Reducing Greenhouse Gas Emissions of the Transport Sector in Urban Areas: Assessing Possible Actions Through Specific Performance Indicators

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***Abstract*—The transport sector is responsible for more than a quarter of the total Greenhouse Gas (GHG) emissions. Several actions can be implemented to reduce them, especially in the urban areas. For this reason, to facilitate the selection of the actions to be implemented, a literature review was carried out to provide a list of actions that the different stakeholders can adopt. Moreover, to facilitate their assessment, a set of Performance Indicators (PIs) was formalized, exploring their impacts on four sectors, including environmental, energy, social, and economic. Finally, considering the pivotal role of local public transport in reducing GHG emissions in urban areas, an example of the actions implemented by Gruppo Trasporti Torinese, which is the local public transport company of Turin is presented.**

***Index Terms*—Environment, Public Transport Company, Actions for GHGs, Performance Indicator**

The transportation industry has the largest energy consumption among all sectors of the economy, and also exerts a substantial negative influence on the climate [1]. Particularly in Europe, the transport sector's overall proportion of energy consumption has risen to 29.9% in 2021, exceeding the next two main energy consumers, industry (25.6%) and households (27.9%) [2]. In the context of the ecological impact of transportation, alone in Europe in 2021, Greenhouse Gas (GHG) emissions due to the transport sector reached 32% of the total, or 980 million tons of equivalent CO_2 in absolute figures, making it the second highest after the energy sector [3].

Several technical standards have been developed to support organizations in monitoring their GHG emission and measuring the effectiveness of the implemented mitigation action protocols. For example, IPCC Guidelines and ISO 14064 are reference standard in quantifying the emissions [4], [5]. Moreover, EC2020 regulates the mitigation of GHG, formally known as the EU emission trading scheme [6].

Different actions can be implemented to reduce the GHG emissions of the transport sector. Particularly noteworthy is the adoption of more sustainable technologies, the management of supply and demand concerning mobility activities and related infrastructure, and the implementation of attractive pricing mechanisms and policy regulations to incentivize more sustainable mobility [6]. Basically, all the involved stakeholders, such as policymakers, Public Transport Companies (PTCs), and citizens, can choose different actions to reduce their emissions. However, several constraints can influence these choices. In particular, the available economic resources, the presence of hills or plains, and the transport needs of a certain territory are aspects that should be considered. Moreover, for a rational strategy, the emissions associated with all the fundamental stages of a Life Cycle (LC) should be evaluated, which are the pre-operational, the operational, and the end-of-service stages [7]–[12].

The right recipe to reduce GHG emissions is probably not always the same. For this reason, the identification and classification of the actions that can be implemented by the stakeholders is crucial. Moreover, the formalization of a set of Key-Performance Indicators (PIs) to compare these actions could drive the stakeholders to identify the best solution. The PIs should investigate several aspects, including environmental, energy, social, and economic domains, among others, to facilitate the evaluation of the actions and impacts.

For this reason, this paper conducts a review of the relevant literature and compiles a list of potential strategies to mitigate the GHG emissions in the transport of people and goods in an urban and suburban context, considering especially the actions that can be implemented by PTCs (Section I). Having the immediate consequences of public administration supported by publicly available finances as well as an authority on the mass transit sector, PTCs have been identified as the fastest method toward reducing GHG

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emissions in the mobility sector [13], [14]. Moreover, this paper provides the formalization of a set of PIs to evaluate the impacts of the actions on several fields, such as the environmental, energy, social, and economic sectors (Section II). Finally, the experience of Gruppo Torinese Trasporti, that is the PTC in Turin (Italy), is presented adopting the implemented assessment methodology (Section III).

I. Actions for the carbon neutrality

In this section, a list of actions to reduce emissions in the transportation sector is provided. In particular, although some of the indications have general validity, we have focused on emission reductions related to land transport of people and goods in an urban and suburban context. These actions can be implemented by public governing institutions, such as municipalities, or national and local PTCs.

They are listed in Table I and grouped into 4 categories: the first one provides high-level measures to organize the transport modes and promote the public transport services. These can be implemented by public institutions, autonomously; the second concerns the technology improvements of the public vehicle fleets. The requirements and strategies can be mainly identified by PTCs; the third and fourth ones are related to actions that require strong coordination between the involved stakeholders (especially the public institutions and the PTCs), since their immediate impacts on the citizens. They are related to the economic lever (the taxation and pricing schema) and the planning of the local public transport vehicle routing, respectively.

A. Political strategies and high-level planning

The exhaustive compilation of actions under this category may be further characterized as follows: A1) The development of urban and ex-urban transportation systems, developing bus lines, increasing commuter and underground train capacity, and building new parking and riding amenities [15], [16]. A2) Designing integrated mobility, by proposing an integrated regional transportation system consisting of technology-separated bus and rail lines [17]. A3) Promoting walking and cycling, and ride-sharing [12], [17], [18]. A4) Preserving agricultural land during infrastructure development, for instance, utilization of the spatial information sciences model for integrating the land usage information and its environmental impacts [19]. A5) Reducing speed limits influences road transportation emissions [20], while freight transportation governs one entity of PTCs, such as trains [21]. Moreover, promoting a driving style characterized by moderate speeds and no sudden acceleration is another possible action, for both private and public transport. A6) Promoting public transport modes over personal automobiles, such as ride-sharing, transit pass programs, and bus mode sharing [12], [16]. A7) Strategies for facility energy consumption include retrofitting tunnel lights, improving facility lighting, recycling water for vehicle washing, and installing solar energy panels in buildings and transport facilities [12].

B. Vehicle Technology

These actions are based on the technological improvements in the engine and fuel sectors. A detailed summary of this category's activities follows: A8) The use of Battery Electric Bus (BEBs) [22], especially for urban routes [8], mapping BEBs and charging infrastructure needs [10]. A9) The use of Hydrogen Fuel Cell Vehicles (HFCVs), which is seen as an environmentally friendly technology [14], [22], [23], offering an effective alternative to BEB in ex-urban areas [8]. A10) The use of CNG as a substitute for diesel due to its slightly lower emissions [8]. A11) Using LNG as another sustainable fuel alternative [22]. For example, LNG-powered freight trucks emit comparatively fewer emissions than petroleum and diesel vehicles [24]. A12) Transportation and refueling infrastructure improvement include the measures to improve road and rail infrastructure [25], improvements to the energy sector, such as the installation of Renewable Energy Sources (RES) [26].

C. Taxation and Pricing

Increasing financial investment, pricing, and tax policies may help reduce emissions. Actions under this category include: A13) Road pricing charges motorized vehicles to minimize traffic and encourage public transit use during peak hours, for instance as done in London [15], energy–environment modeling framework for the forecasting of demand of public transportation [20], and multi-criteria assessment for economical impact analysis and trade off for freight transportation [27]. A14) Varied pricing schemes for different forms of transportation, such as compelling pricing for Zero-Emission Vehicle (ZEV) [20] and for all transport [28]. A15) Considering taxes may restrict carbon-based fuels, infrastructure, and transportation. Such a scenario of public transportation is encouraged by taxation on personal vehicles in densely populated areas [18]. A16) Allocation of emission quotas for a given period depending on PTC's fleet size and service area, allowing them to correctly monitor and report emissions to regulatory authorities to obtain economic and financial incentives for emissions below the quota and penalties for emissions above it [29]. A17) Transportation companies cooperate in emission trading to restrict overall emissions. This is accomplished through the exchange of quotas, with companies with higher emission levels purchasing quotas from those with lower emission levels.

D. Vehicle Routing

Increased demand for PTVs leads to greater consumption, resulting in elevated emissions. Thus, we identified a few practical interventions that might cut emissions while considering supply and demand management through the routing of vehicles. A18) Routing could reduce PTC vehicle journeys and distance while coordinating stops in real time. In particular, optimizing routes, duration, fuel consumption, and emissions of entities of PTC [30], ZEVs [9] and buses of various fuels [8]. A19) Demand and supply management explicitly refers to routing-selected routes. A unique statistical analysis for the planning stops of PTVs [31], and demand management of transportation energy to decrease emissions are two such examples. A20) Transportation distance optimization has been suggested for reducing emissions. Reducing commute distances in public transport planning and operation [22], implementing dedicated distance proportional allocation algorithm [32], and optimizing distances and energy usage in public transport entities [8] are some strategies in the literature.

II. Assessment methodology

PIs can help in evaluating the effectiveness of specified actions. In this section, a list of PIs is provided, formalizing

TABLE I
CLASSIFICATION OF THE ACTIONS TO REDUCE THE GHG EMISSIONS OF THE TRANSPORT SECTOR.

Section	Action	Reference
I-A	$\mathbb{A}_1$- Planning of transportation	[15], [16]
	$\mathbb{A}_2$- Integrated mobility	[17]
	$\mathbb{A}_3$- Promoting walking and cycling	[12], [17], [18]
	$\mathbb{A}_4$- Preserving agricultural land during infrastructure development	[19]
	$\mathbb{A}_5$- Reducing speed limit on highway	[20], [21]
	$\mathbb{A}_6$- Promoting public transit	[12], [16]
	$\mathbb{A}_7$- Strategies for facility energy use	[12]
I-B	$\mathbb{A}_1$- Planning of transportation	[15], [16]
	$\mathbb{A}_9$- Sustainable fuel option, HFCV	[8], [14], [22], [23]
	$\mathbb{A}_{10}$- Sustainable fuel option, CNG	[8]
	$\mathbb{A}_{11}$- Sustainable fuel option, LNG	[22], [24]
	$\mathbb{A}_{12}$- Infrastructure improvement	[25], [26]
I-C	$\mathbb{A}_{13}$- Road pricing	[20], [27], [27]
	$\mathbb{A}_{14}$- Attractive pricing scheme	[27], [28]
	$\mathbb{A}_{15}$- Considering Tax policies	[18]
	$\mathbb{A}_{16}$- Emission quota allocation	[29]
	$\mathbb{A}_{17}$- Emission trading system	[33]
I-D	$\mathbb{A}_{18}$- Optimizing journeys	[8], [9], [30]
	$\mathbb{A}_{19}$- Demand and supply	[31]
	$\mathbb{A}_{20}$- Optimizing distances	[8], [22], [32]

and categorizing them into four main sectors of impact: environmental, social, economic, and energy. For each of them, associated sub-sectors of influence were defined.

Table II summarizes the PIs of each sector and sub-sectors, providing a short description, and the functional unit. Meanwhile, a comprehensive breakdown of the table for further explanation is discussed in the following subsections, considering each sector individually.

A. Environmental

The PIs $CII1$ and $CII1b$ are the carbon intensity indexes as defined by the GRI Standards 305 [34]. The first one provides the direct GHG emissions per km traveled, while the second considers only the fuel contributions. $CO2_e$ provides the total amount of equivalent carbon dioxide. The PIs CO_2, $NMHC$, CH_4, and N_2O, expressed in Mg $(1\,\mathrm{ton})$ of equivalent carbon dioxide (CO_{2e}), indicate the emission of carbon dioxide, methane and nitrous oxide, respectively. These PIs are useful to assess the global environmental impacts of a service or the effectiveness of a certain mitigation action. In fact, all these chemical compounds are GHGs, therefore contributing to global warming.

Similarly, the PIs related to LC phase emissions should be considered for the evaluation of local environmental impacts. They provide the air emission of a specific pollutant, measured in Mg $(1\,\mathrm{ton})$. The main ones are the fine particulate matter (PM), nitrogen oxides (NO_x), sulfur oxides (SO_x), and ammonia (NH_3).

Moreover, to have a better understanding of climate changes, the earth's atmospheric composition PIs can be adopted. They are measured in normalized energy and vehicular units and refer to specific chemical compounds, that are: Carbon (C), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), and Sulfur hexafluoride (SF_6). Normalized values are presented as points per kWh for EVs and points per liter for diesel-powered vehicles [7], [17].

In addition, two other PIs can help in understanding the nature of the emissions and in identifying the best mitigation strategies: ISO_{DE} and ISO_{IE}. They represent the relative percentage of direct and indirect emissions with reference to the total amount. Direct and indirect emissions are defined and computed according to ISO 14064-1 and may originate from either direct sources, which are under the organization's control and ownership, or indirect sources, which are neither owned nor controlled by the organization [37].

B. Energy

These PIs are useful to quantify the energy consumption or to evaluate the energy savings associated with a certain action or group of actions.

For a better understanding, these PIs are divided into two groups: the first one considers the absolute amount of energy consumption, measured in J; the second one is typical of the transport sector, and provides the normalized energy consumption with reference to a traveled distance.

C. Social

Social impact evaluation needs intensive public and passenger health and mobility investigations. Typical social PIs, comprises mortality indicators expressed by H-Mortality, corresponding to fatalities due to the local emissions, measured in deaths. Whereas mobility PIs, indicates the public transport recognition by transit ridership (M-Ridership), travel efficiency by congestion (M-Waiting)), and connection to key services by public access (M-Public Access), they are measured in people, minutes, and trips respectively.

D. Economic

Impact evaluation of ownership costs encompasses planning, purchase, and development costs. More precisely, infrastructure planning and feasibility studies are parts of planning cost; the cost of vehicles and equipment comprise purchase cost; and the cost of facilities, transportation networks, and infrastructure constitute development cost. All the costs can be measured in a proper reference currency (e.g. in €).

Similarly, operational costs are defined considering the peculiarities of the transport sector. They include both the maintenance and fuel provision expenses and refer to the cost due to making a certain transport service run for $1\,\mathrm{km}$, and therefore can be measured in €/km.

III. CASE STUDY: THE PUBLIC TRANSPORT IN TURIN

Gruppo Torinese Trasporti (GTT) was founded on January 1, 2003, after the fusion of ATM and SATTI. GTT serves over 200 million passengers yearly via its subway line, buses, and trams in Turin and 26 additional municipalities. The urban and sub-urban infrastructure of Turin and surrounding have 83 bus routes, 8 tram lines, and 1 underground line. The urban bus network categories are two: 1) Power lines for high-mobility routes not served by trams or metros. These lines employ 18- or 12-meter vehicles. 2) Completion and connecting lines: connecting power lines with mostly 12-meter buses. In addition, GTT administers extra-urban, parking, and tourism services [38]. GTT has worked to reduce its carbon footprint with several projects, in collaboration with other stakeholders. In this context, it is important to emphasize the project "Nuovo Trasporto Torino" (NTT), which was launched in 2023 in partnership with the City of Turin, to execute particular actions via three strategic lines: i) Metro Line-1 extension. ii) Enhancing the tram system with

TABLE II
DEFINITION AND DESCRIPTION OF PIS FOR IMPACT ANALYSIS OF PTC

SECTOR / Sub Sectors	DESCRIPTION	PI	FUNCTIONAL UNIT
Environment			
GHGs (global effects)	Carbonic intensity index - scope 1. Direct GHG emissions, expressed in CO_2e per km traveled [34].	$CII1$	kg/km
	Carbonic intensity index - scope 1 - category 1b. Direct GHG emissions, expressed in CO_2e per km traveled from fuels in mobile devices [34].	$CII1b$	kg/km
	Equivalent emission of carbon dioxide.	CO_{2e}	Mg (1 ton)
	Emission of non-methane hydrocarbon.	$NMHC$	Mg (1 ton)
	Emission of nitrous oxide.	N_2O	Mg (1 ton)
	Emission of carbon dioxide.	CO_2	Mg (1 ton)
	Emission of methane.	CH_4	Mg (1 ton)
Air pollutants (local effects)	Emission of particulate matter as defined in Reg. CE 715/07 and Reg. UE 858/2018 [35], [36].	PM	Mg (1 ton)
	Emission of nitrogen oxides	NO_x	Mg (1 ton)
	Emission of sulfur oxides	SO_x	Mg (1 ton)
	Emission of ammonia	NH_3	Mg (1 ton)
Climate	Carbon emission, measured in points obtained by normalizing over the global average emission per kWh or liter [7], [17].	C	Pt/kWh, V-Pt/km
	Hydroflurocarbon emission, measured in points obtained by normalizing over the global average emission per kWh or liter [7], [17].	$HFCs$	Pt/kWh, Pt/km
	Perflurocarbons emission, measured in points obtained by normalizing over the global average emission per kWh or liter [7], [17].	$PFCs$	Pt/kWh, Pt/km
	Sulfur hexafluoride emission, measured in points obtained by normalizing over the global average emission per kWh or liter [7], [17].	$SF6$	Pt/kWh, Pt/km
ISO 14064	Percentage of direct emission with reference to the total emission amount.	ISO_{DE}	%
	Percentage of indirect emission with reference to the total emission amount.	ISO_{IE}	%
Energy			
Consumption	Energy consumption for the energy vector F (Gasoline, CNG, LNG, Electrical Energy) in a specified period of time.	Energy-F_D	TJ
Transport	Energy consumption for the energy vector F (Gasoline, CNG, LNG, Electrical Energy) to run 1 km in standard condition.	Energy-F	TJ/km
Social			
Health	Number of traveled km	H-km	Mkm
Health	Number of deaths due to emission	H-Mortality	Death
Mobility	Number of ridership of a certain mobility mode.	M-Ridership	People
Mobility	Waiting time of a certain mobility mode.	M-Waiting	min
Mobility	People access.	M-People-Access	Trips
Economic			
Ownership	Planning cost	Cost-Planning	€
	Purchase cost.	Cost-Purchase	€
	Development cost.	Cost-Development	€
Operation	Average maintenance cost in a specified period of time.	Cost-Maintenance	€$/km$
	Average fuel cost for the energy vector F in a specified period of time (Gasoline, CNG, LNG, Electrical Energy).	Cost-F	€$/km$

additional routes and vehicles. iii) Bus fleet renewal for Bus Rapid Transit (BRT) system, and electric traction expansion.

The actions implemented by GTT are analyzed below, considering the GHG mitigation strategies reported in section I and the evaluation methodologies presented in section II. To clarify the efforts and results obtained, the actions are organized according to the types of actions in Table I.

A. Bus electrification

The electrification of the fleet (Action A8 in Table I) is certainly one of the cornerstones of the GTT renewal project that has its roots in the early 2000s with the company's first acquisition of n.23 7.5 meters buses ELFO, equipped with 34 lead acid gel batteries, transformed in 2015 into lithium iron phosphate (LiFePO4) batteries with plug-in charging and induction charging. Later on, in 2017, GTT further developed its electric bus fleet with the purchase of a total of 163 buses in service by 2023, with overnight plug-in charging stations in 3 urban depots and opportunity charging at 2 bus terminus.

The NTT project will transform GTT's fleet to 63% electric, 24% methane, and 13% diesel by 2027, including 5 charging stations in urban depots and 6 terminal charging stations.

Moreover, a tender was granted in 2023 to buy 245 BEBs, including 28 BRT variants, 20 8-meter, 135 12-meter, and 90 18-meter vehicles, and specialized charging infrastructure.

The electrification of the urban buses produced a reduction in the average fuel cost. Comparing 12 m electric buses and 12 m E6 diesel buses, the average fuel cost was reduced by 55% and the average maintenance cost by 70%. On the downside, the purchase cost of urban 12 m electric buses were 40% higher than the equivalent E6 diesel buses, while the operational cost can vary depending on bus battery autonomy, lines, and traffic. GTT carbonic intensity index ($CII1b$) is progressively reducing from $1.31\,\mathrm{kg/km}$ in 2021 to $1.20\,\mathrm{kg/km}$ in 2023, thanks to the renewal of the fleet.

The total emission amount in GTT (ISO_{DE} referred to baseline year 2021) are predominant and represent the 75% of total emissions, a predictable fact given that the company's activity is characterized by processes that determine the combustion of fuels in vehicles in circulation. Also as shown in Table III, GTT carbonic intensity indexes are progressively reducing, thanks to the renewal of the fleet.

Thanks to the complete renewal of the fleet in 2027, direct emissions will change as shown in Table IV, leading to a drastic reduction in urban pollutants harmful to human health.

TABLE III
CHANGES IN CARBON INTENSITY INDEX DUE TO FLEET RENEWAL.

PI	U.M.	2021	2022	2023
H-km	Mkm	38.1	40.5	41.4
$CII1$	kg/km	1.52	1.51	1.37
$CII1b$	kg/km	1.31	1.26	1.20

TABLE IV
CHANGES IN DIRECT EMISSION DUE TO FLEET RENEWAL IN 2027.

PI	U.M.	2023	2027-Projection	$\Delta\%_{2027-2023}$
H-km	Mkm	41.4	37.8	-9
$CO2e$	Mg	49534	19879	-60
$NMHC$	Mg	31.5	0.54	-98
NOx	Mg	244.0	18.0	-93
PM	Mg	3.1	0.10	-97

Table V compares the projection of traveled kilometers and energy consumption (expressed in tons of oil equivalent) in 2027 with the reference year 2023. Thanks to the electrification of the vehicle, and considering the same number of kilometers traveled by the entire fleet, a reduction of 9% is expected.

B. Energy efficiency and production from RES

Installing LED lighting (for example in warehouses and metro stations), the connection of depots to district heating, improving the efficiency of systems serving maintenance, encouraging sustainable behavior among personnel, and powering GTT sites from 100% RESs since 2018 [39] are actions that can be classified as $\mathbb{A}_7$. Moreover, GTT will invest in two PV systems at Gerbido and Collegno. In the first site, both PV panels and a storage system will be installed, with a total capacity of 950 kW and 800 kW, respectively. In the second one, only a PV power plant will be installed and its capacity will be 660 kW. The new PV system at the Gerbido depot, which will be added to the current 1MW plant in operation since 2013, will be able to satisfy 30% of the consumption needs for the dedicated charging of electric buses (with an electricity production of 1,1 GWh per year). By 2027 the overall PV electricity production in GTT will go from the current 0.9 GWh to 2.8 GWh with a 200% increase, being able to meet 13% of total electricity consumption for electric buses. Thanks to the implemented efficiency actions listed above, between 2021 and 2023 there was a 20% reduction in energy consumption for heating and 25% reduction for electricity consumption in all operational sites.

TABLE V
COMPARISON OF THE TRAVELED KM (PI: H-KM) AND ENERGY CONSUMPTION (PI: ENERGY-F$_D$)IN 2023 AND 2027

	H-km [Mkm]		Energy-F$_D$ [TJ]	
	2023	2027	2023	2027
Diesel bus	29	13	540.9	216.8
CNG bus	8	9	210.2	227.0
Electric bus	5	16	50.1	173.5
Tram	5	6	163.6	233.5
Metro	10	11	129.0	143.8
Total fleet	55	55	1093.8	994.5
% electric/total	34%	60%	31%	55%

IV. CONCLUSION

The transportation sector holds around 30% of the total energy consumption in Europe, impacting significantly climate change. In 2021, European transportation contributed 32% of total greenhouse gas emissions, prompting the development of standards like ISO 14064 and EC2020 to regulate emissions. Various measures, including sustainable technologies, demand management, and pricing mechanisms, are advocated for emission reduction, though constraints such as economic resources and geographical factors exist. Identifying and classifying mitigation actions, along with establishing Performance Indicators (PIs), are crucial for stakeholders to select the most effective solutions. This paper collects a list of actions that can be considered to design and tune strategies for mitigating greenhouse gas emissions in urban and suburban transportation. The actions can be implemented by different stakeholders of the transport sector, such as the public governing institutions and the local public transport companies. Moreover, the paper also presents a formalized set of PIs to evaluate environmental, energy, social, and economic impacts. As an example of GHG mitigation action implementations in the transport sector, the case study of Turin (Italy) is presented. The actions already implemented or planned for the future by GTT, which is responsible for the public transport in Turin, were described and assessed using the formalized PI.

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