construction.
		Urban space engagement	For the storage, loading/unloading, handling or transshipment of cargo and for parking of freight vehicles where UFT activities take place.
		Infrastructure usage	Degree of usage of infrastructure (e.g. hours/day or equipment).
Societ y	**Greening**	Green reputation	Reputation of involved stakeholders for implementing "green" measures.
		Green concern	Degree that stakeholders are oriented towards environmental preservation resulting from the measure implementation.

Table 3. Impact areas, criteria and indicators – Part 3

	Criterion	Indicators	Explanation
Society	**Conve-nience**	Perceived visual & audio nuisance	Degree to which people are annoyed by the visual and audio nuisance, caused by goods' deliveries in the city.
		Diffusion of information	Public satisfaction on the diffusion of information used to get the public acquainted with the modification of mobility standards due to goods' deliveries in the city.
	Living standards	Perceived alternative mobility	Citizens' recording of increase in the use of environmental friendly modes and ways for goods' deliveries in the city.
		Quality of life	Quality of level, addressed by land use optimization, full access restrictions for goods' deliveries, detachment of UFT activity areas, etc.
		Changes in legislation – EU	The range of changes in legal regulations introduced at a EU level, which can have a negative influence on UFT.
		Changes in legislation - City	Changes by a local authority in the guidelines for obtaining permits for investments, which may cause problems with UFT activities.

		Changes in the guidelines	Changes introduced by a local authority in the guidelines for obtaining permits for investments, which can cause problems with UFT activities.
		Duration of the implementation	The level of slip in UFT activities caused by delays in obtaining permits from a local authority or other institution.
		Uncertainty of activities	The level of dependency of a UFT activity on a local authority.
		Changes in consumer behavior	The range of changes in consumer behavior society, which influences the management of a UFT activity.
		Aging society	The level of influence of an aging society (+65) on the management of a UFT activity; may require a more complex approach for implementation.
		Large cultural diversity of society	The level of influence of cultural diversity of society on the management of a UFT activity.
		Lack of awareness of UFT impacts	The level of awareness of UFT stakeholders of the impact of freight transportation on environment.
		Bad habits of UFT users	The range of UFT stakeholders who have poor managerial habits in the field of UFT.
		Protest and interference of nearby residents	The duration of the protests and interference of nearby residents which have an influence on the management of a UFT activity.
		War	The level of changes in the schedule of a UFT activity's implementation caused by war.
		Riots, strikes	The level of changes in the schedule of a UFT activity caused by riots or strikes.
		Natural disasters	The level of changes in the schedule of a UFT activity's implementation caused by natural disasters.
Policy and measure maturity	**Awareness**	Awareness level	Knowledge of the goods' delivery systems that are used in the city.
	Managerial risks	Organizational cultures	The range of different organizational cultures (standards, norms, decision-making process, etc.) represented by UFT stakeholders.
		Involvement of stakeholders	The range of involvement by representatives from municipality departments whose tasks relate to the area of implementing UFT activities.
		Excessive bureaucracy	The level of bureaucracy (frequency of developing detailed reports and other documents) while planning and implementing UFT activities.
		Large number of stakeholders	The proportion of trade and transportation companies from the SME sector interested in the implementation of UFT activities.
		Insufficient number of employees	Positions of employees responsible for UFT in an organizational structure of a city council.
		Insignificant number of UFT stakeholders	The range of UFT stakeholders' involvement in the process of planning and implementation of UFT activities.
		Information flow problems	Range of implemented standards and procedures on information flow and communication among stakeholders.
		Lack of leadership	Position of leadership in planning and implementing UFT activities.
		Lack of proper task organization	The manner of organization and assignment of tasks to particular members of the team while planning and implementing UFT activities.
		Time planning misjudgment	The range of delays in funds being received caused by the wrong assessment of time.

Table 4. Impact areas, criteria and indicators – Part 4

	Criterion	Indicators	Explanation
Policy and measure maturity		Contract by subcontractor	The level of breach of contract by subcontractors.
		Lack of know-how	The level of expertise and experience of project teams in planning and implementing.
		Diversity of stakeholders	Number (in percentage) of actors and stakeholders who have completely different requirements in implementing UFT activities.
		Lack of cooperation	% of actors and stakeholders who do not want to cooperate in terms of UFT.
		Data sharing restrictions	Number (in percentage) of actors and stakeholders who do not want to share data on UFT with other actors and stakeholders.
		Unknown requirements	% of actors and stakeholders whose requirements toward UFT are not investigated.
		Misestimated cargo flow	Forecast error (mean absolute percentage error) about the volume of cargo flows.

		Lack of data on UFT	The range of UFT data availability (in %).
		Failure to inform	%of the public (citizens) who were not informed about the implemented UFT activity.
	Back-ground	Experience	Analysis of results from past projects elaborated for this city in the same field.
		Research	Level of current research on the adoption and implementation of new, innovative city logistics policies and measures.
		Replication	Replication of policy/measure already implemented as good practice.
		Planning	Existence of related policy at local, regional or national level, regulations, master / action plan or stakeholder consensus towards the realization of policies and measures.
Social acceptance	**Social approval**	Public acceptance	Behavioral change towards intervention or degree people favorably approve the measures/policies/changes in UFT activities' organization.
		Social consciousness	Level of maturity and approval of new city logistics' policies and measures from the part of the local residents.
		Adjustability	Level of applicability and incorporation of innovative city logistics' measures/policies in UFT activities' business as usual operability, after having been approved, accepted, replicated and adopted by the stakeholders.
		Final user awareness	Percentage of stakeholders (e.g. SMEs) in the area of interest being informed before / after the beginning of the pilot deployment phase.
		Final user acceptance	%of stakeholders (e.g. SMEs) in the area of interest using the service before and after the beginning of the pilot deployment phase.
		City authority's popularity	Percentage of society (public) being in favor of the current city authority's policy concerning UFT activities' organization, administration and management.
		Decision-making acceptance	Number of positive / negative votes when city authority sets decisions on UFT activities under public consultation.
	Regula-tions accepta-nce	Compliance	Degree to which regulations are respected by the public.
		Enforcement	Easiness of compliance with new measures, rules and regulations.
		Eco-driving practice before the journey	Professional drivers' intentions to practice eco-driving before they start the journey, e.g. vehicle proper maintenance, trip planning, "light" travel, etc.
		Eco-driving practice during the journey	Professional drivers' intentions to practice eco-driving during the journey, e.g. compliance with speed limits, smooth acceleration and braking, etc.
		Motivation for eco-driving practice	Compliance with eco-driving practice for fuel savings, reduction of pollution emissions, and increase of road safety.
User uptake	**Flexibility**	Penetration	City case policies and measures' penetration and integration in local UFT policy.
	Stakehol-der approval	Stakeholder acceptance	Stakeholder attitude towards the implementation of policies and measures or any changes in the city's UFT activities' layout.
		Stakeholder %	% of stakeholders in favor of the deployment of the policies and measures.
		Adoption rate	% of involved stakeholders willing to adopt the city case beyond project duration.
		Promotion	Correct specification of the benefits or of the first outcomes and successes of the major stakeholders, obtained for a given city logistics solution.
		Integration	Potential integration with internal/external schedules of the stakeholders involved.
	Consensu s	Contracting	Stakeholders signed special agreements such as MoU, Freight Master Plan etc. engaged to comply with special rules and regulations on UFT activities.
	Transferab ility	Transferring rate	% of involved stakeholders willing to introduce the city case concept to other partners in UFT market, replicating good practice methods, results and findings.
	Success	Success rate	Percentage of city case policies and measures planned to be replicated by other cities.

Note: Full list of measures and indicators can be found here: http://ttlog.civ.uth.gr/wp-content/uploads/2016/08/criteria_indicators.pdf

V. EVALUATION MODULES

In addition to impact areas, the proposed framework embeds well-structured and mostly-used assessment analyses, which provide additional analytical capacities to users for assessing logistics measures. The five modules presented here may be used either as standalone tools or supplementary to the sustainability evaluation of logistics measure. Each module uses a set of indicators from Tables 1 to 4 and provides information to users which differs from the output of the sustainability assessment. Modules operate independently, therefore indicators may be used in more than one module. In this section the five modules, respective indicators and outputs are presented, the 5 modules are:

1. Impact assessment
2. Social cost-benefit analysis
3. Adaptability and transferability analysis
4. Risk analysis
5. Behavioral modeling

A. *Impact Assessment Module*

A first step towards evaluation is the assessment of impacts. Methodologies used for the estimation of 25 indicators related to environmental, traffic and safety are included in this module, linked to the impact areas of "Environment" (10 indicators) and "Transportation and mobility" (15 indicators). Depending on the selected indicator and the capacity of the city to estimate it, alternative methodologies are provided. Likewise, depending on the resources of the city, possible indicators are suggested. The criteria and respective indicators that are used to support this module are:

1. Air quality: Air quality emissions are detrimental to human health and ecosystems. The six air pollutants that account for the main impacts to air quality by considering the measure's lifecycle stages are CO, SOx, NOx, VOC, NH3 and PM10.
2. Greenhouse gas emissions: Three pollutants are combined to show the impact of GHGs: CO_2, CH_4 and N_2O. The three greenhouse gases contribute to global warming by considering measure's lifecycle emissions.
3. Noise: The level of noise is used as an outcome of the UFT measure impacts on living annoyance.
4. Level of service: Six indicators are interrelated with the level of service: punctuality, quantity, quality, market response, customer satisfaction and supply chain visibility.
5. Safety and security: Four indicators are associated with human and material loss.
6. Transportation system: Two indicators are related to performance transportation system.
7. UFT vehicles: Three indicators concern UFT vehicles utilization when the measure is implemented.

B. *Social Cost Benefit Analysis Module*

The main purpose of the Social Cost Benefit Analysis Module is to assess the measure's effectiveness expressed in social benefits. The module engages all economic related internal and external criteria and indicators of the evaluation framework. The final output is a Cost/Benefit Index. External costs are costs arising from transportation activity, which are not transferred to the user by the market and are mostly environmental costs covering the cost of climate change, air pollution, noise, congestion costs, accidents, marginal infrastructure costs and costs of up and downstream processes [37, 38].

The module is composed of 34 indicators, which are linked to the impact area of "Economy and Energy" and "Environment" as shown in Table 1. The criteria used are:

1. Energy: The amount of energy generated by non-renewable sources and consumed during the creation/construction, operation, maintenance and closure/disposal of the measure is used.
2. Development: Three indicators (working potential, business and local development) express the socio-economic related local development - direct or indirect - after the introduction of the measure.
3. Benefits: Two indicators (i.e. income generated and diversification of local economy) express the socio-economic benefits after the introduction of the measure.
4. Costs: Seventeen indicators express the financial costs of the measure for the creation/construction, operation, maintenance and closure/disposal.
5. Air quality: Pollution costs are used for six air quality indicators to monetize their impact. Costs depend on the type of transportation and the time and place of its creation.
6. Greenhouse gas emissions: Costs are used for three GHG indicators to monetize their impact. Costs depend on the type of transportation and the time and place of its creation.
7. Noise: The indicator of noise is monetized to express impacts associated with noise annoyance.

8. Transportation system: The indicator of delay (i.e. congestion) is associated with the interaction of the participants of transportation in conditions of limited road capacity [38]. The costs of congestion are the result of increased travel time, resulting delays and the excess operating and maintenance costs of the vehicles [38].

C. Adaptability and Transferability Module

Transferability explains the level of similarity among cities implementing the same measures, and identifies the possibility that a measure is transferred from one city to another. The adaptability/ transferability process is based on the qualitative and quantitative analysis on all stages of the measure's lifecycle. The outcome of the module is the estimation of the respective City Adaptability Index and City Transferability Index, which are estimated based on the degree of fulfillment of the relevant indicators as compared to the maximum level of fulfillment. The context of the specific analysis investigates the feasibility of a measure to be utilized in a city, in the case of:

- Developing a new measure from the beginning – creation
- Directly copying a measure proven to have worked in other cities – transfer
- Formulating a measure proven to have worked in other cities, by adjusting it to the specificities of the implementation environment – adaptation

Relevant indicators look into two dimensions:

- Adaptability of the measure to meet the city requirements
- Adaptability of the city as the environment of the implementation for the specific measure

They are collected based on stakeholders' opinions on the degree of the measure's effectiveness during creation, operation and management, thus covering the spectrum of lifecycle stages. Estimations enable early reaction in case of any irregularities during creation and introduction of any adaptations' requirements during operation. The level of similarity between the source and destination city also affects the level of adaptability/transferability process and it is taken into consideration.

The module uses 16 indicators; these are linked to the impact areas of "Policy and measure maturity", "Social acceptance" and "User uptake". The criteria that are used to support the module are:

1. Background: Four indicators are associated with past experience (state of the art and state of practice) in the field of UFT and city logistics policies, measures and rules / regulations application, testing and evaluation in the city.
2. Social approval: Three indicators pertain to the level of acceptance and adoption of new and innovative city logistics concepts from the local community, indicating public's maturity, readiness and willingness to comply with.
3. Flexibility: The indicator under this criterion implies the degree of city policies and measures' penetration and integration in local or regional UFT policy.
4. Stakeholder approval: Five indicators focus on the stakeholder acceptance and support towards the new and innovative city logistics concepts investigating the level of compliance with their plans, needs, goals, expectations and benefits, which determine the adoption rate of the applied UFT policies and measures by the majority of them.
5. Consensus: The relevant indicator refers to the number or percentage of stakeholders that are engaged or committed under special contracting agreements to comply with the new city logistics policies, measures and regulations.
6. Transferability: The relevant indicator expresses the potential for replicating good practice methods, results and findings from the part of the involved stakeholders to other partners in the local UFT market.
7. Success: The indicator of success expresses the percentage of city case policies, measures and rules that will be planned for replication by other cities.

D. Risk Analysis Module

Risk management in the area of UFT is difficult and complex, and requires the efficient management of processes throughout the lifecycle of UFT measures in close cooperation with all involved stakeholders. Various institutions have developed standards and guidelines for risk management [39, 40, 41]. However, in the case of UFT, there are no guidance and standards, which enable stakeholders to perform efficient risk management. The Risk Analysis Module considers risks in UFT measures' implementation and addresses threats that impede their realization.

In this module, also, risk sources are broken down into external and internal risks. The sources of the external risks are socio-political, economical, availability of infrastructure, technology innovations, natural disasters and civil disturbances. The internal sources of risk include management, human resources, marketing, information technology and financial. The identification of risk indicators is indicated in relation to selected measures separately and takes into account their entire lifecycle (creation-construction, operation, maintenance and closure disposal).

The Risk Analysis Module (RAM) includes 64 indicators, which are associated with the impact areas, "Economy and Energy", "Transportation and Mobility", "Society", "Policy and Measure Maturity" and "Social Acceptance". Both qualitative and quantitative methods are used for the assessment of the risk indicators. The criteria, with the number of indicators per criterion that support RAM are the following:

1. Economic and financial risks: Thirteen indicators express the economic and financial risks that may arise from a potentially unstable situation of the country or the involved stakeholders, and it is possible to influence the available budget and progress of the measure implementation.
2. Safety and security: Two indicators (i.e. crime/theft events and vandalism) express the unsafe incidents, such as vandalisms or thefts, which may occur either at the facilities, or when the shipments are en-route.
3. IT, infrastructure and technology: Twelve indicators depict the potential barriers or gaps to the smooth implementation or operation of a measure, resulting from the lack or failure of IT systems, infrastructure and technologies.
4. Living standards: Fourteen indicators demonstrate the possible socio-political factors, such as legislation modifications, which can generate restrictions and make the logistics processes complicated, and natural disasters and civil disturbances, and may directly cause significant changes in the scheduling and financing of a concept or measure.
5. Managerial risks: Nineteen indicators show the risks that may arise from the insufficient management of people and processes, inadequate human resources, and limited or not-well designed marketing.
6. Social approval: Four indicators (i.e. final user awareness, final user acceptance, city authority's popularity and decision-making acceptance) illustrate the related to final users and authorities and assessing the degree that the measure implementation reached their expectations.

E. Behavioral Modeling

Behavioral modeling assesses the behavioral change towards the implementation of the UFT measures, by providing detailed guidance on the implementation of respective methodologies. Two methodologies are considered for estimating behavioral changes, and guidance is provided.

1. The Transtheoretical Model of Change focuses on the decision-making process that individuals should follow in order to gradually change their behavior, and eventually adopt the desired or recommended behavior [42].
2. The Agent-Based Models, also known as Multi-Agent Systems, are used to analyze the complex environment of UFT, through the design of the features of each system components and the interactions among them [43].

Behavioral modeling includes 12 indicators, which are associated with the impact areas, "Society", "Policy and Measure Maturity" and "Social Acceptance". A survey is used to indicate stakeholders' initial attitudes towards the implementation of a sustainable measure by responding to questions using a Likert scale (1-5). The criteria, with the number of indicators per criterion that support behavioral modeling are the following:

3. Greening: Two indicators express stakeholders' opinion regarding "green" measures and environmental preservation.
4. Convenience: Two indicators indicate annoyance and satisfaction by goods delivery in the city.
5. Living standards: Two indicators (i.e. perceived alternative mobility and quality of life) show frequency of selecting environmentally friendly modes and perceived quality of life related to goods' deliveries.
6. Awareness: One indicator represents the awareness of goods' delivery systems that are used in the city.

7. Regulations acceptance: Five indicators are related to compliance with regulations and eco-driving behaviors relative to goods' delivery.

Behavioral modeling also provides support to the collection of the qualitative data of the evaluation framework, required also by the previous four modules, through a structured template.

VI. Application of Framework

The framework is adjustable and flexible, thus applicable to any city and measure. This application in the City of Graz, Austria is presented to test and demonstrate the framework's applicability on the assessment of a UFT measure. Specifically, an ex-ante evaluation is conducted about a new Urban Consolidation Center (UCC), which is planned near the city center of Graz, Austria, and uses before and after values for a set of indicators and equal time periods.

Graz is the second biggest city in Austria with a population of about 270,000 inhabitants, and aims to combine a historic preserved city-centre with a modern "City of design". The city has an extensive public transportation network in the city and wants to make freight operations more environmental friendly. At the moment, every freight forwarder delivers the goods separately to the shops located in the city centre. As a result, sometimes there are only one or two packages in a delivery van. In addition, the headquarters of the freight forwarders are mostly located outside of Graz, which leads to long delivering distances. The planned UCC near the city centre is expected to coordinate and optimize the existing capacities and reduce travel distances in the urban area. Goods are planned to be distributed by cargo-bikes and e-vans by using optimized routes in order to meet the needs of the shops in the centre of Graz.

The mapping of the UCC's processes throughout its lifecycle have been performed in order to identify which lifecycle stages, impact areas, criteria and indicators are applicable to the specific measure. The mapping revealed that all four lifecycle stages are applicable to the UCC. The demonstration of the assessment framework is performed based on the opinion of the Supply chain stakeholder category and data for two lifecycle stages, creation-construction and operation. The lifecycle stages of the measure are [44, 45]:

Creation-construction: This stage includes the construction and establishment of the UCC (i.e. designing the business and operational framework of UCC; identification of involved stakeholders and their role; identification of cargo and vehicle types; survey on the necessary equipment; investigation on the social acceptance; analysis of the investment plan; description of the business and operational framework).

Operation of the UCC: This stage includes operation of the UCC and its integration in the supply chain as a major freight transport node and transshipment point (i.e. UFT activities and provided services, equipment for controlling and monitoring of freight flows linked to the UCC, alternative fuel cargo and vehicle types to serve the UCC, handling of goods and loading of vehicles, vehicle/time utilization in respect to delivery time, stakeholders and their roles).

It should be noted that these two lifecycle stages as well as the impact areas, criteria and corresponding indicators that are shown in Tables 5 and 6 have been selected by the city Supply chain stakeholders as the most suitable for assessing the performance of the UCC. Based on Tables 1-4, five impact areas are considered as of interest to Supply chain stakeholders, comprising 13 criteria and 52 basic indicators, as shown in Tables 5 and 6.

Indicator values are expressed in different units, thus, they require normalization. This is done by comparing the indicator value with the best alternative as the most appropriate for this case. Values were estimated for "before" and "after" the establishment of the UCC, and are normalized based on min and max formulae (Equations 1 and 2), depending on the direction of the optimum value of the indicator [46].

$$\bar{r}_{ij}^{+} = \frac{I_{ij}^{+}}{I_{max,j}^{+}} \quad (1)$$

$$\bar{r}_{ij}^{-} = \frac{I_{min,j}^{-}}{I_{ij}^{-}} \quad (2)$$

Where:

$\bar{r}_{ij}^{+}, \bar{r}_{ij}^{-}$ are the normalized indicators with positive and negative impact, respectively achieved by alternative *i* with respect to indicator *j*

I_{ij}^{+} and I_{ij}^{-} are the values of indicator j, achieved by the *ith* alternative

Where min or max is used as a subscript in the value, the minimum or maximum value of indicator *j* for all alternatives is denoted. Aggregation of results into indices is performed by using the Weighed Sum Model (WSM). The WSM is the earliest and most commonly used method. WSM was used to evaluate sustainability of transportation systems based on the assessment of sustainability criteria [25, 28, 47]. According to this model, normalized indicators are multiplied by their respective weights and the utility V_i for each alternative is estimated by Equation 3.

$$V_i = \sum_{j=1}^{n} w_j \bar{r}_{ij} \qquad i = 1, \dots, m \tag{3}$$

Where:
$\bar{r}_{ij}$ is the normalized value of indicator *j* for alternative *i and* w_j is the weight for indicator *j.*

Weights are estimated based on pairwise comparison and the Analytical Hierarchy Process [48], under which the significance of each evaluation component is compared against elements within the same hierarchical level (impact areas, criteria, indicators). Results for creation-construction and operation lifecycle stages are presented in Table 5 and 6, respectively, and illustrated in Fig. 3.

Supply Chain stakeholders are mostly interested in Economy and Energy (40.7%), with most important criterion being the cost (58.4%). The impact area of Transport and Mobility follows by an attributed importance of 32%, with congestion being the main concern (62.5%) of Supply Chain stakeholders as it affects freight transportation performance.

The creation-construction stage of the UCC affects the city of Graz, as the lifecycle stage index is lower for the “after” case compared to the “before” case, with a 35% decrease (from 0.898 to 0.586). This is attributed mainly to the construction costs and required energy, which account for 33.2% of all evaluation components, and to the increased delays anticipated for freight vehicle movements and the rest of the traffic during the construction stage. On the other hand, the city benefits from the UCC operation, since the lifecycle stage index is improved by 55% (0.969 in the “after” case as compared to 0.624 in the “before”). It is important to note that the index for the operation stage improves for all impact areas. When combing the indices for the two-lifecycle stages (equally weighted), in order to obtain a single outcome based on which decision-making should be supported, it is found that for the “after” case there is a marginal improvement of roughly 2.2%.

Table 5. Assessment of UCC for the creation-construction stage

Impact area	Criteria	Indicators	(+)/(-)	Unit	Overall Weight	Value Before	Value After	Normalized before	Normalized after
Economy and energy (0.407)	Energy (0.232)	Energy consumption	-	Mjoule	0.232	0	15000	1.000	0.000
	Development (0.184)	Local / Regional development	+	Likert scale (1-5)	0.184	2	4	0.500	1.000
	Costs (0.584)	Planning and managerial costs	-	EURO - €	0.292	0	25000	1.000	0.000
		Investment costs	-	EURO - €	0.292	0	1000000	1.000	0.000
Relevant index for economy and energy								**0.908**	**0.184**
Transport & mobility (0.320)	Transport system (0.845)	Delays	-	Veh-hrs	0.845	750000	950000	1.000	0.789
	IT, infrastructure and technology (0.155)	Underdeveloped transport infrastructure or the lack of it	-	Likert scale (1-5)	0.014	2	4	1.000	0.500
		Low quality of transport infrastructure	-	Likert scale (1-5)	0.014	1	4	1.000	0.250
		Limitations at developing and changing the existing infrastructure	-	Likert scale (1-5)	0.014	2	3	1.000	0.667
		Lack of or limited access to modern technologies (e.g. High-speed internet)	-	Likert scale (1-5)	0.014	2	3	1.000	0.667
		Lack of IT	-	Likert scale (1-5)	0.017	2	3	1.000	0.667
		Incorrect assumptions for the development of IT prototype	-	Likert scale (1-	0.017	2	4	1.000	0.500

				5)					
		Failures of IT systems and other modern technologies	-	Likert scale (1-5)	0.017	1	4	1.000	0.250
		Conflicting interfaces of work items	-	Likert scale (1-5)	0.017	1	4	1.000	0.250
		Urban space engagement	-	Likert scale (1-5)	0.017	2	4	1.000	0.500
		Infrastructure usage	+	Likert scale (1-5)	0.017	1	5	0.200	1.000
Relevant index for transport and mobility								**0.987**	**0.749**
Society (0.154)	**Greening (0.333)**	Green reputation	+	Likert scale (1-5) {1 (lowest value) - 5 (highest value)}	0.333	2	2	1.000	1.000
	Living Standards (0.667)	Quality of life	+		0.484	2	2	1.000	1.000
		Changes in legislation at European and national level	-		0.004	3	3	1.000	1.000
		Changes in legislation at city level	-		0.004	3	2	0.667	1.000
		Changes in the guidelines for obtaining permits for various types of investments	-		0.004	4	3	0.750	1.000
		Extending the duration of the project due to delays in obtaining permits from local governments	-		0.004	4	3	0.750	1.000
		Uncertainty of continuation of earlier activities / established plans due to cyclical nature of elections and hence changes in managerial positions in local government	-		0.004	2	2	1.000	1.000
		Changes in consumer behavior society	-		0.004	4	3	0.750	1.000
		Aging society	-		0.004	3	3	1.000	1.000
		Lack of awareness of UFT users of the dangers arising from freight transport (pollution, congestion, road accidents)	-		0.004	4	4	1.000	1.000
		Bad habits of UFT users in the organisation and execution of transport in a city	-		0.004	4	2	0.500	1.000
		Protest and interference of nearby residents	-		0.004	1	1	1.000	1.000
		War	-		0.047	5	5	1.000	1.000
		Riots, strikes	-		0.047	3	4	1.000	0.750
		Natural disasters	-		0.047	4	4	1.000	1.000
Relevant index for society								**0.993**	**0.988**
Policy maturity (0.053)	**Awareness (0.200)**	Awareness level	+	Likert scale (1-5) {1 (lowest value) - 5 (highest value)}	0.200	3	3	1.000	1.000
	Background (0.800)	Research	+		0.800	2	3	0.667	1.000
Relevant index for policy and measure maturity								**0.733**	**1.000**
User uptake (0.067)	**Adaptability (0.800)**	Stakeholder acceptance	+	Likert scale (1-5) {1 (lowest value) - 5 (highest value)}	0.291	3	4	0.750	1.000
		Stakeholder percentage	+		0.291	0	0.8	0.000	1.000
		Adoption rate	+		0.136	1	3	0.333	1.000
		Promotion	+		0.053	1	3	0.333	1.000
		Integration	+		0.029	1	4	0.250	1.000
	Knowledge and experience transfer (0.200)	Transferring rate	+		0.200	1	5	0.200	1.000
Relevant index for user uptake								**0.329**	**1.000**
Lifecycle stage index								**0.898**	**0.586**

Note: Weights for impact areas and criteria are shown in brackets.

Table 6. Assessment of UCC for the operation stage

Impact area	**Criteria**	**Indicators**	**(+)/(-)**	**Unit**	**Overall Weight**	**Value Before**	**Value After**	**Normalized before**	**Normalized after**
Economy and energy (0.407)	**Energy (0.232)**	Energy consumption	-	Mjoule	0.232	25000	15000	0.600	1.000
	Development (0.184)	Local / Regional development	+	Likert scale (1-5)	0.184	3	4	0.750	1.000
	Costs (0.584)	Management (Operating cost)	-	EURO - €	0.041	8000	5000	0.625	1.000
		Wages(Operating cost)	-	EURO - €	0.041	200000	300000	1.000	0.667
		Fuels (Operating cost)	-	EURO - €	0.041	148500	133650	0.900	1.000
		Warehousing and / or handling (Operating cost)	-	EURO - €	0.041	50000	35000	0.700	1.000
		Transshipment (Operating cost)	-	EURO - €	0.041	75000	60000	0.800	1.000
		Depreciation - infrastructure (Operating cost)	-	EURO - €	0.041	5000	800	0.160	1.000
		Depreciation - equipment (Operating cost)	-	EURO - €	0.041	4000	1500	0.375	1.000
		Training - (Operating cost)	-	EURO - €	0.041	10000	12000	1.000	0.833
		Consumer cost	-	EURO - €	0.108	5	4	0.800	1.000
		Enforcement cost	-	EURO - €	0.114	80000	60000	0.750	1.000

		Shipper/receiver costs	-	EURO - €	0.034	3	2	0.667	1.000
Relevant index for economy and energy								**0.700**	**0.980**
Transport & mobility (0.320)	**Transport system (0.625)**	Delays	-	Veh-hrs	0.625	750000	250000	0.333	1.000
	UFT Vehicles (0.238)	Traffic throughput	-	Veh-km	0.079	2200000	1980000	0.900	1.000
		Load Factor	+	Percentage (%)	0.159	70	80	0.875	1.000
	IT, infrastructure and technology (0.136)	Underdeveloped transport infrastructure or the lack of it	-	Likert scale (1-5) {1 (lowest value) - 5 (highest value)}	0.023	2	4	1.000	0.500
		Low quality of transport infrastructure	-		0.023	1	4	1.000	0.250
		Limitations at developing and changing the existing infrastructure	-		0.023	2	3	1.000	0.667
		Lack of or limited access to modern technologies (eg. High-speed internet)	-		0.023	2	3	1.000	0.667
		Lack of IT	-		0.006	2	3	1.000	0.667
		Incorrect assumptions for the development of IT prototype	-		0.006	2	4	1.000	0.500
		Failures of IT systems and other modern technologies	-		0.006	1	4	1.000	0.250
		Conflicting interfaces of work items	-		0.006	1	4	1.000	0.250
		Hacker disturbance	-		0.006	2	4	1.000	0.500
		Network barriers	-		0.006	2	4	1.000	0.500
		Urban space engagement	-		0.006	2	4	1.000	0.500
		Infrastructure usage	+		0.006	1	5	0.200	1.000
Relevant index for transport and mobility								**0.551**	**0.935**
Society (0.154)	**Greening (0.333)**	Green reputation	+	Likert scale (1-5) {1 (lowest value) - 5 (highest value)}	0.333	2	4	0.500	1.000
	Living Standards (0.667)	Quality of life	+		0.484	2	4	0.500	1.000
		Changes in legislation at European and national level	-		0.004	3	3	1.000	1.000
		Changes in legislation at city level	-		0.004	3	2	0.667	1.000
		Changes in the guidelines for obtaining permits for various types of investments	-		0.004	4	3	0.750	1.000
		Extending the duration of the project due to delays in obtaining permits from local governments	-		0.004	4	3	0.750	1.000
		Uncertainty of earlier activities / established plans due to cyclical nature of elections; changes in managerial positions in local government	-		0.004	2	2	1.000	1.000
		Changes in consumer behavior society	-		0.004	4	3	0.750	1.000
		Aging society	-		0.004	3	3	1.000	1.000
		Large cultural diversity of society	-		0.004	3	3	1.000	1.000
		Lack of awareness of UFT users of the dangers arising from freight transport (pollution, congestion, road accidents)	-		0.004	4	4	1.000	1.000
		Bad habits of UFT users in the organization and execution of transport in a city	-		0.004	4	2	0.500	1.000
		Protest and interference of nearby residents	-		0.004	1	1	1.000	1.000
		War	-		0.047	5	5	1.000	1.000
		Riots, strikes	-		0.047	3	4	1.000	0.750
		Natural disasters	-		0.047	4	4	1.000	1.000
Relevant index for society								**0.585**	**0.988**
Policy maturity (0.053)	**Awareness (0.200)**	Awareness level	+	Likert scale (1-5) {1 (lowest value) - 5 (highest value)}	0.200	3	3	1.000	1.000
	Background (0.800)	**Research**	+		0.800	2	3	0.667	1.000
Relevant index for policy and measure maturity								**0.733**	**1.000**
User uptake (0.067)	**Stakeholder approval (0.800)**	Stakeholder acceptance	+	Likert scale (1-5) {1 (lowest value) - 5 (highest value)}	0.291	3	4	0.750	1.000
		Stakeholder percentage	+		0.291	50%	80%	0.625	1.000
		Adoption rate	+		0.136	1	3	0.333	1.000
		Promotion	+		0.053	1	3	0.333	1.000
		Integration	+		0.029	1	4	0.250	1.000
	Knowledge transfer (0.200)	Transferring rate	+		0.200	1	5	0.200	1.000
Relevant index for user uptake								**0.511**	**1.000**
Lifecycle stage index								**0.624**	**0.969**

Note: Weights for impact areas and criteria are shown in brackets.

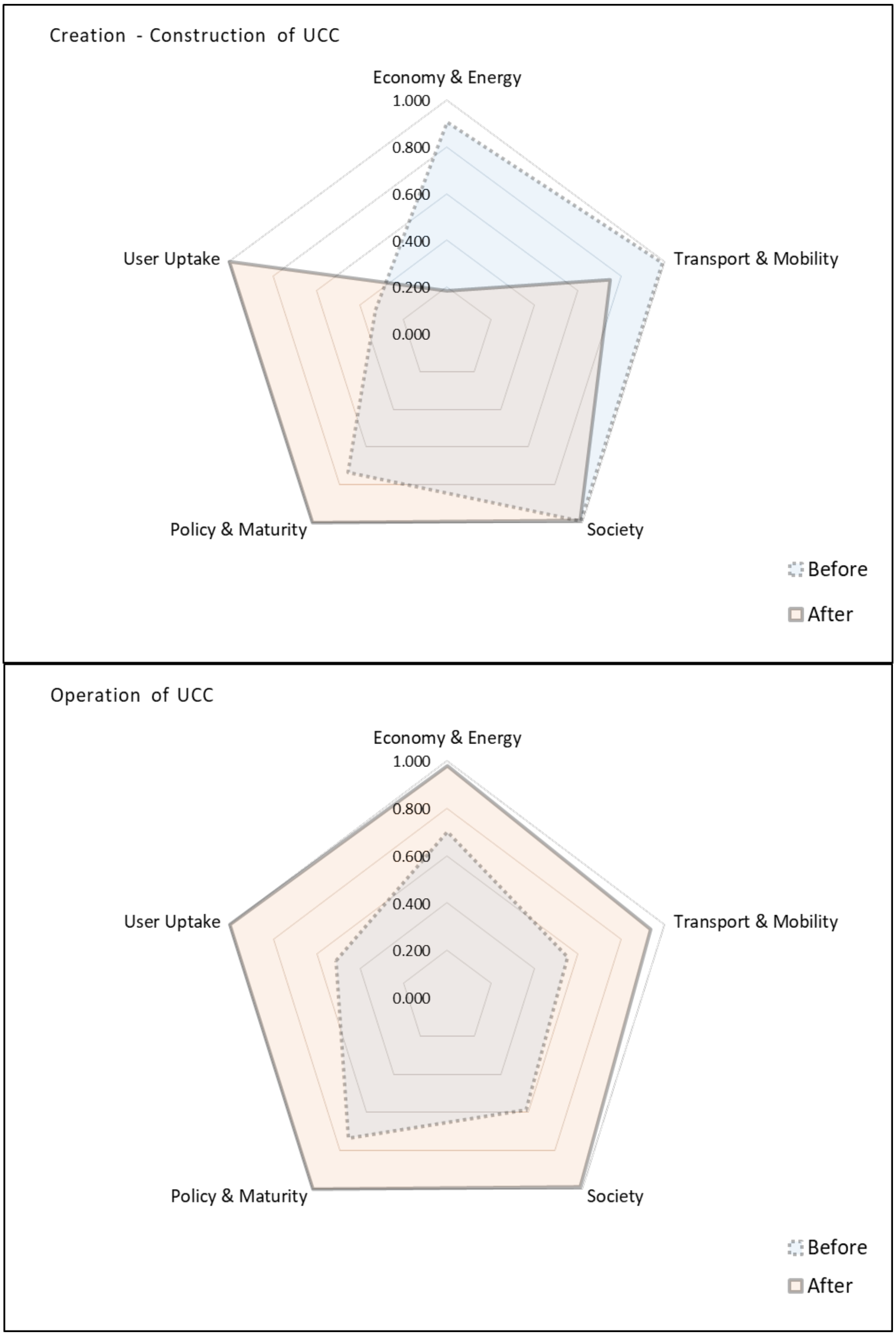

Fig. 3. Comparative impact area indices per lifecycle stage for "before" and "after" cases

VII. Conclusion – Further Research

The evaluation framework proposed in this paper is designed to fill the gap in the assessment frameworks of UFT systems and addresses the issue of sustainability for city logistics measures, taking into account and adopting a lifecycle analysis approach. The evaluation framework develops interrelations among stakeholders and their objectives, measures and lifecycle stages, evaluation parameters (impact areas, criteria and indicators) and integrates scientifically profound and widely used evaluation methodologies, through a hierarchical structured procedure.

The approach is based on the well-established technique of the lifecycle sustainability assessment, and incorporates interests of all relevant sectors, businesses, decision makers, consumers and society. As it has been integrated, the framework has the potential to reveal the trade-offs between the sustainability dimensions, lifecycle stages and impacts, of a measure and support decision-making.

The framework was tested for the city of Graz to compare “before” and “after” cases for the construction and operation of an urban consolidation center by considering the supply chain stakeholders. Quantified indicators were aggregated per case into the Logistics Sustainability Index to depict measure performance for the specific stakeholder category. The main observations are:

- Overall performance of the UCC differs between the construction and operation stages.
- Low LSI for the construction stage is attributed to the high capital investment costs and traffic disturbances in the occupied area of the new project, which is expected to affect freight vehicle movements.
- The operation stage demonstrates an overall improvement of approximately 55% between the “before” and “after” cases.

Owing to its modularity and flexibility, the framework allows for all possible estimations, providing at the same time an overall rating of the assessed measure by keeping individual ratings for each evaluation component and stakeholder. It can be used to assess how alternative measures perform in a specific city, so that to formulate a dashboard of possible UFT measures based on the city’s specific interests and objectives.

The framework comprises a sustainability policy and decision-making tool for bridging multidisciplinary interests in a mutual environment, providing this way, the floor for discussions, understanding, cooperation and agreements among stakeholders towards the optimization of the UFT operations in the city.

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