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Towards a Low Emission Transport System: Evaluating the Public Health and Environmental Benefits

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Received: 20 September 2019; Accepted: 28 September 2019; Published: 30 September 2019

Abstract: Climate change mitigation strategies offer significant societal co-benefits such as improvement in public health, air quality, local economy, and even safety. By considering these co-benefits during the transportation planning process, local governments would be able to link their local appreciate mitigation actions into the Sustainable Development Goals (SDGs), where diverse objectives should be achieved simultaneously. This study first clarifies the co-benefits approach to climate change mitigation in the transport system, by introducing an integrated multiple-impact framework known as A-S-I (Avoid-Shift-Improve) to evaluate the co-benefits. Thereafter, it applies the quantitative modeling approach to assess public health and environmental co-benefits of the implementation of the Tehran Transportation Master Plan, "the TTMP" in the city of Tehran, Iran, which includes targeted interventions such as shifting from private vehicles to the urban transport system, improving vehicle technologies and introducing alternative fuels. The results from the application of "the TTMP" reveal a significant reduction of CO_2 and other local air pollutant emissions by 12.9 and 1.4 million tons, respectively, prevention of about 10,000 mortality cases, and more than USD 35 million savings by 2030.

Keywords: urban transport system; co-benefit approach; climate change

1. Introduction

The planning of the transport system in cities is entirely affected by climate change concerns. A fundamental transformation will be needed in the transportation sector, such as decarbonization of the fleet through clean technologies and non-motorized transport, besides clean power generation for electric cars, if governments worldwide, particularly in developing countries, aim to achieve the Paris Agreement targets and the Sustainable Development Goals (SDGs) [1]. On the other hand, urban transport is vital to achieve several of the SDGs, particularly in developing countries, such as good health (goal 3), affordable and clean energy (goal 7), and sustainable cities (goal 11), besides climate change (goal 13). In developed Asian countries, energy services such as lighting, heating, cooling, cooking, and mobility represent the main sources of carbon emissions [2,3]. For example, in cities such as Seoul and Tokyo, commercial, and residential sectors account for two-thirds of the final energy consumption, which is mostly influenced by the spatial organization and urban density [4].

However, in the rapidly growing Asian megacities, such as Shanghai and Beijing in China, the power and industrial sectors are the major contributors to global carbon emissions. Nevertheless, in all these cities, transportation represents a significant part of the emissions [5].

The concerns of policymakers in Asian cities dealing with the transport sector concentrate on the implications of the use of energy, particularly the severe air pollution-related health impacts on their societies. Therefore, the benefits of the implementation of the climate mitigation strategies in the transport sector include the improvement in both public health and air quality and also savings from hospital admissions and premature mortality; all can be addressed as the co-benefits of climate mitigation in this sector [6–8].

"*The term 'co-benefits' expresses the integration between climate change mitigation and socio-economic systems*" [9]. For policymakers and local governments seeking to develop an appreciate climate change mitigation plan in the transport sector, the application of the co-benefits approach appears to have significant potential, as suggested in the literature [10–12]. However, further conceptual clarification on an operational definition of co-benefits is required among different scholars, governments, and stakeholders [13–16].

In the transport sector, climate co-benefits can be achieved from a series of demand-side policy interventions and infrastructure such as vehicle fleet renewal programs, better traffic management, environmental standards as well as supply-side resilience practices [17]. The efforts that have been done to address this issue were presented by different scholars who showed that the investment in public transport in the big cities would achieve significant gains in co-benefits due to local emissions reduction [18–28]. For example, in [29] the authors studied the environmental impact of urban transport in Eastern Asia and argued that how the earlier decision prioritizes public transportation, and non-motorized transport investment can bring long term co-benefits in this area. In [30] the authors explored how the appreciate policy such as CNG (Compressed Natural Gas)buses can significantly reduce SO_2 and PM_{10} emissions and increase the mitigation potential of GHG (Greenhouse Gases) emissions in the city of Shenyang in China. The additional public health co-benefits associated with the control air pollution measures deployed by the Chinese State council was estimated by [31]. In [32] the authors estimated the number of prevented deaths resulting from the reduction in particle material emission due to the inspection and maintenance of vehicle fleets in the city of Bangkok, Thailand.

From the analytical perspective, methodologies to evaluate climate co-benefits in the transport sector vary depending on how they represent the interactions between this sector and society. Numerous tools have been designed and developed for the evaluation of co-benefits at the national level; however, just a few have been developed for the sector-based assessment, particularly the transport sector. For example, the MESDC (Ministry of Environment and Sustainable Development of Colombia) has developed a quantitative tool to evaluate the climate co-benefits associated with the national low-carbon development strategies [33]. The UNDP (United Nations Development Program) has introduced the NAMA-SDE (Nationally Appropriate Mitigation Action Sustainable Development Evaluation) tool, which was developed for the Nationally Appropriate Mitigation Action (NAMA) developers and policymakers looking for co-benefits and synergies among different goals [34]. The Government of Japan has introduced a *"Manual for the Quantitative Evaluation of the Co-Benefits Approach to Climate Change"* classifying three tiers of assessment methodologies, including using real data, measurement data, and specific equations, which allow to quantify the climate co-benefits type projects, including water quality improvement and waste management [35]. All the tools reviewed above are useful in assessing and addressing the co-benefits of climate change mitigation. However, the top-down methodologies used in all of them present an aggregate estimation of co-benefits at the regional level, which reflects a limitation on sectoral analysis.

Following the recent progress in the development and application of the "co-benefits approach" in the transport sector, this study aims at presenting a quantitative assessment framework for assessing the climate co-benefits of a low-carbon urban transport system and addressing policy interventions to improve such benefits during the execution process in transport plans. The study contributes to sustainable transportation literature in several aspects. First, the study provides a framework (A-S-I, Avoid-Shift-Improve, see below) for the consideration of co-benefits in the urban transport sector. Second, based on the framework, it develops a model to quantify co-benefits in the urban transport system, thereby evaluating the impacts of bottom-up actions and plans to tackle climate change and pollution. Third, the study applies the model to a real case in Tehran, Iran's capital, which is suffering from an inefficient and underdeveloped transport system. This paper is structured as follows. Section 2 provides an overview of the climate co-benefits approach in the urban transport sector, introducing the Avoid-Shift-Improve (A-S-I) approach. Sections 3 and 4 respectively describe the framework and its application in assessing the expected co-benefits from the implementation of a strategic plan for the public transport sector in Tehran.

2. Methodology

The methodology developed in this study introduces a quantitative analysis modeling framework for the simplified representation of the transport sector with an institutional evaluation to evaluate not just the magnitude of emission reductions from local air pollution and carbon emissions but also to determine benefits from improving the air quality and its impact on public health. It uses the A-S-I (Avoid-Shift-Improve) approach which set the standard for low carbon transport modeling and covers the city-wide transport system, thus impacts of multiple of transport choices can be assessed (see Figure 1). The A-S-I approach is a bottom-up framework which can be used as a scenario planning tool in assessing the co-benefits of climate policies in the transport sector [36,37]. Here, the co-benefits refer to the reduced local air pollution and improved public health, which can result from the GHG emission reductions, simultaneously [38]. The A-S-I helps to determine the right action plans and policy interventions in achieving a sustainable urban transport system [39].

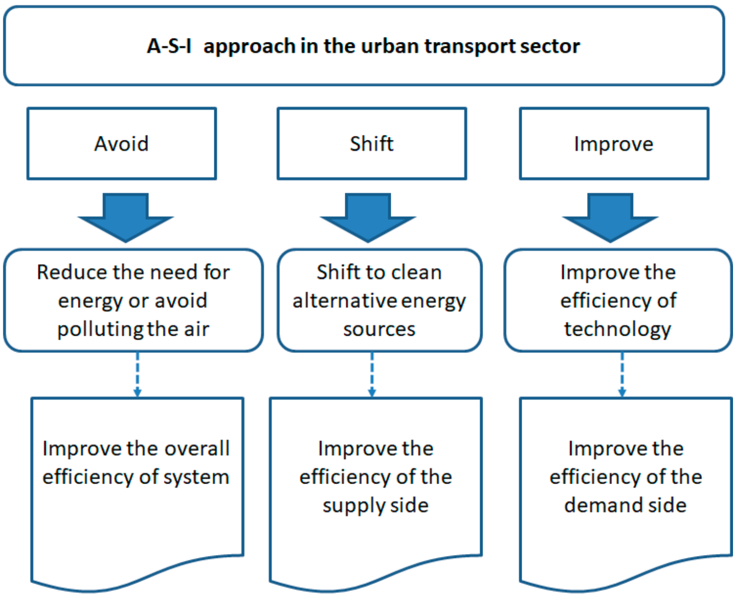


Figure 1. The Avoid-Shift-Improve (A-S-I) framework [37].

2.1. Overall Estimation of Emissions

The mathematical representation of the A-S-I method is as follows [37]:

$$E_t = \sum_m \sum_e \sum_\tau A_{me\tau t} S_{me\tau t} I_{me\tau t} F_{me\tau t}, \quad (1)$$

where;

E: Total annual emissions, including GHG emissions and air pollution (t);

A: Total passenger-kilometers traveled (PKM);

S: Percent share per each mode (%);

I: Energy intensity per each mode (km/liter or km/kWh);

F: Emission factor of each pollutant per each fuel type (g/liter or g/kWh);

m, e, τ, and t refer to the transport mode (i.e., urban bus, train, private car, etc.), fuel type (i.e., gasoline, gas oil, CNG, etc.), technology type (i.e., internal combustion engine, hybrid engine, EV (Electric Vehicle), etc.) and specific time period, respectively.

In the above equation, $\underline{A}$, $\underline{S}$, and $\underline{I}$ refer to the Avoid-Shift-Improve components. $\underline{A}$ represents the demand for mobility, which can be avoided through effective transport demand management and land-use planning. $\underline{S}$ indicates a modal shift from the most energy-intensive transport modes (i.e., private cars, motorcycles, and so on) to the least energy-intensive modes, including public transport modes such as public buses or metro. Finally, $\underline{I}$ focuses on improving the energy efficiency of the vehicle technology by adopting regular inspection or replacing it with new and efficient technology. Hence, the most suitable mitigation scenario for reducing the emissions of harmful gases and particle materials can be developed by intervening in each component (A, S, and I).

In Equation (1), "A", the growth in the demand for mobility (per capita passenger-kilometers) over time, represents the logistic function [40]:

$$A_t = \frac{\alpha}{1 + \gamma \exp(-\beta t)}. \tag{2}$$

α is estimated on the basis of the average speed of mobility and time budget and represents the saturation level of demand for mobility in cities. A regression analysis can be performed to estimate the statistical coefficients of γ and β, using the historical mobility demand data.

Finally, the potential reduction by each scenario can be estimated by using the following formula:

$$\Delta E_t = E_{t,Base} - E_{t,Target}, \tag{3}$$

where, $E_{t,Base}$ and $E_{t,Target}$ represent the total emissions of each pollutant in the base and target scenarios in the time period t, respectively.

2.2. Public Health Co-Benefits

The harmful pollutants calculated by Equation (1) have an adverse impact on public health, which can be estimated by using the following formula [41]:

$$IM_i = \frac{RR_{ij} - 1}{RR_{ij}}, \tag{4}$$

where:

IM_i: Health impact function of each pollutant i.

RR_{ij}: Relative risk of each pollutant i at the exposure category j such as respiratory and cardiovascular mortalities.

In general, the values of RR for each exposure category can be estimated by the help of Concentration-Response (CR) function which describes the risk of particular health disease as a function of the pollutant concentration in a certain exposure time [42–45]. Recommended RR per 10 μg/m^3 for particulate matter, ozone, nitrogen dioxide, and on all-cause mortality in the long term and short-term and exposures were given by [46]. The expected number of casualties can be calculated as follows [38]:

$$EM_{ij} = IM_{ij} \times D_j \times P_j \times C_i, \tag{5}$$

where D_j, P_j, and C_i refer to the mortality rate of disease (i.e., deaths/10,000 people), the share of the population in the exposure category, and the concentration of pollutant, respectively. The concentration of each pollutant (μg/m^3) can be calculated by using the following formula:

$$C_{it} = \frac{E_{it}}{v_t.L.H}, \quad (6)$$

where, E_{it} can be calculated from Equation (1). v_t, H, and L, refer to the wind speed (m/s), the height (m), and the length (m) of the selected location, respectively. Figure 2 shows the calculation flow used in this model.

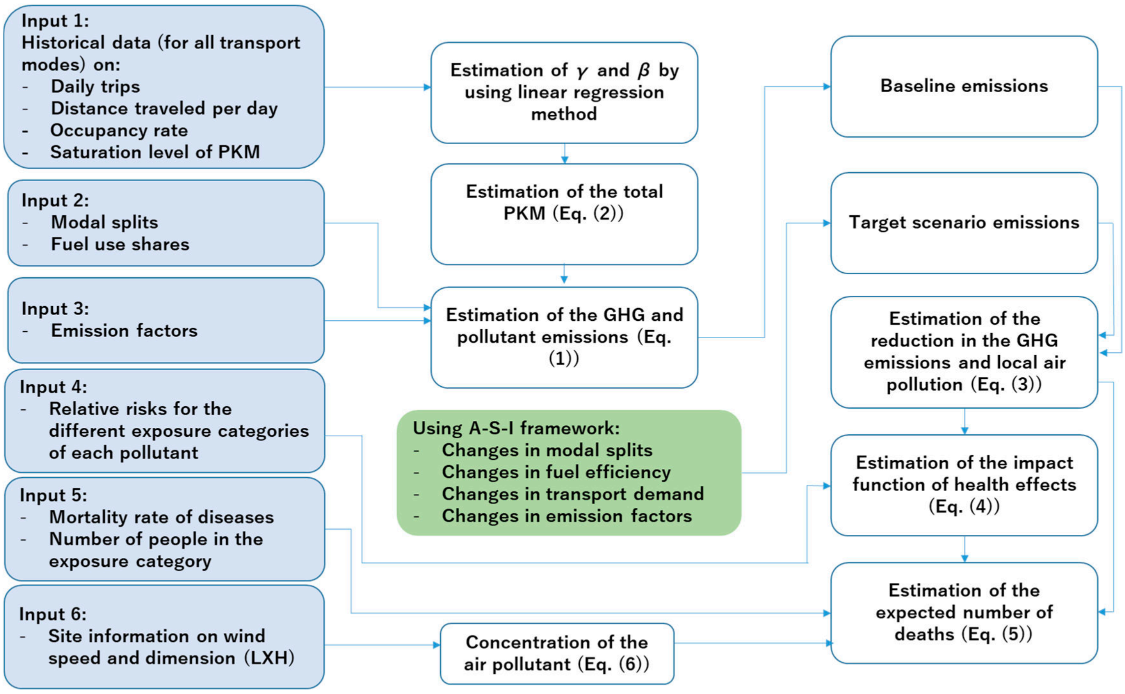


Figure 2. The calculation steps in the model.

The model shows a linear representation of the transport system in a city, from which the implementation of policies can be evaluated in terms of its carbon and local air pollution emissions and also public health impacts. It can be conceptualized in the flow chart shown in Figure 2. The blue highlighted area refers to the input data needed for the baseline evaluation and the green box to the evaluation through scenario input. It is intended to provide a first-order screening of possible options that can be further investigated using more sophisticated data, which have a better representation of travel demand tailored to the city in question. The main idea is to establish a baseline inventory of vehicles and usage data in the city to assess the status of emissions (Input 1–3). The next step is to explore options to develop goals through evaluating co-benefits of options, using the A-S-I approach to examine co-benefits of different policies, which are highlighted in the green box.

3. Results and Discussion

3.1. The Study Area: Tehran Transport Sector

The population in Tehran has increased sharply from 4 million in 1970 to 8.3 million in 2018, with an outer metropolitan population of 16 million inhabitants (see Figure 3). Mobile sources, including private cars, public and private buses, and motorcycles and motor-vans contributed to 90% of Tehran's total air pollution due in part to their low efficiency [47,48]. For example, motorcycles produce CO emission rates of up to seven times the limits set for Euro-3 certification [49]. The critical pollutants responsible for most of the unhealthy air quality days in Tehran are shown in Figure 4 [50]. The critical pollutants responsible for most of the unhealthy air quality days in Tehran have been identified: they are carbon monoxide (CO), total hydrocarbons (THC), oxides of nitrogen (NO_x), and particulate matter (PM_{10}), with shares from mobile sources estimated at 99%, 71%, 70%, and 69%, respectively. Table 1 shows the share of the different fleets in total mobile source air pollution in Tehran [50]. The contribution of private cars, taxis, and motorcycles to air pollution was estimated at around 50% of the mobile sources.

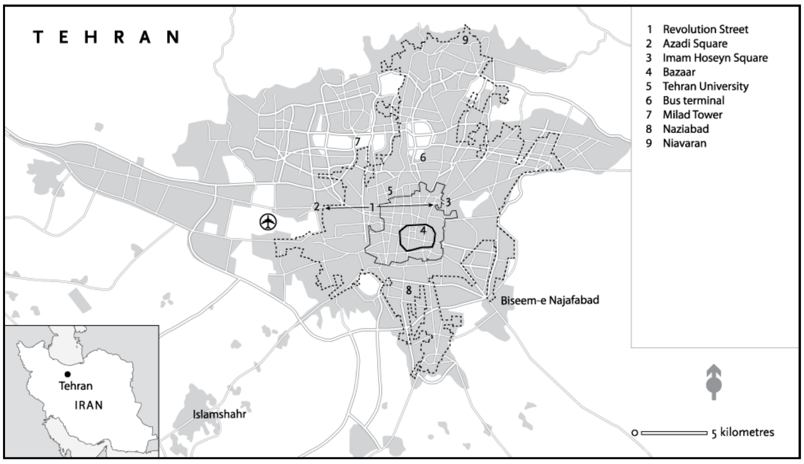


Figure 3. Tehran metropolitan area (adopted from [51]).

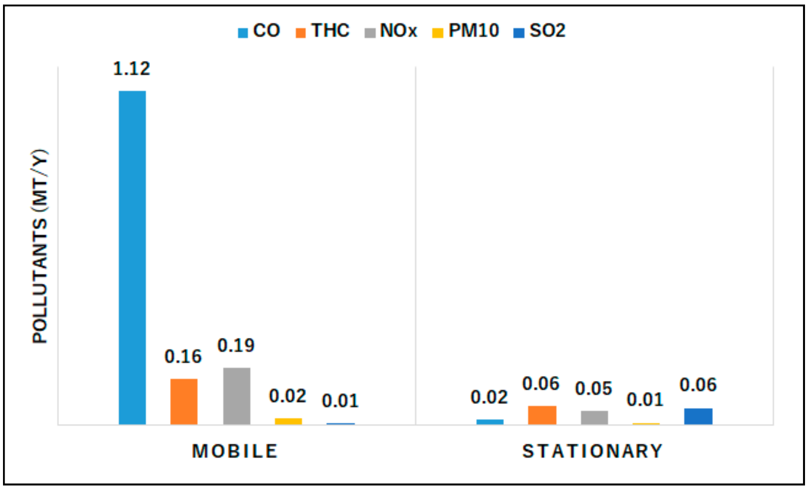


Figure 4. Tehran's mobile and stationary sources (i.e., industries, power plants, oil refinery, etc.) of air pollution [50].

Table 1. Share of vehicle fleets in mobile air pollution source in Tehran (%) [50].

	CO	PM_{10}	SO_2	NO_X	HC
Bus	2	9	60	5	10
Motorcycle	18	9	1	2	33
Taxi	7	1	1	10	8
Private Vehicle	66	64	9	77	40
Others [1]	7	17	29	6	9

[1] Van, Minibus, and LDT.

3.2. Baseline Scenario

The baseline scenario was developed to show how the future of Tehran's transport system might look based on the perpetuation of current policies. Table 2 shows the modal splits, fuel use, and efficiency in the urban transport sector in Tehran. Historical data on daily trips and distance traveled by each mode of transport were collected from the SCI (Statistical Center of Iran) [52], which are given in Table 3.

Table 2. Modal splits, fuel use and efficiency in the urban transport sector in Tehran [52].

Vehicle Categories	Mode Share (%)	Fuel Use	Fuel Efficiency (km/liter)
Passenger car	39	Gasoline (94%) CNG (6%)	Gasoline (7.8) CNG (7.6)
Taxi	24	Gasoline (31%) CNG (69%)	Gasoline (7.8) CNG (7.6)
Motorcycle	6	Gasoline (100%)	Gasoline (20.7)
Urban Bus	22	Diesel (55%) CNG (45%)	Diesel (4) CNG (1.7)
Metro	9	Electricity (100%)	Electricity (0.3) *

* km/kWh.

Table 3. Daily trips and distance traveled by each mode of transport in Tehran [52].

Year	Million Trips Per Day					Distance Traveled Per Year (Million Kilometers)				
	Car	Taxi	Motorcycle	Bus	Metro	Car	Taxi	Motorcycle	Bus	Metro
2004	5.7	3.5	0.9	3.2	1.3	21,199	9976	2718	5534	4355
2005	5.8	3.6	0.9	3.3	1.3	21,634	10,181	2774	5647	4444
2006	5.9	3.6	0.9	3.3	1.4	22,070	10,386	2829	5761	4534
2007	6.0	3.7	0.9	3.4	1.4	22,506	10,591	2885	5875	4623
2008	6.0	3.7	0.9	3.4	1.4	22,506	10,591	2885	5875	4623
2009	6.3	3.9	1.0	3.6	1.5	23,522	11,069	3016	6140	4832
2010	6.5	4.0	1.0	3.7	1.5	24,103	11,342	3090	6292	4951
2011	6.6	4.1	1.0	3.7	1.5	24,683	11,616	3165	6443	5071
2012	6.8	4.2	1.0	3.8	1.6	25,264	11,889	3239	6595	5190
2013	6.9	4.2	1.1	3.9	1.6	25,700	12,094	3295	6709	5280
2014	7.0	4.3	1.1	4.0	1.6	26,135	12,299	3351	6822	5369
2015	7.1	4.4	1.1	4.0	1.6	26,571	12,504	3407	6936	5458

Taking natural logarithms of Equation (2) and using the linear regression method to the historical data of 1980–2015, the estimated values of γ and β at three levels of saturation (high, medium, and low) for each mode of transport are given in Table 4.

Table 4. Estimated values of γ and β in Equation (2) for the different saturation levels (α).

Mode	Private car			Taxi			Motorcycle			Bus			Metro		
α (BPKM)	Low	Med.	High	Low	Med.	High	Low	Med.	High	Low	Med.	High	Low	Med.	High
	50	60	70	50	60	70	7	10	15	50	60	70	15	18	20
γ	−0.59	−0.18	0.13	−0.11	0.24	0.50	0.21	0.78	1.33	−0.13	0.22	0.48	−0.23	0.13	0.32
β	−0.09	−0.06	−0.05	−0.06	−0.04	−0.04	−0.04	−0.03	−0.03	−0.06	−0.04	−0.04	−0.06	−0.05	−0.04

The results of the multiple linear regression model indicate that $\ln \gamma$ and $\ln \beta$ are significant at a 5% significance level. The coefficient of determination, R^2, is more than 0.992 in all cases. Furthermore, the F-statistic reaches the 1% significance level in all cases. These results show that the model can adequately explain travel demand in Tehran.

Figure 5 represents the projection of the travel demand in Tehran, which is expected to increase steadily to 180 Billion Passenger-Kilometers (BPKM) in 2030.

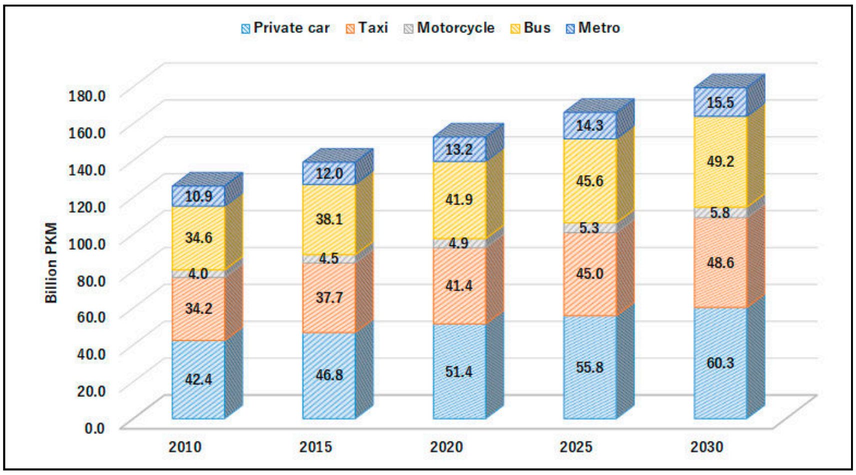


Figure 5. Baseline projection of travel demand estimated at the maximum sat. levels.

The total GHG emissions increase to 17.4 Mt CO_2-eq in 2030, as reported in Table 5. The significant rise in CO emissions can be mainly attributed to the high average age of the fleet, inefficient technologies, and traffic congestion in this city [53]. The emission factors used in the estimation of the CO_2 and air pollutant emissions are given in Table 6.

Table 5. Air pollution and GHG emissions in Tehran's transport system 2010–2030.

	2010	2015	2020	2025	2030
CO_2 (Mt/y)	12.2	13.5	14.8	16.1	17.4
CO (Mt/y)	1.4	1.5	1.7	1.8	2.0
SO_2 (kt/y)	3.2	3.6	3.9	4.2	4.6
NO_X (kt/y)	140.3	154.7	169.9	184.7	199.6
PM_{10} (kt/y)	14.5	16.0	17.6	19.1	20.7

Table 6. Emission factors for the different vehicle types in Tehran (g/kg_{fuel}).

	Bus		Car		Motorcycle
	Diesel	**CNG**	**Petrol**	**CNG**	**Petrol**
CO_2	3140	2750	3180	2750	3180
CH_4	0.2	30.6	0.8	31.6	5
N_2O	0.1	-	0.06	-	0.07
SO_2	0.56	-	1.50	-	-
NOx	42	17.7	27	19.0	2.72
PM_{10}	2.43	-	0.6	-	0.6
CO	36	36.7	550	36.1	730
HC	8	4.3	63	4.5	530

As a direct result of the incremental growth of private vehicles, the emissions of air pollutants, particularly PM_{10}, CO, and NOx in the transport system in Tehran is predicted to increase by a factor of

1.4 from 2010 to 2030. The associated air pollution problem of private transportation modes have had adverse effects on the health of the general public, with a marked rise in the incidence of respiratory and heart diseases. Therefore, there is a real need for the municipal government of Tehran to have the transport planning framework to make a sustainable decision and prepare the practical mid-term solutions for the transportation issues in the future.

3.3. Tehran Transportation Master Plan

So far, policymakers have developed a series of initiatives to deal with the severe challenges of air pollution in Tehran. For example, 250,000 spark-ignition engine vehicles were decarbonized through engine deposit removal by the Iranian Department of Environment, to reduce the atmospheric pollutant emissions such as HC and CO emissions [54]. More recently, Tehran's central area has been added to the list of the traffic restricted zones, limiting the entry of private vehicles on weekdays. However, these measures have not been adequate to reduce pollution significantly, and Tehran remains a heavily polluted city. The Municipal Government of Tehran has launched a comprehensive plan, named "Tehran Transportation Master Plan (TTMP)" which outlines an integrated clean transportation system to tackle GHG emissions and air pollution in 2030 [55,56]. In the following section, we will examine the potential co-benefits and impacts of the TTMP, using the A-S-I modeling framework.

The A-S-I actions of the TTMP and their impacts on Tehran's transport system are shown in Table 7. According to the TTMP, the mass transit system accounts for 70% modal share of total Tehran's daily trips in 2030. To this aim, the total length of Tehran's urban rails and Bus Rapid Transit system increase to 514 and 202 km, respectively. Moreover, the share of CNG (Compressed Natural Gas) buses increases from 45% to 100% in the total fleet. Based on this plan, preventing the unauthorized entry to the Restricted Traffic Zone (RTZ), using ANPR (Automatic Number Plate Recognition) systems and introducing the Non-Motorized-Transportation (NMT) such as bike routes will result in reducing about 4.3 BPKM traveled by private vehicles in this city. According to the TTMP, a modal shift from private modes to the public transport systems, including the metro and BRT, can help reduce energy consumption, CO_2 emissions, and the pollution load in the city of Tehran. On major streets in this city with relatively high traffic congestion, public transportation modes, like such as buses and trains, are more fuel efficient. Therefore, improving BRT priority lanes in the city of Tehran will increase energy efficiency in transportation by reducing traffic congestion and the travel speed and comfort level of the passengers will also be improved. As a consequence, the implementation of the TTMP will reduce traffic congestion by increasing the average travel speed and passenger mobility on major streets in this city.

Table 7. The actions and initiatives of the Tehran Transportation Master Plan (TTMP) [56].

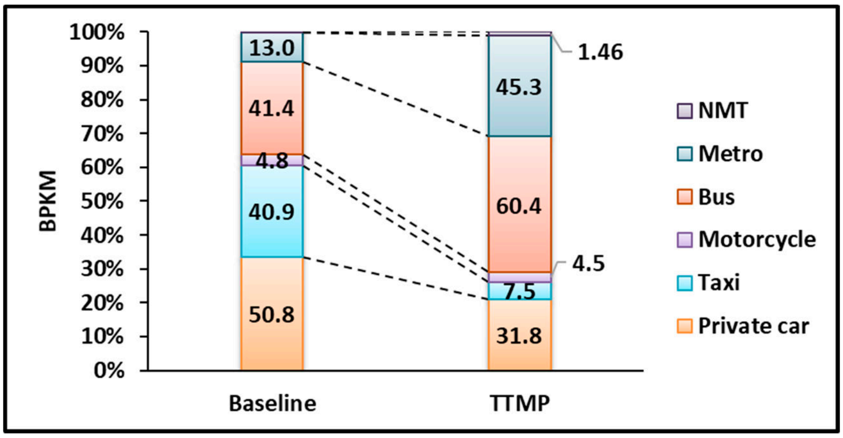
Action	Scenario	Baseline	TTMP (in 2030)	Impact
Shift	Developing Tehran's rail system	Total length of 179 kilometers	Increasing the total length of subway lines to 514 kilometers [1]	Increasing about 32.3 BPKM traveled by urban rail system [2]
	Developing the Bus Rapid Transit (BRT) system	10 lines with a total length of 172 kilometers	Increasing the total length to 202 kilometers [1]	Increasing about 19 BPKM traveled by BRT [3]
	Increasing the number of natural gas buses	Compressed Natural Gas (CNG) buses accounted about 45% of total fleet	Increasing the share of CNG buses to 100% in total fleet [4]	Reducing about 1.14 billion liters of diesel [5]
Avoid	Improving the Restricted Traffic Zone (RTZ) enforcement	160,000 unauthorized vehicles entering the RTZ	Preventing unauthorized entry of 196,000 vehicles by installing 303 cameras equipped with ANPR [6] system in the RTZ	Reducing about 2.86 BPKM traveled by private vehicles [7]
	Developing the Non-Motorized-Transportation (NMT)	Total length of 158 km of bike routes	Increasing the total length of bike routes to 919 kilometers	Reducing about 1.46 BPKM traveled by private vehicles [8]
Improve	Updating and improving the vehicle fuel economy	7.8 km/liter	12 km/liter [9]	Reducing about 0.86 billion liter of gasoline

1. According to [57]. 2. According to [56], it is assumed that the share of metro increases by 30% in 2030 which results in increasing of its trips per day from 1.6 million in 2015 to 8.1 million in 2030. 3. According to [56], by introducing the new BRT lines, the share of urban buses in total fleet will increase from 22% in 2015 to 40% in 2030. 4. The total bus fleet includes urban buses and BRT. 5. The average fuel economy of an urban bus in Tehran was considered about 0.25 L/km (for Diesel) with an average mileage of 250 km/day [58]. 6. Automatic number plate recognition. 7. Assuming an average distance traveled about 5 km for each unauthorized entry with an average occupancy rate of 1.6, which results in reducing about 4.9 million distance traveled per year. 8. A total number of 100,000 bicycles will be available (rent/share) for use on the designated paths, with an average mileage of 5 km/day [56]. 9. According to [56].

Figure 6 shows the comparison of transport mode shares between the baseline scenario and the TTMP in 2030. The amount of fuel-saving in the urban bus fleet was estimated based on an average fuel intensity of 25 L/100 km and an average mileage of 250 km/day [59]. The most fuel saving is expected from reducing about 2.94 billion liters in gasoline consumption by cars and taxies. The expected reductions in CO_2 emissions and air pollution from the TTMP in Tehran's transport system in 2030 is depicted in Figure 7. The expected decline in air pollutant emissions is identified as the co-benefit obtained from the implementation of the TTMP (see Table 8).

Table 8. Expected GHG emissions and pollutants reductions from the TTMP in 2030.

Scenarios	GHG (Mt/y)	SO_2 (kt/y)	NO_X (kt/y)	PM_{10} (kt/y)	CO (kt/y)
Baseline	17.4	4.6	199.6	20.7	2
TTMP	4.5	0.7	88.0	4.2	0.90



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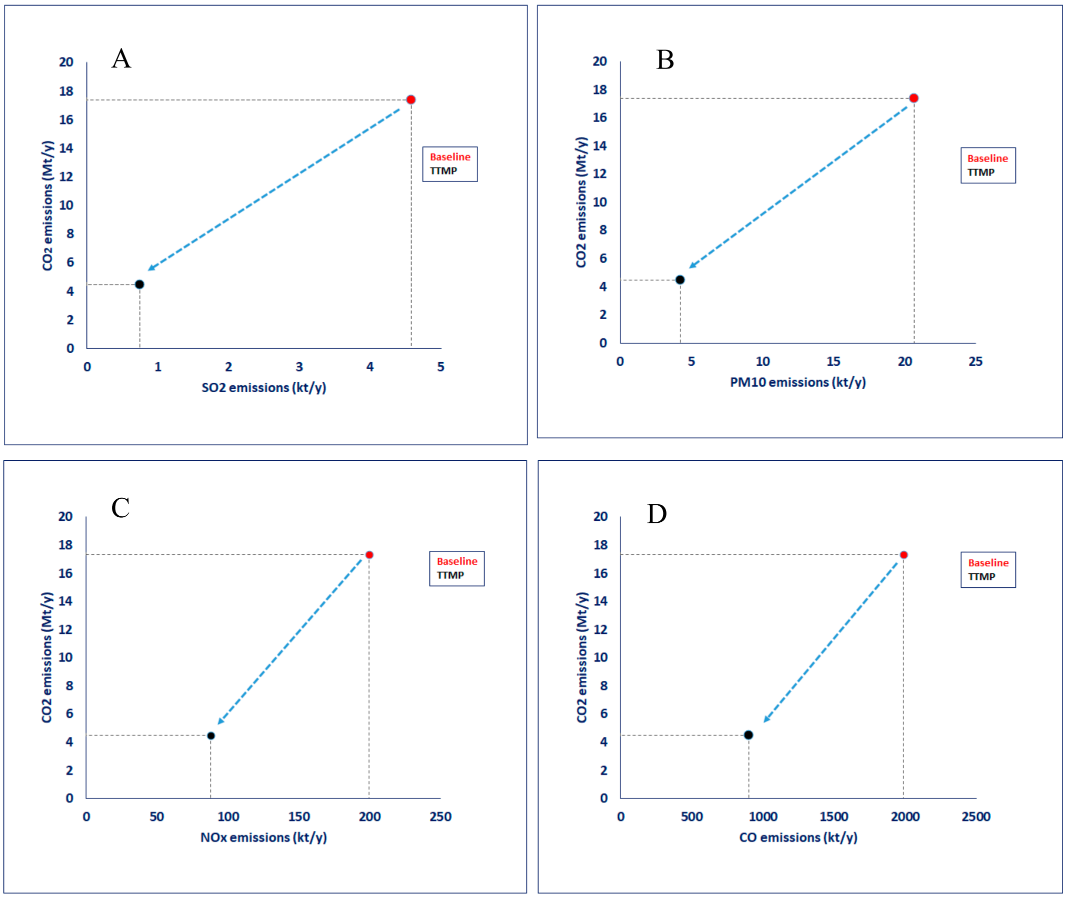

Figure 7. Expected reduction in CO_2 emissions and air pollution from the TTMP in 2030 (A: CO_2 Vs. SO_2; B: CO_2 Vs. PM_{10}; C: CO_2 Vs. NOx and D: CO_2 Vs. CO).

Besides emission reduction, utilization of efficient urban transportation in Tehran is associated with public health benefits. The estimated values of the Relative Risk coefficients used in this study are collected from [60], which are listed in Table 9.

Table 9. *RR* values (95% CI) for each 10 μg/m^3 increase in the daily mean concentration of each pollutant [60].

	Total Mortality	Respiratory Mortality	Cardiovascular Mortality
SO_2	1.003 to 1.048	1.006 to 1.140	1.002 to 1.120
NO_x	1.002 to 1.004	1.011 to 1.045	1.003 to 1.005
PM_{10}	1.004 to 1.008	1.005 to 1.020	1.005 to 1.013

In this study, we assumed that the wind speed and the geographical parameters remain unchanged across the period. The expected public health co-benefits (annual death prevented) from the TTMP are given in Figure 8.

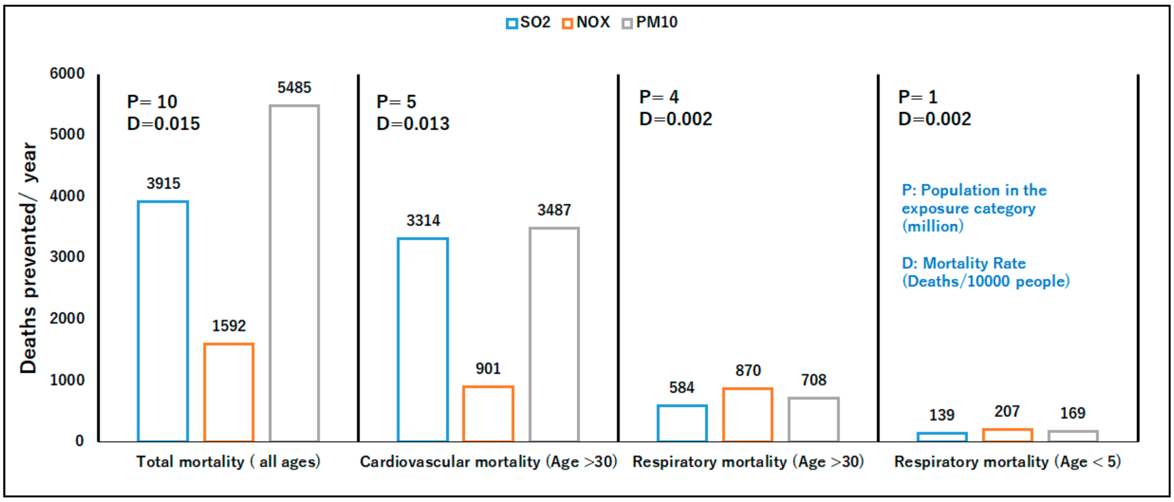

Figure 8. Expected public health co-benefits from the TTMP in 2030 (1. Data collected from the Ministry of Health and Medical Education for 1990–2013 [61]. 2. The respiratory disease mortality rate for children under five years was collected from [62]).

As can be seen from Figure 7, the annual reduction in total mortality varies from 5485 cases to 1592 cases for the projected 10 million inhabitants in Tehran in 2030. The effect of PM_{10} on both cardiovascular and respiratory mortalities is significant, which implies that the reduction of the levels of this pollutant plays a vital role in attaining the expected public health co-benefits in Tehran. The cost-saving from the health co-benefits is estimated at USD 35 million per year, using available data on hospital admission and premature mortality costs in Tehran [52]. Table 10 summarizes the expected annual co-benefits from the TTMP in 2030 in the city of Tehran.

Table 10. Expected co-benefits from the TTMP in 2030.

Reduction in CO_2 Emissions (Mt)	12.9 Million Tons
Co-benefits	
Reduction in local pollutant emissions	1.4 million tons
Public health impact	10,000 deaths prevented
Cost savings	35 million USD

Figure 9 illustrates the implication of the A-S-I actions which were considered in the TTMP. It can be observed from this figure that the implementation of the shift actions such as developing the Tehran's rail and BRT systems together with the CNG buses have a significant impact on improving the air quality and public health in this city.

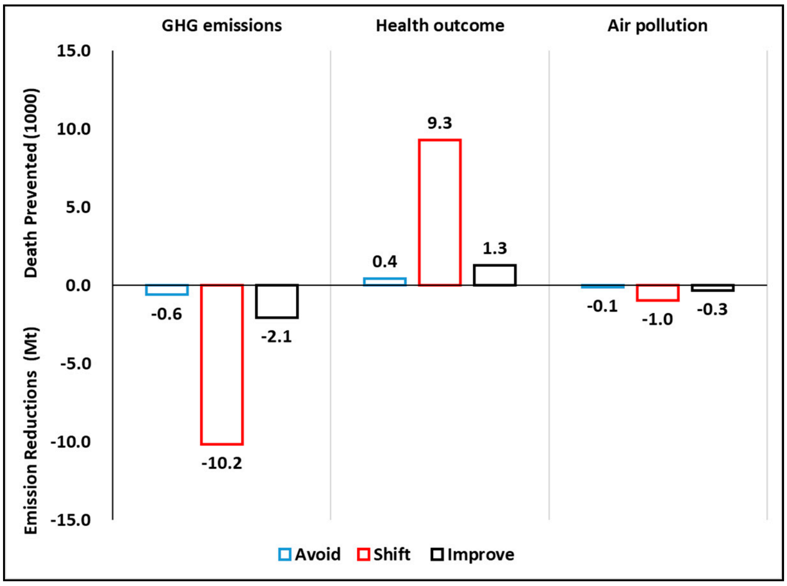

Figure 9. Expected co-benefits from each action in the TTMP.

To compare the expected co-benefits across different A-S-I actions, the results were normalized on a scale of zero to one, using the min-max calculation method. Figure 10 shows the aggregate scores for each action group in the TTMP. The shift actions perform well in all expected co-benefits in the transport sector, followed by the Improve action, which is linked with upgrading fuel-economy in the passenger car fleet. The expected co-benefits from preventing unauthorized entry of passenger vehicles in the RTZ and developing the NMT (Avoid actions) are expected to be achieved from the reduction in NO_x emission in Tehran's transport sector.

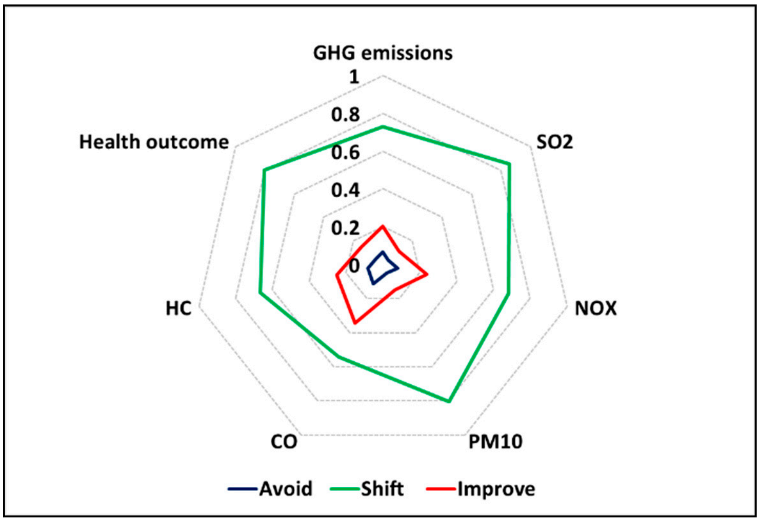

Figure 10. Impact assessment of the TTMP (Max = Total amount of each expected co-benefits, Min = 0).

4. Conclusions

Sustainable transport, particularly in developing countries, is an important element of climate change policies, which can be integrated into development objectives such as good health and well-being as well as clean energy and sustainable cities. In order to meet both climate protection and other human development goals, it is important to seek perceptible co-benefits to justify interventions. In the transport sector, the climate change mitigation actions are usually linked with the application of clean technologies or behavioral changes by introducing affordable travel options. However, developing a low-carbon transport system can bring additional benefits beyond GHG emissions reduction, such as improved air quality and public health as well as reducing traffic congestions, injuries, and noise. Therefore, analyzing the co-benefits of climate change mitigation in the urban transport and energy sector may be high on the agenda of important policy actors, since there is large potential to introduce the co-benefits approach into ongoing projects and existing climate change mitigation actions, as exemplified by this study in Tehran, which suffers from several social, economic, and environmental problems caused by a poor urban transportation system.

This paper introduced the co-benefits approach to climate mitigation in the urban transport system by developing a quantitative model which is based on the Avoid-Shift-Improve method. The A-S-I modeling framework presented in this research simply follows a well-established method of evaluating mitigation potentials and related benefits, using simple and robust input data. However, the development of the model needs to be accompanied by investments in developing a database for having more precise and updated results, including sectoral data and emission factors for the urban transport system. Testing the model in Tehran's transportation system has revealed a significant potential of expected environmental and health co-benefits from the implementation of the TTMP in this city. The most important finding of this analysis is that climate actions focused solely on "shift" such as replacing private car trips with public mass transit and increasing the number of CNG buses can cause additional co-benefits. By providing policy makers with a comprehensive overall view of the extent of the co-benefits associated with the TTMP, they can make precise adjustments to the mitigation interventions to achieve the desired the ancillary benefits of the actions. It also helps with envisioning several low-emission development strategies with multiple benefits to facilitate the achievement of the SDGs in the city of Tehran. Moreover, the initial scope of co-benefits, such as those provided in this investigation, help Tehran's decision-makers to determine if intensive analyses are needed in the future.

Author Contributions: Conceptualization: H.F. and J.A.P.d.O.; methodology, investigation, formal analysis, H.F., writing—review and editing, H.F. and J.A.P.d.O., B.M. and H.O.

Funding: The research for this paper was supported by the Asia-Pacific Network for Global Change Research (Ref. CRRP2017-07SY-Farzaneh) and the Kurata grant of the Hitachi Global Foundation. The author wishes to thank those organizations for their supporting of this.

Conflicts of Interest: The authors declare no conflict of interest.

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