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Sustainable Transportation Trinity: Energy, Technology and the Environment

ثلاثية أنظمة المواصلات المستدامة : الطاقة والتقانة والبيئة

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Abstract: Despite having brought many advantages into the advancement of our productive and increasingly mobile life, motor vehicles do emit large quantities of carbon monoxide, hydrocarbons, nitrogen oxides, sulfur dioxides, and a full spectrum of toxic substances, such as fine particles and lead. Each of these, along with their polluting daughter-products (e.g., ozone), can cause serious effects on public health and the environment. The intrinsic linkage between the environment and development necessitates the needs for coordinated initiatives, efforts and policies in order to tackle the issue in a comprehensive approach. Reducing pollutions emanating from transport requires an integrated strategy, which may entail sensitive traffic management, transport demand management, optimal roads systems, cleaner fuels and energy-efficient technologies, environmental emission standards for new vehicles, and sound maintenance programmes for old vehicles to curtail their emissions. This paper addresses the key issues involved in the sustainable development, prevention, improvement and mitigation of transport emissions and resultant atmospheric pollution. Also, it considers the obstacles encountering urban air quality management programmes and reviews experience to harmonize policies in different sectors with air quality management efforts. Furthermore, it offers recommendations for priorities in developing countries by integrating strategies and policies relevant to the environment, transportation, and energy sectors.

Keywords: *Sustainable Transportation System, Air Pollution and Vehicular Emission, Traffic Management System, Clean Fuel, Environmental Sound Automotive Technologies.*

المستخلص: على الرغم من إحرازها العديد من الفوائد نحو تعزيز تقدمنا في الانتاج وزيادة وتيرة حركة حياتنا المعاصرة ، فإن مركبات النقل والمواصلات تنتج كميات كبيرة من غاز أول أكسيد الكربون والهيدروكربونات المنطلقة وأكاسيد النيتروجين وثاني أكسيد الكبريت والكثير من المواد السامة مثل الجزيئات الدقيقة والرصاص في الجو . ويمكن أن تسبب كل من هذه المواد المنبعثة (مثل الغازات) أو نواتجها الملوثة تأثيرات حادة على الصحة العامة والبيئة . ويقتضي الارتباط الوثيق بين البيئة والتنمية الحاجة إلى تضافر المبادرات والجهود والسياسات المنظمة لمعالجة هذه المشكلة من خلال منهجية شاملة. حيث يتطلب تقليل التلوث المنبعث من وسائل النقل والمواصلات استراتيجية متكاملة ، تنطوي على إدارة دقيقة لحركة السير والمرور ، وإدارة الطلب على وسائل النقل ، وأنظمة تصميم أمثل لشبكات الطرق ، واستخدام الوقود الأنظف ، وتقانات كفوءة في استهلاك الطاقة ، واعتماد شروط ومواصفات بيئية للانبعاثات الناتجة عن المركبات الحديثة ، وكذلك برامج لتحسين صيانة المركبات القديمة من أجل تقليل انبعاثاتها . وتطرح هذه الورقة العلمية القضايا الأساسية الداخلة في صلب التنمية المستدامة ، من الوقاية والتخفيف والتحسين والحد من انبعاثات وسائل

النقل والمواصلات والتلوث الجوي الناجم عنها. كما أنها تهتم بالصعوبات التي تواجه برامج إدارة نوعية الهواء في الحضر ، وتعرض الخبرات المختلفة بهدف توحيد الجهود والسياسات في كافة القطاعات المعنية بإدارة نوعية الهواء وجودته . علاوة على ذلك ، فإنها تقدم التوصيات والمقترحات بخصوص أولويات التنمية في البلدان النامية عن طريق مكاملة الاستراتيجيات والسياسات المتّبعة في قطاعات البيئة والمواصلات والطاقة.

كلمات مدخلية : *منظومة النقل والمواصلات المستدامة، تلوث الهواء وانبعاثات المركبات، نظام إدارة حركة السير والمرور، الوقود النظيف، التقانات السليمة بيئياً للمركبات وآليات الحركة.*

INTRODUCTION

The development of a country's transport sector has often been seen as an indicator of its economic welfare and success, and ownership of a car and leisure travel has become status symbols. Over the past fifty years the world's vehicle population has grown fifteen-fold: it now exceeds 700 million units and will soon reach 1 billion units (UNEP, 1999). The vehicular population increase reached 11.5% between 1995 and 2000. Over the same 50-year period, the total number of kilometers traveled annually by each person on earth has tripled. Overall, the transport sector accounts for 2 to 4 % of the labor force in OECD countries and 4 to 8 % of GNP – more than a US $ trillion each year. The turnover of the largest three automotive manufacturers alone exceeds the GNP of the whole African continent.

Transportation already accounts for more than one-quarter of the world's energy consumption, and is a major driving force behind the growing world demand for energy. Since 1970 fuel consumption for transportation has more than doubled, reaching 18 million barrels of oil per day, and the US Department of Energy projects that it will grow by another 77 percent (to 27 million barrels per day) by 2020. Globally, fuels consumption in transportation is about 1550 MTOE/Year of which 60% is gasoline, 40% is diesel and <2% is alternative fuels (Douaud, 2002).

Most vehicles have been in industrialized countries, but vehicle population growth rates in developing countries are catching up quickly and most of the future growth in world oil consumption is expected to take place in developing countries, much of it related to increased demand for transport and hence transportation fuels. Vehicular population in the Arab Region is about 20 million i.e., 74 vehicles/1000 people (UNEP, 2002) however this rate varies considerably from one Arab State to another (e.g., 12 vehicles/1000 people in Mauritania to 408 vehicles/1000 people in Kuwait). Also, the rate of increase in vehicular population is also diverse between various Arab states (e.g., the rate of increase between 1980 and 1977 in Kuwait was 5%, in Jordan 20% and in Tunisia 68%). The transportation sectors use up about 25% of the total energy consumption in the Arab Region. This consumption has increased 240% in the last two decades versus 32% increase in the world.

Atmospheric Pollution

Current transport patterns have substantial environmental impacts: they contribute to climate change, local and regional air pollution, resource consumption, land use change, and noise. Different modes of transport have different environmental impacts, both qualitatively and quantitatively. Air pollution related to motor vehicles and transportation emissions is an issue of significant implications and pronounced impacts on local, national and global scales.

The transport sector is an important contributor to the greenhouse effect on climate change through the emission of greenhouse gases (GHGs). The main GHGs are carbon dioxide (CO_2), methane (CH_2) and nitrous oxides (N_2O). Others include carbon monoxide (CO), non-methane hydrocarbons (NMHC), and oxide of nitrogen (NO_x). The latter two groups of gases contribute to increasing concentrations of tropospheric ozone, which is an important GHG. Carbon monoxide, once emitted to the atmosphere, is oxidized to form CO_2. Carbon dioxide, methane and nitrous oxides all have an impact on the level of radiation retained by the Earth and hence impact on the level of climate change expected. As a result, it is important to include considerations of the impact of transportation on the global environment. Other regional and local impacts include the formation of photochemical oxidant from the precursor emissions NO_x and non-methane hydrocarbons (NMHC), together with formed acidic aerosols and acid deposition, the main cause of which is the emission of sulfur and nitrogen compounds. Furthermore, direct health risks to humans from motor vehicle emissions are most common in urban areas, local to the source, where large populations are exposed to high concentrations of air pollutants.

A study on urban air quality conducted by the United Nations in 1988 found carbon monoxide, lead, particulates, nitrogen dioxide and oxidants, all of which emit from vehicles, are present in cities in concentrations frequently exceeding international health standards. Of these pollutants, lead and fine particulates are the major health problems especially in developing counties (subject to meteorological conditions), and ozone can also be a serious health concern. Vehicular pollutants comprise the following:

Particulate matter is the general term for the mixture of solid particles (dust, dirt, smoke) and liquid droplets found in the air. Scientific studies show a link between particulate matter and a variety of health impacts including breathing and respiratory impairment, aggravation of existing respiratory and cardiovascular disease, and alterations in the body's defense systems against foreign materials, damage to lung tissue, carcinogenesis, and premature mortality.

Carbon Monoxide is produced by the incomplete combustion of carbon-based fuels. Carbon monoxide is a colorless, odorless gas that enters the bloodstream through the lungs and inhibits the capacity of blood to carry oxygen to the body's organs and tissues.

Nitrogen Oxides produce a variety of health and welfare effects. Nitrogen Oxide can irritate the lungs and lower resistance to respiratory infection. Nitrogen Oxides are a precursor to ground-level ozone and to acid rain and may affect both terrestrial and aquatic ecosystems.

Tropospheric Ozone is formed by reactions involving nitrogen oxides and photochemically reactive organic compounds, commonly referred to VOCs. These include aldehydes, olefins, and aromatics with two or more alkyl groups. Ozone is responsible for photochemical smog and has been associated with transient effects on the human respiratory system.

Lead added to fuels as an inexpensive octane booster is toxic, affecting many organs and organ systems and leading to impaired sensory motor function, impaired renal function and increased blood pressure. It is particularly harmful to small children because it damages the brain and the nervous system. Lead poisoning affects the poor disproportionately; the available data suggest that more lead is absorbed in individuals suffering from iron or calcium deficiency, and the amount of lead absorbed by the body increases significantly if the person ingesting it is malnourished. Lead replacements such as *methyl tertiary-butyl ether* (*MTBE) and methylcyclopentadienyl manganese tricarbonyl (MMT)* are also of concern due to its toxicity (it is banned in most States of the USA).

Sulfur Dioxide is a product of combustion of sulfur-containing fossil fuels; sulfur is present to a greater or lesser extent in all crude oils. Periodic exposure to high concentrations of sulfur dioxide cause reduced lung function in asthmatics and exacerbates respiratory problems in sensitive individuals. Sulfur dioxide contributes to the formation of secondary particulate matter. It furthermore contributes to acid precipitation.

Volatile and toxic emissions from vehicles also include *benzene, aromatics and aldehydes*, all of which are classified as carcinogens by the World Health Organization. Table (1) summarizes in general the air pollutants emanating from transportation systems.

Poor air quality is related to approximately three million deaths each year and contributes to the plight of millions of individuals who suffer from asthma, chronic obstructive pulmonary disease, cardiovascular disease, and lung cancer. Motor vehicles emit large quantities of air pollutants including carbon monoxide, hydrocarbons, nitrogen oxides, sulfur oxides and toxic substances such as fine particles, benzene, aromatics and aldehyde

– and in countries where it is still used as a fuel additive – lead. Motor vehicles thereby contribute to poor air quality, particularly in those urban areas that have older vehicle fleets and a geography that constrains air movement. The World Health Organization (WHO) estimates that only 15% of cities in developing countries have acceptable air quality, and that approximately 460,000 people die prematurely each year as a result of exposure to particulate matter alone (UNEP, 1999; UNEP, 2002).

Table 1. (OECD, 1997) Air pollution transportation: types, sources and impacts.

Pollutant	Type of impact						Source of Pollutant	Health Effect of Pollutant
	Local	Regional		Global				
	High Concentrations	Acidification	Photo-Chemical Oxidants	Indirect GHG	Direct GHG	Stratospheric Ozone Depletion		
Particulate matter	x		x				Products of incomplete combustion of fuel; also from wear of brakes and tires	Irrigates mucous membranes; respiratory / pulmonary effects; carcinogenic
Lead	x						Added to gasoline to enhance engine performance	Acute circulatory, reproductive, and nervous system
Carbon Monoxide	x		x	x			Incomplete combustion product of carbon-based fuels	Reduces oxygen carrying capacity of red blood cells
Nitrogen Monoxide	x	x	x	x		x	Formed during fuel combustion at high temperatures	Irritates lungs; increases susceptibility to viruses
Sulfur Dioxide	x	x					Combustion of petroleum products	Reduce lung function / impairment of respiratory system
Volatile Organic Compounds	x		x	x			Combustion of petroleum products; also evaporation of unburned fuel	Irritates eyes, causes intoxication; carcinogenic
Tropospheric Ozone		x	x	x			Not an exhaust gas; product of photochemical reaction of NO_X and VOC_s in sunlight	Irritates mucous membranes of respiratory system; impairs immunities
Carbon Dioxide					x		Combustion product of carbon based fuels	
Methane					x		Leakage during production, transport, filling and use of natural gas	
Nitrous Oxide				x	x	x	Combustion products of fuel and biomass, also formed in catalytic converters	

The type and quantity of pollutants emitted from transport vehicles depend on vehicle type, age, maintenance profile, mileage and driving style, and fuel characteristics. In developing countries, in general, the age of the vehicle fleet is much older than in developed countries, vehicles are often ill maintained and fuel quality is generally poorer, putting an increasing number of urbanized areas in developing countries under pressure from mobile source air pollution. In developed countries on the other hand, due to technological improvements in fuel specifications and vehicular design and maintenance schemes, the total amount of pollutants emitted per Kilometer traveled has declined from approximately 100 gr/Km in the 1970s to 2-3 gr/Km in 2000, and is continually decreasing to reach significantly less than 1 gr/km in 2005. Such improvements include the phase-out of lead as a gasoline additive and decrease in levels of sulfur, benzene, aromatics and olefins in transport fuels. This clearly entailed a range of changes involving fundamental reformulation of fuels, adjustments to refining processes, and changes in combustion technologies.

SUSTAINABLE TRANSPORTATION MANAGEMENT:

Reducing pollution from vehicles requires a comprehensive multi-dimensional strategy incorporating transportation systems, energy, fuel and automobile technologies, and environmental management and control regimens. This may include (but is not limited to): emission standards for new vehicles, clean fuels, programmes designed to ensure that vehicles are maintained in a manner that minimizes their emissions and traffic and demand management measures. In a nutshell, such an integrated strategy contains measures on the technological, policy as well as organizational sides; and utilizes cleaner fuels and cleaner vehicles, and effective transportation system management. The following sections explain the overall 3-pillar approach for developing a holistic strategy for sustainable transportation systems. In general, the methodology is centered on Technology as well as Management based measures.

Technological Measures

This section reviews technical measures involving fuels and vehicles, transportation system design and management measures, infrastructures improvements, and land-use planning approaches for curbing vehicular air pollution emission and reducing GHGs release. Accordingly, the technological measures are classified as follows:

Alternative Fuel Options

Switching to alternative fuels, particularly to less carbon-intensive fossil fuels or to non-petroleum based fuels, could significantly reduce overall GHG and air pollution emissions due to their lower emissions per unit of service (vehicle-kilometer traveled). Alternative fuels and automotive systems that use them consist of three types: internal combustion engine technologies, electric vehicle technologies, and hybrids. Table (2) depicts the alternative fuel options, and Table (3) outlines their characteristics and impacts (UNEP, 2001).

Table 2. Automotive systems and fuel options.

System	Alternative Fuel Options
Internal Combustion Engine	Diesel (oil) Compressed Natural Gas – CNG (natural gas) Liquefied Petroleum Gases – LPG Methanol (from coal, natural gas, or wood), Ethanol (from corn, sugar cane, or wood), Hydrogen (various possible primary energy sources for the electricity used to make hydrogen. Modified internal combustion engine systems currently in production include (1) flexible fuel internal combustion engine systems that can bur ethanol, methanol, gasoline, or any mixture of these, and (2) bi-fuel vehicles that can switch back and forth between fuels, such as gasoline and natural gas
Elective Battery or Fuel Cell	Battery systems: electricity (can come from many possible sources; currently most likely scenario is changing off local grid) Fuel cell systems: Hydrogen (feedstock can be gasoline, natural gas, or electricity derived renewable sources like ethanol or solar power)
Hybrid	A combination of electric battery and internal combustion engine system with options described above

Automotive Improvement Options

Technical options for improving vehicle efficiency and environmental performance include weigh reduction, reducing aerodynamic resistance and improved combustion. Table (4) outlines some of these options and their market potential and the environmental impacts (UNEP, 2001).

The automotive improvement options however, may be classified into two categories as follows:

- Options for New Vehicles: including weight reduction; reducing aerodynamic drag; rolling resistance reduction; improvements to spark-ignition (gasoline) engines; and reducing transmission and accessory losses.
- Options for In-Use Vehicles: including regular maintenance, replacing engines and accessories; and reducing rollin.

Table 3. Characteristics and environmental impacts of alternative fuel options for vehicles.

Fuel Option	Examples	Status	Technical Feasibility	Conversion Efficiency	Environemnt Impact	Market Potential Time Frame
Alcohol Fuels	Neat methanol Neat ethanol	Demonstration fleets Field trials in large vehicles Commercial availability of blends	Supply limitation and cost needs Change in OEM design Low-cost emissions control option Multiple feedstock	15% improvement	VOC and CO_2 reductions	0-20 years
Natural Gas and LPG	On-board storage System integration	Demonstration fleets Field trials Fuels commercially available	Range extension needed System cost abatement	Close to gasoline with engine adaptation	VOC and CO_2 and particulate reduction	0-5 years
Hybrid Vehicles	Battery powered and CNG systems Battery powered and gasoline systems	Demonstration fleets Field trials in niche markets	Adopting hybrid drives can overcome many limitations of current electrical system options	Dependent on base fuel with 20-40% gain possible	Reduction of VOC and CO_2 and particulate vehicle emissions Environmental benefit to be gauged against overall fuel cycle (especially for electrical component)	0-10 years
Hydrogen (in an ICE)	Neat H_2 in ICE storage systems	R & D and prototypes	Infinite source of supply Distillation & production hurdles	Dependent on feedstock and storage system	Substantial reductions in all pollutants	30 years
Electric Vehicles	Electric batteries Fuel cells Solar photovoltaic cells Hybrid systems	Demonstration fleets Field trial in niche markets	Range and cost limitations may limit market Adopting hybrid drives may increase use options	Dependent on base fuel with 20-40% gain possible	Reduction to zero of all vehicle emissions Environmental benefit to be gauged against overall fuel cycle	10 years

Table 4. Technological automotive improvement options.

Technology	Examples	Status	Technical Feasibiltity	Conversion Efficiency	Environmental Impact	Market Potential Time Frame
Weight reduction	• Light structure • Bonded/composite structure • Light power trains	• Commercial/demonstrated • Bonded structure in limited use • Composite materials in most vehicles	• Continuation of improvements • Limited by material properties and relative cost of manufacture	• 0.2 to 0.4% gain for every 1% weight reduction	• Reduction of all emissions in proportion to efficiency gains • Greater effect on acceleration emissions (urban traffic) as vehicle inertia is diminished	• 0-10 years
Reduced Aerodynamic and Rolling Resistance	• Drag Coefficient reduction • Reduced rolling resistance • Reduced bearings friction	• Commercial potential for improvement in low-friction bearings and lubrications • Low friction tyros to be test	• Continuation of improvements dependent on material properties & cost of manufacture • Study on basic physics	• Speed sensitive benefits • Gains of 1-5% possible	• Reduction of all emissions in proportion to efficiency gains	• 0-10 years
Improved Combustion	• Ceramic Components • Ignition systems • Flow dynamics Variable valves • Turbine engine	• Incremental improvements	• Good variety of technology • Available technology must integrate with current ICE	• 5-10% engine efficiency gains	• NOx particulate and CO_2 reduction	• 0-10 years
Transmission	• Electronic shift • Multi-step lock-up • Continuously Variable transmission (CVT) electric drives • Drivelines and suspensions	• Commercial/demonstrated technology • CVT available • High power CVT in prototype • Lock-up and electronic control	• CVT/IVT in widespread use in next decade • Hybrid power-trains feasible with CVT/IVT	• 10-15% gain over manual with CT or IVT • Electronic drives could further increase this conversion efficiency	• Reduction of all emissions in proportion to efficiency gains • Engine operation optimized, decreasing emissions even more than efficiency improvement	• 0-10 years
Accessories	• On-board electronic controls • Constant speed drives • Efficient components	• Demand responsive systems gaining preference • Constant speed systems in demonstrations	• Highly feasible for constant speed • High efficiency accessory systems	• <5% efficiency gain	• Emissions reduction facilitated by on-board electronic controls and sensors	• 0-10 years

Management Measures

This section describes a framework of measures designed to improve transportation systems management and minimize atmospheric pollution, nonetheless by using the existing transport infrastructure more efficiently. Those are divided into transportation measures on the supply side, and transportation measures on the demand side as in the following:

- Transportation Supply Management (TSM) Measures- have two goals: to alter the conditions of road traffic mode, and to improve the efficiency of motor vehicles operations and their environmental impacts. These measures can be outlined as:
  TSM measures to enhance capacity and throughput, and traffic flow and operations; and
  TSM measures to restrain traffic flow and throughput.
- Transportation Demand Management (TDM) Measures- include a variety of measures to reduce individual transport and change transport demand types. Examples of TDM strategies include improving telecommunications, transit-oriented developments, land development, encouraging switching modes, ride-sharing promotion, and transit user subsidies, congestion pricing and other pricing schemes and reducing free and subsidized parking.

Table (5) (UNEP, 2001) summarizes options for transportation system management. It shows examples of where transport system management can be applied to reduce emissions by encouraging better use of resources.

SUMMARY AND CONCLUSIONS (Otto, 2003; Al-Yousfi, 2004; UNEP, 2005)

Reducing the pollution that emanates from vehicles require a comprehensive strategy, which may entail emissions standards for vehicles, clean fuels, energy systems innovation and refinement, vehicle maintenance programmes that minimize emissions, urban planning, as well as traffic supply and demand management measures.

Table 5. Summary of transportation management options.

Category	Examples
Capacity and Throughput-Enhancing Transportation Supply Management Strategies	New road construction
	Widening of existing roadways
	Creation of High Occupancy Vehicle lanes
	Street and parking management for more efficient goods delivery
	Computer controlled traffic management, including traffic signal timing
Flow and Throughput-Restraining Transportation Supply Management Strategies	Barriers or restrictions to traffic access
	Circulation rationing or licensing
	Narrowing street
	Increasing stops
	Applying contrasting and textured road surfaces
Transportation Demand Management	Increased telecommuting options
	Transit-oriented, compact, and mix-use development
	Ride-sharing promotion
	Transit user subsidies
	Congestion pricing
	Reduction of subsidized parking

The technological measures embrace a vast array of options, including the use of alternative and cleaner fuel sources and improvement of vehicle efficiency (both through improved design of new vehicles and retrofitting and routine maintenance of in-service vehicles). Potential improvements include reducing aerodynamic drag, rolling resistance and weight of vehicles, all of which have implications for fuel consumption and hence emission of GHG and local pollutants.

On the planning side, the Transport Supply Management (TSM) includes measures to optimize capacity, throughput and flow in order to reduce vehicular emissions. The Transport Demand Management (TDM) offers means of increasing mobility choices and incentives of using less (least) polluting modes of transport. Targeted commuting, which balances peak travel periods in urban areas, is one such technique, as is the improvement and augmentation of public transit schemes.

Land use planning can also be employed to reduce transportation demands and hence curtail air pollution emission. Proper zoning and urban planning and management (including infrastructure services networks, e.g., road systems design) should also maximize transportation efficiency, minimize congestions, reduce emissions and enhance air quality. These measures can be fortified by routine and systematic monitoring, inspection and enforcement regimens of vehicular emissions and ambient air quality impacts.

Table (6) summarizes all potential technological and management measures that can be considered for the improvement and mitigation of transport emissions and pollution impacts (UNEP, 2001).

Table 6. Summary of technological and management measures to improve the environmental performance of the transportation sector.

Instrumental or Regulatory Option	Focus (Target)	Expected on Transport	Expected Impact on Emissions
Carbon Tax	Fuels	Demand decrease Fuel substitution Substitution of transportation modes	Direct impact on carbon emissions Indirect impact on other emissions
Vehicle Specific Taxes	Vehicles	Demand decrease Substitution of vehicles Substitution of transportation modes	Indirect impact on carbon emissions and other emissions
Road Pricing	Driving intensity	Reduced traffic Reduced congestion	Indirect impact on carbon emissions and other emissions
Traffic Control Systems	Traffic flows	Increased fuel efficiency Reduced congestion Activity decrease	Indirect impact on multiple emissions
Grants/Subsidies for Technology Innovation and Penetration (Soft Loans)	Technologies	Increased technology penetration Reduced operation cost	Direct and indirect impacts on multiple emissions
Vehicle Maintenance Programmes	Vehicles efficiency	Increased fuel efficiency Decreased operation costs which can lead to increased activity	Indirect impact on multiple emissions
Fuel Economy Standards	Vehicles efficiency	Increased fuel efficiency Decreased operation costs which can lead to increased activity	Indirect impact on multiple emissions
Exhaust Emission Control Systems	Exhaust gases	Increased capital costs Changed fuel consumption	Direct impact on specific emissions
Public Investments or Grants to Infrastructure (Including Freight and Mass Transit)	Supply of transport services by different modes	Mode substitution Activity increase	Indirect impact on multiple emissions
Planning of Land Allocation and Industrial Zones	Transportation demand	Activity decrease or increase	Indirect impact on multiple emissions

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