TURNING THE RIGHT CORNER

Ensuring Development Through a Low-Carbon Transport Sector

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Foreword

Growth and development are primarily a matter of mobility. Mobility of people for access to employment, education and health, mobility of goods to supply the world markets that ensure the dynamism of economic activity. In our globalized economy, it is the infrastructure and transport services that underpin trade, linking production centers to consumption areas, integrating territories beyond administrative boundaries, and thus offering everyone the opportunity to contribute to value creation, as well as to enjoy its benefits.

So mobility has value. So much value, actually, that when looking into options on how to set the transport sector on a low carbon path, those cutting down on mobility can hardly be entertained, such is the risk that they would significantly undermine development. In other words, stop moving, emit less, is not an option.

Then the challenge becomes: how to progress towards a low-carbon mobility? And how do we finance such a transformation in transport patterns, so as to make it sustainable? And what will be the role of technology in helping along this route?

Those are some of the key questions this report seeks to answer. Or when the answer is not that straightforward, at least to provide some fertile avenues for further analysis and better understanding of the mechanisms through which transport may help make sustainable and inclusive green growth possible.

Transport is too often taken for granted. Without a deliberate policy agenda to steer the sector towards a sustainable future where mobility is provided to people and freight while simultaneously protecting the planet from increased congestion and ineluctable asphyxia, this evolution is unlikely to happen by itself. Or mobility will be curbed, under pressure from emerging crisis conditions, with development and growth being among the first casualties. And as so often in these situations, the poor are likely to suffer most, with social inclusion giving way to survival of the fittest.

So now is the time to think through those issues and propose clear policy choices, which will hopefully help chart a way towards the future we—and our children—aspire to live in.

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0. Overview.

Transport Efficiency Promotes Development and Protects the Environment

Affordable transport services are crucial for development. They connect rural areas to sales opportunities and inputs, and nations to export markets and foreign technologies. Affordability refers not just to consumer prices but to all costs to society: time losses due to congestion, the sometimes dramatic consequences of accidents, the health costs of local pollution, and the damage that severe climate events inflict on the population. Transport decisions, particularly those for infrastructure investments, will determine these costs for decades to come, offering opportunities to countries whose transport systems are not yet mature.

Recognition of climate implications in transport, unlike other sectors, has had a slow start. One reason is that the transition to a low-carbon context appears to be more costly than in other sectors. But broadening the policy agenda to shift behavior changes the cost picture completely, especially measures to reduce congestion, local air pollution, safety risks, and energy imports.

Policies to guide demand to low-emission modes and technologies must be part of investment programs and projects. Such policies can reduce transport demand in the longer run by changing the economic geography of cities and countries. But that will take close coordination of transport, environmental, and health policies. This report’s main messages are these:

- Climate policies should not compromise transport’s contribution to development.
- If past trends continue, transport greenhouse gas emissions will increase dramatically.
- Innovations in engine technologies will not produce deep cuts in emissions.
- To avoid a vicious lock-in, cutting emissions urgently requires a new modal
composition for infrastructure and transport services.

- Reducing transport's vulnerability to climate change starts with better maintenance and management of infrastructure.
- Climate change widens financing gaps in transport.
- Current carbon finance is inadequate to address transport's needs.
- Benefits to transport from broad sector reforms would reduce the cost of climate policies.
- Integrating supply and demand actions requires institutional change and coordination.

0.1. Climate Policies, Transport, and Development

Lower transport costs drive urbanization and growth. High local demand leads to higher productivity because unit costs for larger firms are lower and access to specialized inputs is easier. Lower transport costs increase competition in smaller cities and regions, further concentrating production and increasing productivity. Movement of workers to larger cities puts pressure on wages, leading to a new virtuous cycle of larger local markets, greater production scale, and higher real incomes.\(^1\) Putting development first, therefore, climate policies for transport should not come at the expense of mobility.\(^2\)

0.2. The Direction of Transport Greenhouse Gas Emissions

Because development and the demand for mobility go hand in hand, energy use in transport increases with per capita income. The main driver of increased fuel use is the expansion of roads, but high levels of national development are possible with very large differences in transport energy consumption. The high-income Asian countries, which developed rapidly after WWII, define the lower bound of per capita energy consumption (figure 1). Numerous European countries have low per capita energy consumption for road transport relative to income, and Canada, the United States, and some oil-producing countries have very high consumption. Some of the differences can be explained by geography, but others are due to energy demand policies and technology differences.

\(^1\) Krugman (1991).
Motorization has driven the expansion of roads and the increase in energy use. It accelerates in most countries at per capita incomes of $5,000 to $10,000 (figure 2). There is no direct link between motorization and development; small countries with high per capita incomes in particular have large differences in motorization.
Projecting patterns of motorization and energy use into the future, the transport sector would eventually become the main consumer of oil (figure 3). Absolute oil consumption would increase dramatically until 2030, and alternative sources of energy would have minor impact. Longer-term scenarios suggest that the trend would continue until the century ends. Deep cuts in transport greenhouse gas emissions through fuel substitution are expected to be possible with the emergence of new biofuel feedstocks that do not compete with food production and require less water—or as fuel cell cars become economically viable.

Figure 3. Transport Consumption of Oil Long-term

Oil consumption increases in the medium term...


... and in the long.

Source: Clarke (2007).
If today’s developing countries repeat what has happened in developed countries, almost all the increase in transport oil demand would come from non-OECD countries. China, India, and the Middle East would see the largest increase (figure 4). Progress in engine technologies would reduce fossil fuel consumption in some parts of the OECD, but such savings in non-OECD countries would be far exceeded by the rise in motorization.

Figure 4. Transport Oil Demand, OECD and non-OECD Countries, 2007–2030

* Includes residential, services, agriculture and other energy sectors.


0.3. The Effect of Technology Innovation on Emissions

Unlike other sectors, where mitigation is mainly about replacing the fuel-using technologies of a small number of users whose reactions are highly predictable, mitigating greenhouse gases in transport is a matter of changing the behavior of an enormous number of people. Billions of consumers make separate decisions about whether to use a car, which type of car to use, which type of fuel to use, and which length of trip to take. Reducing emissions in transport thus involves shifting a large number of consumers toward cleaner technologies.

Because climate change is a global policy problem, climate policies require global agreement. To achieve the 2°C cap on average global temperature increase over preindustrial times, by 2100
carbon prices will have to increase to $700 a ton.\(^3\) The more a country invests in roads, the more the carbon price will affect the price of a passenger-km or a ton-km. And the less a country has done to reduce transport greenhouse gas emissions, the more painful the transition to a low-carbon regime will be.

*Differences in European and North America auto technologies illustrate this point.* North America consumes four to six times more gasoline per head in transport than Europe. Why? Because Europe unilaterally implemented higher fuel prices. If all OECD countries had the low fuel prices of the United States, fuel use would have been 30 percent higher throughout the OECD. Conversely, if all countries had the high gas prices of Italy, the United Kingdom, or the Netherlands, OECD gasoline consumption would have been 44 percent lower, for an annual savings of 8.5 billion tons of CO\(_2\). If all countries had U.S. fuel prices, the OECD would have used more than twice as much gasoline (133 percent more) than if all countries had Dutch prices.\(^4\)

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\(^3\) Clarke and others (2007a).

\(^4\) Sterner (2007).
spillovers of technical progress in light-duty vehicles. The aviation fleet will reduce emissions in accord with international efficiency agreements and reduce its average fuel consumption from 4.6 liters per 100 revenue passenger-km to 2.6 liters in 2030.

Figure 5. The Optimistic View: Transport-Related CO₂ Emissions Through 2030

![Figure 5](image)

*Includes rail, pipeline, domestic navigation, international marine bunkers and other non-specified transport.


Figure 6. The Optimistic View: Technical Standards for New Vehicles

![Figure 6](image)

Pessimists expect a far slower spread of plug-in vehicles and electric cars and see high barriers to adoption of advanced vehicle technologies in developing countries.\(^5\) They assume that plug-in hybrids will be adopted only in developed countries due, for example, to the recycling risks of battery technologies and the high costs of infrastructure for alternative fuels. In developing countries, emission reductions must rely on advanced internal combustion engine technologies that can achieve 35 miles per gallon for gasoline engines and 37 for diesel.\(^6\) In the MiniCam model of the Pacific Northwest National Laboratory (PNNL), consumers and firms choose between different vehicles and modes of transport. Choices are driven not by technical vehicle standards but by a universal carbon price that holds for other sectors as well. The transport sector will, under the pessimistic assumptions about progress in vehicle technology, grow into the main emitter, even with a carbon price regime that stabilizes greenhouse gas concentrations at 450 ppm (figure 7). It takes the lead by 2050, when its emissions will have increased by 47 percent over 2005.

Pessimists expect that the prominence of transport as a greenhouse gas emitter could be amplified by rapid technical progress in the energy sector. A recent PNNL scenario based on the Global Change Assessment Model (GCAM), the successor to the MiniCam model, sees much greater potential for biofuel use in transport. The GCAM also covers agricultural production and land use, with biofuel production reacting to the carbon price.\(^7\) It is the first scenario to take into account how technical developments in different sectors interact through their impact on the carbon price. Even if there were large-scale use of biomass, however, transport might remain the main polluter, depending less on technical developments in transport than on the availability of carbon capture and storage (CCS). Without CCS, a high carbon price will lead to massive substitution of biofuels for gasoline and diesel. With CCS, much lower carbon prices are needed to get to the 450 ppm stabilization level, removing the pressure to find substitutes for fossil fuels (figure 8).

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\(^{5}\) Calvin and others (2009); Clarke and others (2007b).

\(^{6}\) Kim and others (2006).

\(^{7}\) Luckow, Wise, and Dooley (2010).
Figure 7. The Pessimistic View: Transport the Predominant Emitter by 2095, even with carbon pricing leading to a greenhouse gas concentration of 450 ppm

Source: Clarke and Calvin (2008).

Figure 8. The Pessimistic View: Transport and Carbon Capture and Storage

Source: Luckow and others (2010).
Without the rapid emergence and global adoption of low-carbon engine technologies, deep cuts in transport greenhouse gas emissions will depend on shifts in mode. Transport emissions can be reduced below the levels envisaged in the scenarios by shifting from

- road transport to rail and waterborne modes
- air transport to rail
- Individual car use to urban mass transit.

Transport is less emissions-intensive in countries were the role of roads is smaller (figure 9). The Republic of Korea, Singapore, Hong Kong SAR (China), and Japan are all at the lower bound. Countries with low-carbon transport demonstrate that a balanced modal structure is not correlated with low growth. In fact, the “development miracles” of the late 20th century have fairly low shares of road transport and low emissions per passenger-km and ton-km.

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8 This translates into a mirror image in per capita emissions in transport (see figure 1).
Finding alternatives to road transport will be a challenge for rapidly growing cities in developing countries. Megacities Singapore, Seoul, Hong Kong, and Tokyo have all combined accessibility and mobility with low emissions by directing transport toward a balanced modal structure. Thirty years ago in Hong Kong SAR (China), car ownership doubled in a decade, and time lost to congestion exploded. The integration of road building, a massive expansion of mass transit, and demand management halved vehicle ownership by 1985—by then 10 percent of the passenger cars were taxis—, drastically reducing travel times without making the city less attractive for business.\(^9\) It ranks second on the infrastructure index of the Global Competitiveness Report and second on its goods market efficiency index.

0.4. The Effect of the Modal Composition of Transport

The durability of transport equipment, the longevity of its infrastructure, and high fixed costs mean that current investments lock in the modal structure of transport for decades. The high costs that would result from failing to establish a low-carbon transport

\(^9\) Cullinane (2002).
infrastructure system early on would persist for many years, and the inertia of consumer preferences for many transport attributes other than energy efficiency exacerbates the infrastructure lock-in. That calls for prompt action because of the long time lags between policy implementation and sector changes. Slow changes in the modal composition of infrastructure drastically increase the costs of mitigation because the capital stock has no alternative use. To change travel behavior and the modal choices of users of transport systems thus requires long adjustment periods.

Consumers who buy a vehicle incur high fixed costs. A change in fuel costs or taxes affects only a small part of total expenditures on the car. With changing fuel prices, fuel-inefficient cars lose value on the resale market. The lower price on the resale market translates into a capital loss if the car is sold. If that loss cannot be recaptured by switching to a more fuel-efficient vehicle, substitutes for energy-inefficient transport equipment will be introduced only with the technical depreciation of polluting vehicles.

Most roads are used for more than 70 years, and the expected lifetime of Dutch bridges is 84 years. Once investments have been made, the expenditures are sunk. Economic analysis of a switch from an existing infrastructure network to a new one—say, with a different modal structure—would compare the costs of operating the current system with the high costs of new networks. If past national policies have produced heavy car-dependence, modal shifts are very costly in the short term. But countries at early stages of development can reduce future transport costs substantially by investing in infrastructure that supports low-carbon modes.

The immediate path-dependence of infrastructure induces a secondary path-dependence in settlement patterns. Reliance on road transport and a high share of individual car use favor dispersed settlement, with jobs widely separated from residential locations and long commuting distances. This further constrains the opportunities to reduce the greenhouse gas emissions of urban transport. Changing the modal composition of urban transport then faces the barrier that mass transit

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10 Lecocq, Hourcade, and Ha Duong (1998). 
cannot serve dispersed settlements. Shalizi and Lecocq (2009) describe the different dimensions of transport infrastructure lock-in. The U.S. interstate highway program of the 1960s, for instance, determined later investments in state road projects, strengthening road sector network effects and pre-empting expansion of other types of infrastructure like rail. Shalizi and Lecocq see the sprawl of U.S. cities as induced by the build-up of the interstate highway system.

The consumption inertia in transport is reflected in a low price elasticity of transport demand—for developed countries between 0.23 and 0.27. That is, a 10 percent increase in fuel prices would reduce fuel consumption by 2.3–2.7 percent. The temporary lock-in of consumer decisions for vehicle choice is evident in long-term price elasticities that are three to four times higher than short-term elasticities. The difference reflects the time required for consumers to change their transport equipment, and possibly their residence. The emphasis of U.S. infrastructure policy on roads has reduced transport’s responsiveness to price signals, such as the costs of carbon.13

A more flexible modal composition of transport infrastructure increases the opportunities to respond to future changes in energy and emission prices. The price elasticities for European countries well endowed with public transport are 20 percent above the global average.14 And the more the flexibility, the smaller the future adjustment costs and the risk that climate action will increase transport costs.

0.5. Transport Adaptation Needs

Transport is not simply a major emitter of greenhouse gases and contributor to climate change. It is also threatened by it. Climate policies for transport have to address two risks: the physical risk of transport disruptions due to extreme weather events, and the policy risk of an emission-intensive transport sector, with limited opportunities to respond to future climate policy imperatives.

Climate change, particularly the higher frequency of extreme weather events, will disrupt transport services more often. Storms and floods will damage

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13 Hughes, Knittel, and Sperling (2006).
costly infrastructure and interrupt access to villages and cities, sometimes for days. Interruptions to commuting and intermediate goods deliveries will lead to production losses. Inventories to protect production against climate-induced supplies irregularities will bind up large amounts of capital. With transport services less reliable, trade relations will become less attractive, and the benefits of a greater division of labor will not materialize. Trucking and other transport-intensive sectors might relocate to regions where they will be less exposed to extreme weather events. If, then, the transport sector is not made more resilient to changing weather conditions, the lower reliability of transport services could have huge development costs.

Adaptation will reduce the risk of extended interruptions to transport. Adaptation concerns management of infrastructure in the short run, and designs and location criteria for infrastructure facilities in the longer run. Threatening the reliability of transport are higher average temperatures, fewer very cold days, earlier spring thaws, and later autumn freezes. Droughts will become more likely in continental areas, while the intensity of rainfall will increase, particularly in coastal areas. Accelerated hydrological cycles will further intensify rainfall and wind storms.

These climatic and hydrological changes will affect infrastructure operations and maintenance. Extreme temperatures can expand and erode surface pavements and buckle rail tracks. Intense rainfall slows road and rail traffic, and flooding completely disrupts it. In aviation, climate change requires larger drainage systems to cope with more intense rainfall, and longer runways and load restrictions to respond to the higher heat during liftoff.

Climate change will exacerbate the deficits in infrastructure administration common in many countries. In many countries maintenance services are underresourced. The value of losses of infrastructure assets often exceeds by far the maintenance spending required to avoid them. Climate change will increase demand for maintenance services to ensure that transport services stay reliable. The follow-on effects of increased landslides, flash floods, and erosion of land transport services will also require expansion of emergency services to avoid long

15 Foster and Briceno-Garmendia (2010).
interruptions. Because emergency services are often financed from maintenance budgets, more weather-related emergencies would worsen maintenance fiscal deficits.\(^\text{16}\)

*Because the consequences of climate change for transport will vary greatly among geoclimatic regions, adaptation must be specific to local conditions.* The smaller the geographic area, the more uncertain are any predictions related to climate change, and fine-tuning current climate models will not entirely eliminate the uncertainty. Recurrent assessments of weather-related risks should generate as needed new regulatory frameworks, new institutions, and new policies. The process should periodically produce an action plan, updated in the light of new information on local climate conditions and the consequences for transport.\(^\text{17}\)

*The higher demand for maintenance may alter the tradeoff between capital investment and maintenance.* The higher costs of more resilient new investment could bring high future savings in retrofitting or more frequent and costly maintenance. Resolving this tradeoff depends on institutional changes to increase maintenance capacity.

*The longevity of transport infrastructure calls for a long planning horizon and a process to update decision rules for investing in infrastructure.* A first low-cost step is to change the decision rules for locating new facilities. Assessing rising risks from changing weather conditions and avoiding high-risk sites is economical insurance against climate-related disruptions. But inertia in planning locations can have very high costs. Inundations of more than one meter completely destroy roads. With its current location decisions, for example, Bangladesh risks losing more than 10,000 km of roads.\(^\text{18}\)

*The biggest challenge for long-term infrastructure planning is to avoid looking only at the past.* Because local climates can change abruptly, past changes may not inform what might happen. Standard updating procedures—based on recording weather events and revising the probabilities of their occurrence—can distract from crucial adaptation measures. What is needed are decision tools that can incorporate information from forward-looking nonlinear

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\(^{16}\) World Bank (2010b).

\(^{17}\) Fay, Ebinger, and Block (2010).

\(^{18}\) Dasgupta and others (2010).
Robust decision making, a process designed for use when probability distributions are unknown, gives proper attention to the possibility of high-impact events even if there is a very low probability that they will occur.\(^\text{19}\)

\textit{In the longer run, new building codes need to counter short-termism and the temptation to save on capital expenditures.} Short-termism manifests itself in overdiscounting the future costs of retrofitting or replacement. New standards can be put in place if new facilities are built and there is progress in predicting climate change.\(^\text{20}\)

\subsection*{0.6. Climate Change and Transport Financing Gaps}

\textit{Adaptation and mitigation policies will lead to more incremental financial demands.} Global scenarios suggest that a large part of mitigation is in vehicle substitution, a cost borne by private households. Yet most incremental costs for adaptation are infrastructure costs. Because the scenarios underrate the modal shift in cutting greenhouse gas emissions, they also underestimate the added costs of redirecting the sector to less road and more rail, waterway, and nonmotorized transport. For interurban transport, the rail infrastructure costs per passenger-km for the San Francisco–Los Angeles corridor are more than twice aviation infrastructure costs, and 15 percent higher than the costs of highways.\(^\text{21}\) Within cities, the costs for light rail infrastructure alone are at least three times those for bus systems.\(^\text{22}\)

\textit{Incremental financial needs for transport infrastructure will add to the deficits in the sector’s fiscal resources.} Many studies have found underinvestment in transport infrastructure, independent of the incremental costs of responding to climate change.\(^\text{23}\) And in many countries, chronic underinvestment in transport maintenance has reduced infrastructure asset values by more than the required maintenance would have cost.\(^\text{24}\)

\textit{The incremental costs of adaptation compound these deficits.} Funding requirements for adaptation are estimated by assessing how much new investment will be needed in infrastructure, multiplying that value by

\begin{itemize}
  \item \textsuperscript{21} Levinson, Kanafani, and Gillen (1999).
  \item \textsuperscript{22} Zimmerman (n.d.)
  \item \textsuperscript{23} Bougheas, Demetriades, and Mamuneas (2000); Canning and Bennathan (2000); Esfahani and Ramirez (2003).
  \item \textsuperscript{24} Foster and Briceno-Garmendia (2010).
\end{itemize}
the share of infrastructure considered vulnerable, and multiplying that result by a mark-up factor for likely increases in infrastructure facilities costs.\textsuperscript{25} A median value for the transport share in national infrastructure investment is 20 percent. Using that assumption, the global incremental financial demands for transport would be $1.6–$26 billion a year (the wide range is due to differences in definitions of what constitutes infrastructure vulnerability). Another way of identifying the incremental funding requirements is to use cost functions that couple macroeconomic data with engineering information on expected infrastructure cost increases for infrastructure. A recent World Bank study using this approach arrives at an estimated $10 billion for additional investment and maintenance costs. The incremental annual adaptation investment is estimated to be $7.2 billion a year until 2030, which is a small share of the baseline investment.\textsuperscript{26}

These estimates could underestimate the true incremental costs for two reasons:

- They neglect the infrastructure gaps of developing countries; closing those gaps will increase the additional capital costs. They also neglect the fact that capital costs will be higher because investments must reduce future maintenance requirements.
- They implicitly assume that current maintenance expenditures are optimal for maintaining the value of transport infrastructure. But actual expenditures are far lower than what is needed. Fay and Yepes (2003) estimate that true maintenance needs are 3.3 percent of GDP in low-income countries, 2.5 percent in lower middle-income countries, and 1.4 percent in upper middle-income countries.\textsuperscript{27} With actual maintenance expenditures often below 1 percent of GDP, the true deficit in maintenance expenditures might thus be large.

\textit{The estimated incremental costs for mitigation are far higher}. The only estimate for additional spending to mitigate transport greenhouse gas emissions is that of the IEA: $100 billion a year between 2010 and 2020, moving up to $300 billion in 2030. Most of the additional spending is for investment in

\textsuperscript{25} UNFCCC (2007).
\textsuperscript{26} World Bank (2010c).
\textsuperscript{27} Estache and Fay (2010).
low-emission vehicles. That explains the exponential increase after 2020, which is the point at which plug-in hybrids and electric vehicles would become economically viable (leading to an increment of $52–$159 billion). For low-income and middle-income countries, the scenario underestimates the additional infrastructure investment needed to ensure seamless multi-modality of infrastructure because it assigns only a small role to modal shifts.

0.7. The Inadequacy of Current Carbon Finance

Carbon finance covers only a very small share of the additional costs for transport adaptation and mitigation activities. Transport does not get much from the Clean Development Mechanism, the most important carbon finance mechanism for curbing greenhouse gas emissions. Of more than 2,200 registered projects, only three are transport projects. The greenhouse gas savings of all three projects add up to less than 300,000 tons of CO₂-equivalent (CO₂-eq), with a mere 0.1 percent of investments. Within the accounting and evaluation standards of the Clean Development Mechanism and its focus on reducing emissions by technology substitution rather than behavioral change, the transport projects look to be less effective in reducing emissions than projects of other sectors.

The transport sector fares not much better with the Global Environment Facility, which provides grants to innovative projects that benefit the global environment; in the past 20 years only 28 transport projects have been approved, for a total of $182.4 million (6.4 percent of all resources allotted). Transport figures more heavily in the country programs of the Clean Technology Fund (CTF), which has a broader multisectoral approach. The CTF provides limited grants, concessional loans, and partial risk guarantees to help countries scale up clean technology initiatives to transform their development path. In half the CTF country plans, transport is a priority, though its share varies considerably between countries. Transport receives on average 16.7 percent of CTF funding and 23 percent of the total investment, including leveraged government funding, multilateral development bank financing, and private investment. Total
Transport investment (CTF and leveraged) is $8.4 billion.

The carbon finance resources now spent on transport are a tiny share of needs. If transport policies follow a narrow climate change agenda, the high costs of climate action in transport make it unlikely that this will ever change. So far the narrow agenda focuses on reducing CO₂ by changing the technology. If the benefits of less local air pollution, reduced congestion, and greater transport safety are also considered, the prospects for more climate finance will improve. Projects confined to the supply side, without demand incentives, risk a mismatch of supply and demand. They are likely to wastefully underuse transport capacity. It would be more effective to incorporate demand measures to induce behavioral change—reducing uncertainty about the balance of supply and demand and increasing the domain of actions eligible for carbon finance. Thus a broad transport reform agenda that prices in climate, health, and congestion costs would better balance supply and demand and reduce emissions.

0.8. Transport Reforms and Climate Policy Costs

Measures to reduce greenhouse gas emissions will reduce congestion costs, local air pollution, and safety risks. Reducing these social impacts of transport will also reduce greenhouse gas emissions. Educating users about transport environmental, safety, and congestion costs will reduce its social costs. Without policies to do so, transport users have no opportunity to learn about health costs due to air pollution and no incentives to change their behavior to reduce them. The policy deficit in making such costs felt is enormous. The highest social costs are due to

- Congestion
- Local air pollution
- Road accidents
- Greenhouse gas emissions

Efforts to reduce these costs do more to reduce greenhouse gas emissions than a narrow climate change agenda. Moreover, reducing them would produce revenues to finance the transition to low-carbon transport.

An obvious reform step, one that would reduce the social costs of transport and

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28 Parry (2007).
create fiscal opportunities, is to remove subsidies that give the wrong signals. Most important are subsidies for gasoline and diesel. The U.S. pump prices for gasoline and diesel are a good approximation to tax-free and subsidy-free consumer prices. In comparison, many developing countries subsidize gasoline and diesel, with substantial consequences for government spending. The Islamic Republic of Iran could save $20 billion a year, and Saudi Arabia $12 billion, by removing transport fuel subsidies. Poorer countries could also have major savings. If it cut its transport fuel subsidies, Myanmar could save more than $300 million. The Islamic Republic of Iran and Colombia are now making substantial strides toward reducing transport subsidies.

The most direct way to convey the costs of transport related to climate change is to price carbon. A gallon of gasoline contains 0.0024 tons of carbon. Hypothetical carbon prices of $20, $30, or $300 per ton of carbon would translate into an additional 5, 12, or 72 cents per gallon of gasoline. The carbon price would thus change consumer prices moderately. If there were no changes in travel behavior, the hypothetical carbon charges would bring the United States annual revenues of $10 billion, $24 billion, or $145 billion.

The fiscal consequences of charging for local air pollution differ—in some cases, as in the United States and European Union, they are very high. For the Los Angeles area, containing the health costs of local pollution ranged from 1 to 8 cents per mile in 2000. Given the number of vehicle miles driven in the area, such charges would produce revenues of $400 million to $3.3 billion. The health costs for Beijing were estimated at $3.5 billion in 2007, equivalent to 3.5 percent of local GDP. Similar estimates can be made for congestion and accident costs. Signaling the true costs of transport to users could open considerable opportunities to address the chronic underfinancing of transport and the incremental costs to transport of climate policies.

Those measures would also generate substantial income and welfare benefits. By maximizing the development gains from limiting greenhouse gas emissions, local air pollution, and the costs of

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29 GTZ (2009).
30 Parry, Walls, and Harrington (2007).
32 Creutzig and He (2009).
congestion and accidents, they produce not only revenues but also net benefits for consumers. Rough estimates suggest that the revenue potential could even be higher than the additional funding required for the transition to a low-carbon regime. If so, making transport more efficient would even make it possible to reduce taxes that are harmful to growth and welfare. A broad reform agenda to make the sector efficient provides far more powerful incentives to reduce greenhouse gas emissions than a narrow climate policy program that implicitly assumes that all other inefficiencies have been removed. An efficient transport sector thus protects the environment and advances development—win, win.

0.9. Integrating Supply and Demand

Climate policies in transport have suffered from a disconnect between infrastructure and environmental policymaking and implementation. They have focused on increasing the capacity of infrastructure for low-emission modes and setting regulatory standards. Yet the less the horizontal coordination between supply and demand policies, the greater the uncertainty about how emissions can be effectively reduced. The expansion of mass transit in the United States, for example, led to higher average emissions per passenger-km in public transport than in individual car use due to smaller loads for buses and rail systems.\(^3\) Isolated subsectoral agendas can thus have unintended negative effects. By contrast, London’s congestion charges were accompanied by a massive increase in bus capacity, which avoided the mismatch. The broad sector reform proposed here requires horizontal coordination not only between different aspects of transport policymaking but also between departments as diverse as finance, land use regulation, security, and health.

The different spatial dimensions of the social costs of transport require vertical coordination of different jurisdictional levels. Because greenhouse gas emissions create global damage, ideally they should be addressed globally. The scenarios of the PNNL show how globally agreed carbon prices could lead all emitting sectors to lower their emissions to arrive at targeted atmospheric concentrations. The local health costs of air pollution can differ greatly by city and region. Policy measures to address these costs should

\(^3\) Small and van Dender (2007)
thus differ locally. Congestion and transport safety are similarly local.

*Competition between countries, regions, and cities requires vertical coordination to avoid a race to the bottom.* Even if there were a collective agreement on climate action, it could be difficult for individual governments to commit to climate policies. The difficulty is that they want to benefit from collective climate actions without reducing emissions. To counter this, higher jurisdictions must frame and coordinate local policies to reduce greenhouse gas emissions. The Indian Sustainable Urban Transport Project is an example of a national strategy to avoid a race by cities to the bottom.\(^{34}\)

*Individual projects to reduce the carbon intensity of transport need to be combined with programmatic policies.* The difficulty of including transport in carbon finance mechanisms like the Clean Development Mechanism illustrates this point: Uncertainty over whether bus or rail projects will attract car users or minibus users could prompt the conclusion that transport investments are less effective than other sectors in reducing emissions.

Appropriate Mitigation Actions (NAMAs) recognizes that programmatic and multisectoral policies can enhance the role of transport role in global climate policy.

\(^{34}\) World Bank (2009d).
Overview - References


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1. Transport, Mobility, Emissions, and Development

The transport sector is one of the biggest contributors to greenhouse gas (GHG) emissions, and unless there is a shift to low-carbon transport, technology that emits less GHG, and reduced transport use, it will remain so. Whether it can reach emission targets depends on technical opportunities, user behavior, and infrastructure investment. Continuing business as usual in the face of global climate change could result in higher costs, less mobility, less transport support for development, and greater disruption not only of transport services but also of production reliant on these services.

So far, policies have failed to recognize the centrality of transport role in global climate change: Joint Implementation initiatives do not include a single transport project; the CDF has only 3 transport projects out of 2,587; and the Global Environmental Facility (GEF) has only 30 transport projects out of 2,533. One reason for the lack of new transport projects is their high cost. However, accounting for synergies between related efforts in the sector to reduce traffic congestion, air pollution, and dependence on fuel greatly increases the cost-effectiveness of reducing transport emissions.

1.1. The Relationship of Mobility and Development

Historically, affordable transport has driven development, with dramatic changes in transport kicking off rapid economic development. Access and mobility make it possible to share facilities, goods and services, and knowledge, thus increasing productivity (box 1.1).

- Development depends on infrastructure—marketplaces, schools, hospitals, and public administration offices, for instance—to provide basic services, but infrastructure requires substantial fixed investment. A reliable and affordable transport system increases the number of users and thus reduces fixed costs.

- If transport costs are reduced, workers are more likely to commute or migrate to jobs in larger cities. The larger the local market, the more efficiently consumer goods and inputs to production are produced. The geographic concentration of production made possible by lower transport costs expands opportunities to exploit scale economies.

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35 Parry (2007).

Despite progress in communication technologies, the transfer of knowledge and experience still depends on face-to-face communication. Transport increases productivity by creating more opportunities for sharing technical and organizational knowledge, which is crucial to the invention or improvement of products. Ensuring mobility, and thus the opportunity for direct sharing of knowledge, is a challenge in increasingly congested megacities, particularly in developing countries.

37 For example, Leamer (2007).
Box 1.1. Characteristics of the Transport Sector

The transport sector has increasing returns to scale: higher demand reduces its costs. Coordinating freight trips and balancing irregular demand for deliveries increase returns for the logistics industry (figure A1.1). In the maritime sector, larger container ships reduce ton-km costs.

There is a strong positive correlation between passenger-km traveled and average incomes (figure A1.2). The United States consumes the most passenger-km by far. Switzerland, where the average income is only slightly lower than in the United States, consumes just over a third of the U.S. passenger-kms. Some small countries, such as Lithuania, consume a high level of passenger-km, whereas some middle-income countries where income has recently surged, such as Korea, have kept passenger-km remarkably low.

In addition to per capita income, the size of a country, the history of links to former Soviet Union countries, and the history of rail infrastructure policies all affect the rail share of freight transport (figure A1.3; outliers with very high rail freight transport—Kazakhstan and the United States—have been excluded from the figure).

Across countries, differences in rail passenger-km mirror differences in road passenger-km (figure A1.4). Switzerland is the prototypical country with a high per capita income and high rail passenger-km but low road passenger-km. Compared with other rich countries, the United States has low rail passenger-km. Korea has kept rail passenger-km high throughout its rapid economic development. Former Council for Mutual Economic Assistance countries that have emphasized rail transport still have high rail passenger-km.

Car ownership typically increases dramatically when countries reach an average income of $5,000 in 2000 values (figure A1.5). Motorization in Mexico shot up at this per capita income point; but Singapore, the Republic of Korea, and Taiwan, which have had high income growth in recent decades, have kept motorization low. Some countries, such as Switzerland, that have relatively low road passenger-km in relation to incomes nevertheless have high car ownership.

A similar picture holds for passenger car density (figure A1.6). Some small countries, such as Luxembourg and the Baltic states, have a high number of cars, both in absolute terms and relative to their population and income. The rapidly developing East Asian countries stand out for their low passenger car density. India and China have low per capita incomes but a rapidly growing middle class whose demand for cars is rising. Brazil and Russia have large populations likely to reach the income level at which car ownership increases dramatically, although their passenger car densities per 1,000 people were still low in 2003, with India at 8, China at 10, Brazil at 131, and Russia at 161.
1.2. Climate Risks from Transport

The transport sector emits the greenhouse gases CO₂, N₂O, and CH₄. Since N₂O and CH₄ emissions are small, most GHG emission inventories estimate CO₂ emissions only. In 2006 transport accounted for about 14 percent of global GHG emissions. This is equivalent to 18 percent of global CO₂ emissions and 24 percent of CO₂ emissions from energy-related sources.

Within the sector, road transport accounts for the largest share of emissions at 76 percent, followed by air transport at 12 percent and water transport at 10 percent (figure 1.1). From 1971 to 2006 global transport energy use rose steadily at 2–2.5 percent a year, about the same as economic growth.

Behind these figures are drastic differences between countries in absolute and per capita energy consumption. Per capita energy use differs by a factor of 40 to 50, and the type of fuel used also differs. These differences hold even among the main consumers of fossil fuels—Australia, Europe, Saudi Arabia, Canada, and the United States. For example, Europe uses more diesel fuel per capita than North America. Many African countries use less than 70 kilotons oil equivalent (ktoe), while the United States, Canada,

Saudi Arabia, and Australia have per capita consumption of 1,200 to 5,000 ktoe (map 1.1).

Figure 1.1. Total Transport CO₂ Emissions, by Transport Mode


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40 World Bank (2009).
Globally, transport energy use has more than doubled since 1971, although its distribution across road, rail, aviation, and maritime transport has been fairly constant. But regional patterns of transport have changed. The road sector grew at the same pace as transport over the last two decades in developed countries, but it grew much faster, at 3.3 percent annually leading to a doubling in twenty rather than forty years, in non-OECD countries. An increase in international aviation in the 1990s dominated changes in developed countries, a trend interrupted only briefly by the downturn of aviation after 9/11.

Much of the difference in per capita fuel consumption stems from differences in incomes, but there are also substantial differences between countries with similar incomes, reflecting differences in transport services consumed per capita and types of fuel. International differences in motorization and passenger-car density are paralleled in the relationship between per capita incomes and per capita energy consumption. Hong Kong, Singapore, and Japan are examples of countries with low energy intensities that have seen rapid development in recent decades. As for fuel, the transport sector will generally remain heavily dependent on oil and will be the largest consumer of energy by 2030, increasing its consumption by about 50 percent. Emissions in North America, Europe, and Japan are expected to decline as more fuel-efficient cars are introduced and as car ownership reaches saturation. Emissions are expected to
increase most in China, India, the Middle East, and Latin America (figure 1.2). A comparison of per capita emissions again shows large differences between high-income countries. These energy use differences translate directly into emission differences.

Figure 1.2. Actual and Projected Transport CO$_2$ Emissions, 1980–2030

1.3. Dealing with Inertia in Infrastructure

Because transport infrastructure must be built to last, early action is needed to adapt what is already in place to likely changes in climatic conditions (and technologies) and to mitigate the kinds of problems aging infrastructure can cause.

1.3.1. Immediate Steps to Adapt

Transport infrastructure has a long lifetime. The effective lifetime of roads is 25 to 111 years, and most last more than 70 years. Bridges are expected to last at least 100 years. Since the climate is likely to change over that long a time, transport infrastructure must be made resilient to such changes.

Climate change threats include increasing mean temperatures, more frequent heat waves, more pronounced freeze-thaw cycles, heavier precipitation, stronger winds, and greater storm surges and wave heights. High temperatures can cause road surfaces and rail tracks to deform, floods and snowfalls can paralyze surface transport, and droughts can interrupt waterway transport and destabilize building foundations. Storm surges threaten harbor facilities. Rising sea levels may necessitate relocating infrastructure completely.

A major threat to road transport is landslides. In Malaysia, for example, the cost of landslides has increased dramatically (figure 1.3). Costs spiked there in 2003 when a landslide closed the highway at Bukit Lanjan in Selangor, Malaysia, precipitating a half-year of traffic congestion, road closures, and diversions in the Klang Valley that made this landslide Malaysia’s most costly to date.

Changes in logistics could cushion extreme weather events. Maintaining larger inventories and more location choices could avoid irregularity in transport times, which drive up distribution costs. The cost of importing goods to the United States, for instance, is estimated to be 55 percent of their production value. Higher logistics cost would be the equivalent of higher value-added taxes, which would adversely affect interregional and international trade.

41 Haraldsson and Jonsson (2008).
Transport maintenance is already widely underfinanced and neglected, and will become more so with climate change. Better emergency services could save considerably on maintenance budgets. For example, clearing roads and railways faster after landslides or heavy snowfall could save days of production losses. Infrastructure maintenance and emergency services need serious reform.

Some transport agencies have started to systematically collect information on how climate affects transport. Transit New Zealand, for example, took climate change effects into account as it planned, constructed, and maintained its state highway network as mandated by the 2004 Resource Management (Energy and Climate Change) Amendment Act. A monitoring system tracked how climate weather affected bridges, culverts, causeways, coastal roads, pavement surfaces, surface drainage, and hillside slopes. Of major concern was the threat to highways from a rise in sea level, coastal storm surges, and more frequent and more intense rainfall. The data allowed Transit New Zealand to assess infrastructure vulnerability to see whether retrofitting was needed. The conclusion was that it was less economical to retrofit bridges and

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43 National Research Council (2008).
culverts than to repair them as needed.44

Historical data may not reliably predict climate change. Many climate models warn that weather changes may not be smooth but occur in discrete jumps. To protect transport from nonlinear changes, adaptation policies should be anticipatory.

The total costs of adaptation are calculated roughly as percentages of gross fixed capital formation. The UN Framework Convention on Climate Change (UNFCCC) has estimated that gross capital formation will be $22.3 trillion in 2030,45 taking into account the following:

- Munich Re estimates that 0.7 percent of the gross addition to capital formation is vulnerable; the Association of British Insurers estimates 2.7 percent.
- Of the resulting totals, 5–20 percent are capital costs for adaptation, that is, $53–$650 billion. The estimates assume that infrastructure deficits in developing countries will persist and that adaptation money would thus go to developed countries with larger infrastructure endowments.46 However, if infrastructure capacity in developing countries were to expand,47 the cost of adaptation in Africa would increase from $370 million to $12.3 billion, roughly in line with the World Bank estimates of Africa’s infrastructure deficits.48
- Geographic and climatic conditions as well as the local economy’s transport intensity will determine the transport share in these investments. The UN Millennium Project expects road financial needs to be about 20% of total infrastructure needs. Global transport adaptation needs, according to the UNFCCC estimate, range from $30 billion to $130 billion. A recent World Bank study estimates the annual cost of transport adaptation to be $11 billion to $18 billion.49

Data collection and improvement in maintenance and emergency responses to climate events are self-financing, the great uncertainty of future damages notwithstanding. Improved maintenance brings great benefits to developing countries independent of climate change.50 Further adaptation will then use local weather knowledge to inform design standards, use of materials, and location decisions.

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45 UNFCCC (2007).
46 Parry and others (2009).
47 Sachs and the UN Millennium Project (2005).
48 Foster and Briceno-Garmendia (2010).
49 Hughes, Chinowsky and Strzepek (2010).
50 OECD/ECMT Transport Research Centre (2007).
1.3.2. Early Action and Sector Inertia

While transport is central to mitigating carbon emissions, there are several impediments to making changes. The first is that because of its high sunk costs, infrastructure cannot be changed overnight. The second is the technological inertia in both transport mode and infrastructure design. The third is the land use nexus: that is, regulations related to construction, land use, urban planning, and so on that affect everything from settlement patterns to consumer behavior. Moreover, inconsistent energy pricing policies reinforce inertia that resists change.

The intent of transport adaptation is to reduce the negative impact of climate change on access and mobility. The Copenhagen Accord (2009) expanded the concept of adaptation to include mitigation, with serious consequences for transport. If mitigation leads to higher carbon and vehicle prices, demand could shift from one transport mode to another. Some infrastructure investment would thus become adaptation investment. Because it is uncertain how a local climate will change, current measures are often reactive rather than anticipatory and largely directed to reducing maintenance costs. Some countries, in fact, use up most of their maintenance budget reacting to weather events. Responding to landslides in Morocco, for example, uses 50 percent of the road maintenance budget.51

1.3.2.1. The Forces Behind Transport Sector Inertia

**Infrastructure inertia**: Transport infrastructure facilities tend to be large-scale, lumpy investments with high fixed costs. Capital stock turnover is low because high sunk costs make premature removal of capital costly. That is why inertia is usually modeled within integrated assessment models (IAMS) as a cost multiplier function of capital turnover increase.52 Consequently, changing the modal structure between roads, rail, aviation, and waterways depends on solid economic policies, especially appropriate pricing policies, such as subsidies and taxes. Because infrastructure expenditures are sunk, the opportunity cost of transport capital stock depends on maintenance. The cost of shifting transport services to low-carbon modes thus unfairly compares the marginal costs of reducing emissions within the carbon-intensive transport mode to the full (infrastructure plus operations) cost of shifting to an innovative, low-emission mode. For instance, power station networks for recharging batteries of electrically powered cars require high fixed investment. Thus, the cheapest option would appear to be marginal changes to existing infrastructure rather than investing in a new low-carbon infrastructure. However, climate change uncertainty and inertia argue for early mitigation. Socioeconomic inertia increases the cost of accelerating emissions reduction as initial targets

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51 World Bank (2010).

52 Lecocq, Hourcade, and Ha Duong (1998).
tighten up. At some point expected costs exceed the costs of premature capital removal, thus making early, forceful mitigation measures profitable. Any sound comparative economic analysis must therefore take into account inertia if it is not to omit relevant low-carbon investments.

Technological inertia: Incentives to densify the existing grid arise mostly from technology lock-in and network effects that increase the value of existing services when demand for such services grows. For example, the U.S. Interstate Highway Program launched in the 1960s has largely determined later investments in state road projects at the expense of other transport, such as rail. Energy pricing policies that either subsidize fossil fuels or do not reflect the true social cost of carbon discourage innovation in energy-saving technologies and encourage consumer inertia in favor of carbon-intensive transport.

Built-environment inertia: Besides moving people and goods, transport infrastructure fosters economic development and shapes the pattern of a territory. For example, the sprawling pattern of U.S. cities may be an induced effect of the interstate highway program. Thus transport infrastructure must be considered as just one aspect of broader public policies for land use, regional development, and sustainable development. Changing the regulatory framework is a prerequisite to infrastructure change, although the difficulty of tracking the complex interactions between development and infrastructure planning tends to work against radical change. Early action is needed to overcome inertia and move the sector gradually to a low-carbon state. Inertia toward change stems from three factors: transport services depend on infrastructure, consumers value certain transport services that are weighted against energy savings and lower emissions, and historic infrastructure and energy-related transport policies on the demand side determine current differences in emissions.

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53 Ha-Duong, Grubb, and Hourcade (1997).
54 Economides (1996).
55 Shalizi and Lecoq (2009).
56 Shalizi and Lecoq (2009).
1.3.2.2. Past Infrastructure Policies and Transport Emissions

Building infrastructure promotes self-reinforcing development. How? (1) Investments in transport infrastructure are normally large-scale, lumpy, and have high fixed costs. (2) Infrastructure has a long lifetime, extending over generations if properly maintained, which means long-term forecasting of demand for services and of the capacity needed to meet that demand. (3) Expenditures for infrastructure are sunk; once infrastructure is in place, it cannot be put to another use. Transport infrastructure also creates secondary investments in housing and other urban infrastructure that make changes in it even more costly.

Policies to change infrastructure capacity or the structure of roads, rail, aviation, and waterways are thus costly. Because infrastructure spending is sunk, the opportunity cost of transport infrastructure stock depends on maintenance. Any economic analysis of the shifting of transport services to low-carbon modes will thus compare the marginal costs of reducing emissions within the high-carbon sector to the full (infrastructure plus operations) costs of shifting to a low-emission mode.

Transport infrastructure investment also largely determines settlement and land use. Prioritizing car use, for example, leads to dispersed settlement because low transport costs invite people to move to areas distant from their jobs and retail centers where housing is less costly. U.S. household data suggest that suburban households drive 31–35 percent more than urban residents.57 Dispersed settlements are more difficult to serve by mass transit. In the United States, for example, the share of mass transit passenger miles relative to other modes has been falling steadily for 30 years.58

How responsive users are to fuel cost changes and carbon taxes is an indicator of transport inertia. There is a vast literature measuring the short-run elasticity of gasoline demand. A review of 300 studies for the United States and other developed countries found a median short-run price elasticity of −0.23.59 In other words, a 10 percent increase in fuel price would reduce gasoline consumption by 2.3 percent. An even higher estimated −0.27 elasticity for European countries reflects a higher share of nonmotorized transport and more public transport.60 Long-term elasticities are in the range of −0.6 to −1.0, about three times higher than those for the short term. The higher long-run elasticities are influenced by consumers moving in the shorter run to cars that consume less fuel or to residential locations that require less vehicle-km travel, and in the longer run making residential location decisions that result in shorter commuting and retail trips. Notably, transport has become less responsive to emission cost changes.61 During two

60 Goodwin and others (2004); Graham and Glaister (2004).
61 Hughes, Knittel, and Sperling (2008); Small and van Dender (2007).
periods that had similarly high prices, 1975–1980 and 2001–2006, short-run price elasticities went down considerably, ranging from -0.21 to -0.34 for 1975–1980 and -0.034 to -0.077 for 2001–2006 (Hughes and others 2008). This decrease may reflect more dependence on cars as suburban development increases distances between homes and job and retail locations.

With few incentives for consumers to reduce energy use and emissions, transport policy must intervene if reduction targets are to be achieved. However, sudden and dramatic price increases in equipment and infrastructure, a cap-and-trade system, or the levying of carbon taxes would in the short term create high welfare costs. Severe transport cost hikes would decrease demand for other goods and have a negative secondary effect on economies from infrastructure use, trade, and agglomeration.

Changing only supply-side investment could lead to a mismatch of capacity and demand without bringing down emissions much. Ideally, incentives to guide demand to less polluting modes should be put in place concurrently with the transition to low carbon use. This would limit negative secondary effects and increase political acceptability.

In contrast to what low short-run elasticities suggest, persistent incentives for changing demand can significantly influence fuel and emission intensity (figure 1.4). Per capita gasoline consumption mirrors price developments for the last two decades. A study calculated the hypothetical effect of all OECD countries adjusting permanently to the fuel tax levels of Italy, the UK, and the Netherlands. This would reduce all OECD transport carbon emissions by about 40 percent, or 270 million tons of fuel a year; in a decade 8.5 billion tons of CO₂ would thus be avoided. If all OECD countries were taxed at the level of the United States rather than of the Netherlands, however, the increase in emissions would be 133 percent.

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64 Sterner (2007).
1.4. Low-Carbon Transport and Development

Some low- and middle-income countries that have rapidly reached very high per capita incomes have kept per capita emissions very low. In the late 1970s, Hong Kong resembled metropolitan areas of today: It had real growth of about 10 percent a year, an influx of immigrants, and a roaring demand for private cars. Car ownership had more than doubled in a decade. The result was both a huge loss of time for passengers and freight and significant health costs from air pollution.

The Hong Kong transport department reacted with draconian measures. In 1979 it drastically reformed transport policy, increased road capacity, improved mass transit, and introduced demand management. It trebled the license fee for cars, doubled the first registration fee (up to 90 percent of the value of an imported car), and doubled fuel taxes. Vehicle ownership plunged; by 1985 it was down to 50 percent of the 1979 value, of which taxis represented 10 percent. The public transport system incorporates an underground metro, a heavy rail line linking Hong Kong with mainland China, a light rail system in the northwest New Territories, and a tram on the north side of Hong Kong Island. Five private bus companies operate more than 6,000 buses. Minibuses with fixed fares and exclusive rights to operate on certain routes provide feeder services to the main bus lines. Entry to this submarket is strictly regulated and a maximum number of minibuses is set for city districts. Transfers from one mode of

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travel to another are synchronized to minimize time loss.\textsuperscript{66}

The opening of the Island Eastern Corridor in 1987 and the Island Route of the Mass Transit Railway further reduced congestion. Tolls are levied to improve air quality and keep the city attractive. (Although road pricing had been introduced in 1985, after vehicle ownership had already significantly decreased, it has been dropped.) In the infrastructure index of the Global Competitiveness Report Hong Kong ranks second, with a score of 6.54 out of 7. In goods market efficiency, it scores 5.54, second only to Singapore.\textsuperscript{67} Hong Kong is a prime example of a metropolis that has retained a high level of mobility by taking a multimodal approach rather than focusing only on roads. Avoiding the congestion that plagues other megacities allows both for agglomeration economies and for sustained access and mobility for residents.

\textsuperscript{66} Cullinane (2002).
\textsuperscript{67} World Economic Forum (2010).
Annex 1.1. Characteristics of the Transport Sector

The transport sector has increasing returns to scale: higher demand reduces its costs. Coordinating freight trips and balancing irregular demand for deliveries increase returns for the logistics industry (figure A1.1). In the maritime sector, larger container ships reduce ton-kilometer costs.

Figure A1.1. Road Freight and Average Income, 2006


There is a strong positive correlation between passenger-kilometers traveled and average incomes (figure A1.2). The United States consumes the most passenger-kilometers by far. Switzerland, however, with an average income only slightly lower than that of the United States, consumes only just over a third of U.S. passenger-km. Some small countries, such as Lithuania, consume a high level of passenger-km, whereas some middle-income countries where income has recently surged, such as Korea, have kept passenger-km remarkably low.

In addition to per capita income, the size of a country, the integration of former Soviet Union countries, and the history of rail infrastructure policies all affect the rail share of freight transport.
(figure A1.3; outliers with very high rail freight transport—Kazakhstan and the United States—have been excluded from the figure).

Figure A1.2. Road Passenger Transport and Average Income, 2006

Across countries, differences in rail passenger-km mirror differences in road passenger-km (figure A1.4). Switzerland is the prototypical country with high per capita income and high rail passenger-km but low road passenger-km. Compared with other rich countries, the United States has low rail passenger-km. Korea has maintained high rail passenger-km throughout its rapid economic development. Former Council for Mutual Economic Assistance countries that have emphasized rail transport still have high rail passenger-km.

Car ownership typically increases dramatically when countries reach an average income of $5,000 in 2000 values (figure A1.5). Motorization in Mexico shot up at this per capita income point; but Singapore, the Republic of Korea, and Taiwan, which have all had high income growth in recent decades, have kept motorization low. Some countries, such as Switzerland, that have relatively low road passenger transport in relation to incomes nevertheless have high car ownership.

Figure A1.5. Motorization and Income, 2005

A similar picture holds for passenger car density (figure A1.6). Some small countries, such as Luxembourg and the Baltic states, have a high number of cars, both in absolute terms and relative to their population and income. The rapidly developing East Asian countries stand out for their low passenger car density. India and China have low per capita incomes but a rapidly growing middle class whose demand for cars is rising. Brazil and Russia have large populations likely to reach the income level at which car ownership increases dramatically. However, passenger car densities per 1,000 people were still low in 2003, at 8 for India, 10 for China, 131 for Brazil, and 161 for Russia.

Figure A1.6. Passenger Car Density and Income, 2003

Chapter 1 - References


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2. Avoiding Future Disruption of Services

Recognizing that transportation is essential to growth and development, governments are increasingly concerned about how to grow or at least maintain this sector when emission reduction policies could increase costs and threaten services. Transport and climate change professionals have both focused on GHG, but too often they see their agendas as conflicting. This has made it hard for them to communicate about ways to work together to preserve and expand the economic benefits of transport services—through adaptation.

In all sectors adaptation to the physical impact of climate change constitutes “adjustment in natural or human systems, in response to actual or expected climatic stimuli or their effects, which moderate, harm or exploit beneficial opportunities.”\(^{68}\) Adaptation thus describes all efforts, whether by bridge engineers, bus drivers, or urban planning agencies, to increase the resilience and reliability of transport in anticipation of climate change.

This chapter reviews how climate change is likely to affect transport operations and infrastructure, cost-effective measures for minimizing negative effects, and policies and decision frameworks in support of these measures. Most analytic work on climate change impact and adaptation has been done in high-income countries. This chapter takes those analyses, particularly that of the U.S. Transportation Research Board,\(^ {69}\) as a foundation, highlighting current and projected research findings and examples from developing countries.

2.1. Threats to Transport Infrastructure and Operations

Our climate is already changing (boxes 2.1 and 2.2), but projecting exactly how it will continue to change is difficult. Understanding what global climate models can and cannot tell us is central to understanding how to estimate and address local impacts.

Global and regional models can project broad climate trends over large temporal and geographic scales but cannot predict specific outcomes, especially for shorter periods, such as a decade, or smaller geographic scales, such as a single metropolitan area. Further, while there is consensus on basic temperature indicators, it is much harder to estimate such climate features as surface water availability and extreme events. Even with finer-scale data or new observations from the next few decades, much uncertainty will remain.

Experience from a number of municipalities in high-income countries

\(^{68}\) World Development Report (2010).

\(^{69}\) NRC (2008).
makes a case for looking at broad trends in assessing potential impacts and risks.\textsuperscript{70} Thus the impacts described below comprise a range of possibilities for a spectrum of areas. While planners are encouraged to seek detailed country-specific information to supplement this material, they should recognize that none of the projections are certain.\textsuperscript{71} (The end of this chapter addresses how to deal with uncertainty rather than shying away from it as an excuse for inaction.) Finally, all climate impacts must be considered in terms of other local features and changes.

\textbf{2.1.1. Climate Changes Likely by Mid-century}

Higher average temperatures will bring more temperature extremes throughout the world, with more very hot days and heat waves. The 24-hour temperature range will also narrow because nighttime temperatures will increase more than daytime temperatures. There will be fewer very cold days. Warming will be greatest at the poles, where permafrost has already begun to melt, and ice covering the polar seas will shrink. Polar warming will be greatest in winter. Even in temperate zones, the timing of seasons will shift, with earlier spring thaws, later autumn freezes, and the potential for more freeze/thaw cycles. In the tropics, the hottest months will experience the most pronounced warming.

Annual precipitation averages will shift. There will be a slight increase in global precipitation, but with enormous regional variability. Rainfall will likely diminish in continental interiors and increase in coastal areas. Nearly everywhere, rainfall will be more intense; that is, a given annual total is more likely to fall on fewer days, so that many places may experience both more dry spells and more floods. In addition to this increase in intra-annual variability, inter-annual variability will also increase—that is, there will be more extremely dry and extremely wet years—especially in areas strongly affected by El Niño and La Niña. More intense rainfall and more extreme swings between wet and dry, exacerbated by poor building practices, more impermeable paving, and deforestation, may increase mudslides and flash floods. And as the number of hot, dry spells increases, so too does the risk of wildfires and dust or sand storms.

The warmer atmosphere and accelerated hydrological cycle will bring more rain, wind, and snow storms. The intensity and possibly the frequency of tropical cyclones will increase. As more precipitation falls as rain rather than snow, winter replenishment of glaciers will decline and spring and summer melting will accelerate, eventually leading to the retreat or even disappearance of some glaciers. This will increase flooding during wetter, colder months and reduce water availability during drier, hotter months, when glacial melt is normally relied on to feed streams and rivers used for irrigation. The ocean will expand as it warms; the melting of mountain and polar glaciers will raise the sea level—at what rate is uncertain, but

\textsuperscript{70} Ligeti, Penney, and Wieditz (2007).
\textsuperscript{71} Schneider and Kuntz-Duriseti (2000).
conservative estimates are about 60 to 80 centimeters, with more recent estimates at more than 71 or even two meters by century's end. Upstream diversion of rivers for irrigation and hydropower, declining glaciers, and insufficient rainfall could reduce river flow, and reduced rainfall or population pressure could deplete underground water, both causing coastal subsidence. Subsidence combined with higher sea levels and increased storm intensity would expose many highly populated coastal areas to destructive storm surges.

2.1.2. The Effect on Transport in Developing Countries

Such changes in climate and hydrology have serious implications for transportation infrastructure, operations, and maintenance. This section discusses the impact on land transport (road, rail, metro, bridges, and pipelines); maritime transport (sea ports and inland rivers); and aviation (table 2.1). In a few cases, climate change will actually bring benefits—for example, opening transit routes in Arctic waters (although this will endanger sensitive ecosystems). However, most climate change will make it harder to provide safe, reliable transport, both because of its direct physical impact and because its uncertainty complicates long-term planning and daily decision-making.

Climate change will also affect sectors linked to transport. Agricultural yields will decline in many places but could increase in higher latitudes. Dramatic changes in agriculture could accelerate migration from rural areas into cities, which, along with altering food trade patterns, would affect transport demand. Climate is a major determinant of tourism; if traditional ski areas become too warm, skiing could shift to either higher-latitude mountains or different environments altogether. Such indirect impacts on transport could be large at the local level. The discussion below, however, focuses on the direct impact of climate change on provision of transport and to a lesser extent demand for it.

2.1.2.1. Roads, Bridges, Rail, Tunnels

Higher average temperatures and extreme heat can expand road surfaces and bridge joints, soften and deform paved surfaces, and buckle rail tracks. Damaged and degraded pavement increases accidents, especially when it

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72 The range published by the IPCC in the Fourth Assessment Report (IPCC 2007) is 18–59cm. Because the IPCC strictly limits any claims that contributors consider too uncertain, the range excluded a potentially very large factor: ice sheet melting. Even at the time of publication, the IPCC numbers were widely considered to be underestimates. Subsequent estimates put the plausible range as easily crossing 1 meter. An informal summary of the debate can be found at http://www.realclimate.org/index.php/archives/2010/03/ippc-sealevel-gate/ (accessed June 27, 2010). Major reports and peer-reviewed articles from the past few years include Deltacommissie (2008); Copenhagen Climate Congress (2009); Allison and others (2009); Scientific Committee on Antarctic Research (2009); Grinsted and others (2009); Pfeffer and others (2008); Horton and others (2008); and Rahmstorf (2007).

73 NRC (2008).
is rainy or foggy. Higher temperatures can interrupt bus, truck, and car use; engines can become overheated and air quality or pavement conditions can necessitate temporary limits on vehicle use. For example, in the Shymkent and Kyzylorda Oblasts in Kazakhstan, extreme heat combined with inadequate infrastructure has led to weight and travel restrictions on trucks in summertime when asphalt is softest. The number of days suitable for construction and maintenance might increase in colder areas, but the decrease in suitable days in countries like India or the Persian Gulf states could more than offset this. During hot spells, individuals with the financial means and access may resort to using higher-emitting and congestion-causing cars rather than walking, cycling, or using public transit.

The reduction in very cold days will have a mixed impact. In some places, it will reduce the costs for removing snow and ice and create safer road conditions. In other places, particularly near seas and lakes, slightly warmer temperatures may actually increase the magnitude and thus the cost of snowfalls. Warmer winters will melt permafrost in Alaska, Canada, China, Mongolia, and Russia, as well as in Antarctica and parts of the Andes. Thawing may disrupt the settling process under rail lines and buildings, something already evident in some places, and compromise the integrity of oil and gas pipelines, threatening local safety and disrupting supplies across larger regions. The ice roads used by the logging and mining industries, which may be the only routes to isolated communities, will become impassable for longer stretches. Warmer winters could mean more frequent freeze-thaw cycles in temperate areas, creating frost heaves and potholes on roads and bridges, which in turn may require tighter weight restrictions and costly maintenance—more than half the stresses on Canadian roads result from freeze-thaw cycles.

More intense precipitation, which can trigger flash floods, landslides, erosion, and swollen rivers, will test physical infrastructure and the ability of operators to maintain safe and efficient service. When extreme rains punctuate long dry spells in places where desiccated soils and vegetation are less able to quickly absorb water, these effects are magnified. Intense rainfall also lengthens delays for road and rail traffic, limits vehicle speed, increases the risk of accidents per vehicle-km, and reduces mobility. Other risks include the hydraulic capacity of bridges being exceeded, destabilization of bridge foundations from scouring, and

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74 For example, Huang and others (2008).
75 Nakat (2008).
76 NRC (2008); Nag and others (2009); Kjellstrom and others (2009); Dubai Municipality government news releases; ArabianBusiness.com various articles, e.g. http://www.arabianbusiness.com/press_releases/detail/19527.
77 GTZ (2009).
78 Nakat (2008); Ebinger and others (2008).
79 Frost heave—cracking and uplift of portions of soil or pavement—occurs when water in the subgrade (or in the earth below) freezes and expands upward toward the surface.
80 PIARC (2010).
sediment blockage of culverts and other drainage systems. Extreme precipitation can also interfere with maintenance and construction, even as regular maintenance becomes more important to withstand the stresses of heat, freeze-thaw cycles, and standing water wearing down roads, bridges, and rail beds.

Floods are increasing in many places—Mozambique, Morocco, and Argentina, for instance—and can often be attributed to nonclimatic factors linked to land use, such as deforestation, slope destabilization, and, particularly in rapidly growing cities, expansion of paved areas and reduction of permeable surfaces. Without improvements in infrastructure and strategies for managing risk, intensified precipitation will only become more destructive. In October 2005, near Valigonda in Southern India, more than 100 people were killed when a train was derailed off bridge tracks that had been swept away by the overflow of water from a reservoir filled beyond capacity because of atypically heavy rains.

Of course, more intense precipitation is a challenge not just to developing countries; nor does it always result in large-scale fatalities. The more common outcome may be harder-to-measure costs to transit-service users and businesses, as when the New York subway flooded in September 2004 and August 2007. The intense rains—about 75 mmm per hour, or roughly double the quantity that the subway system is built to withstand—paralyzed the metropolitan area and resulted in at least one death. In the 2007 incident, flooding short-circuited essential electrical signals and switches so that none of the subway lines, which normally carry 7 million passengers daily, could run at full capacity during the morning rush hour.

Even in areas that experience more total precipitation, dry spells and droughts could increase and water availability and soil moisture could decline significantly, killing the natural or planted vegetation around roads and walkways that provides shade and protects against erosion. The combination of drought and intense heat also increases wildfire risk. Wildfires can easily destroy transportation infrastructure, even as firefighting crews become more dependent on functioning transport networks.

Storms that are more frequent, more intense, or both can cause major problems for road transport. Lack of preparedness for dealing with extreme snowfalls, which are likely to become larger or more frequent in some places, can be costly. In January 2008,

81 There are many sources on this, including http://www.cnn.com/2005/WORLD/asiapcf/10/29/india.train/.

82 When cold-season temperatures are still below snow-versus-rain thresholds, moderate warming can actually intensify snowfalls by increasing the rate of evaporation and thus the concentration of water vapor in the air, setting up perfect conditions for a massive snowfall when the moist air collides with cold air. More detailed explanation of the potential for increased extreme snowfalls, and evidence on the increased snows in the Great Lakes region of the United States, are provided in Karl and others (2009).
unexpectedly intense snowstorms in China paralyzed the train system just as migrant workers were trying to return home for the Chinese New Year. Millions were stranded. Worse, with the interruption of coal delivery, food and power could not reach suffering populations in the southern and central provinces.83

Two years later, extreme snowfall on the east coast of the United States entirely shut down the economy of Washington, D.C., first in December 2009 and again in January 2010. Two such large snowstorms normally occur in the area about once every 25 years, not twice in two months.84 Road conditions were so bad at one point that snow-plow trucks themselves were barred from driving. Estimated losses to private businesses vary widely; closure of the federal government cost taxpayers about $71 million a day.85

Tropical storms and cyclones, which according to some evidence are already growing more intense, may well become stronger and more frequent. Storms regularly set off land- and mudslides in mountainous Central America, devastating both people and infrastructure. For example, in late May and early June 2010, landslides and gushing rivers associated with tropical storm Agatha washed out numerous roads and bridges, impeding rescue efforts for the worst-hit areas. In 2005 Hurricane Katrina devastated New Orleans and severely disrupted transport connections: “Key railroad bridges were destroyed, requiring the rerouting of traffic and putting increased strain on other rail segments. Barge shipping was halted, as was export grain traffic out of the Port of New Orleans, the nation’s largest export grain port. The pipeline network that gathers oil and natural gas from the Gulf was shut down, producing shortages of natural gas and petroleum products.”86

Even in places that do not experience tropical storms, such as the Mediterranean coast of Africa, sea-level rises and storm surges threaten settlements and transport infrastructure. Morocco, for example, already experiences increasingly intense heat waves (a 1° to 3° Celsius increase since the 1970s) and droughts, as well as extreme rainfalls more often. This threatens the country’s road pavement, rail tracks, bridges, drainage systems, and embankments, and the damage has already been costly. A flash flood in 2006 destroyed 15 km of the 20-km Tounfite-Agoudim road in the Atlas Mountains—repair costs were equal to half the initial investment. Low-lying Bangladesh, already

83 WDR (2010); Pew Center on Global Climate Change (2010).
86 Grenzback and Lukmann (2008).
extremely vulnerable to cyclones and flooding, is expected to suffer greatly from sea-level rise and more damaging storm surges (box 2.1).

**Box 2.1. Impact of Sea-level Rise and Cyclones on Transport Infrastructure in Bangladesh**

Typically, roads are partially damaged when surge inundation is less than one meter and totally destroyed when it exceeds one meter. If road networks are expanded by 25 percent growth between 2005 and 2050, geographic overlays of the road network and inundation zones indicate that—even without climate change—by 2050 3,998 km will be exposed to an inundation depth of less than one meter and 8,972 km to a depth of more than one meter. With climate change, these numbers will increase respectively to 10,466 km and 10,553 km. Over a 10-year period, larger cyclones could add another 3,461 km of partially damaged roads and 2,205 km of destroyed roads. According to a 2007 damage loss assessment by Sidr, repair costs would be Taka 1 million for partial damage and Taka 2 million for partial and total destruction; bridge, culvert, and other damage would be 1.13 times the road damage. Combined damage costs by 2050 would thus be an additional $239.5 million. (The estimate of damage to roads, bridges, culverts, and the like is $173.6 million by 2050 without climate change, $413.1 million with climate change.) The estimated additional loss in a changing climate is $52.7 million.

*Source:* Dasgupta and others (2010).

2.1.2.2. Impact on Maritime Transport and Aviation

Maritime transport could be affected by changed water levels, more extreme precipitation and storms, higher temperatures, and in particular the opening of the Arctic because of ice melt.88 Lower water levels could plague many inland waterways, requiring stricter cargo weight limits, redesigned vessels, and costly and environmentally damaging dredging. Higher sea levels could reduce clearances under bridges near coasts, directly threatening port infrastructure and road and rail links. The combination of higher sea levels and more extreme coastal storms and precipitation is the greatest threat to ports from damage to bridges, piers, terminal buildings, ships, and cargo. Storms can also cause suspension of operations, reducing reliability and raising costs. Harbors may need to be dredged more often because of increased erosion and silting. By exceeding the capacity of drainage systems, intense rains and storms could cause fuel and industrial contaminants to leech into waterways.

The reduction of Arctic sea ice and the possible opening of new shipping routes represent the most dramatic impact of climate change on maritime transportation. Trans-Arctic shipping

88 Gallivan and others (2009).
could reduce the distance traveled between northern Europe, northeastern Asia, and the northwest coast of North America by as much as 40 percent relative to traditional routes through the Panama or Suez Canal (which might see a decline in their share—though not necessarily the volume—of global shipping).\(^8\)

Diminished sea ice, and eventually new routes, could create opportunities for new investment—for example, in different ship designs. However, an upsurge in traffic could threaten sensitive ecosystems already undergoing dramatic transformation because of climate change. Higher temperatures will affect paved surfaces at port facilities and increase cooling needs for warehousing and transporting goods.

Given its fuel intensity, the aviation sector is sure to be deeply affected by climate change mitigation policies. But beyond fuel, climate change has a direct effect on airport infrastructure, safety, and operations, particularly losses caused by delays. Threats to airport runways, towers, and signaling equipment are quite similar to those in ground transportation, especially the vulnerability of paved surfaces to heat and precipitation and inadequate drainage. Aviation-specific challenges include the impact of higher heat on lift-off, requiring longer runways, lighter loads, or better airplanes. Thawing permafrost and sinking runways already threaten small airports in isolated communities, although one benefit is the possible reduction in ice and snow removal costs. Airports in low-lying coastal zones are vulnerable to changes in sea levels. In fact, in Jakarta—where subsidence (from urban development and groundwater extraction) will make net sea-level rise particularly threatening—the international airport could be underwater before mid-century; flooding has already submerged the highway to the airport numerous times.\(^9\)

At a colloquium in May 2010, the International Civil Aviation Organization warned of the threat of extreme weather to safety, noting that while technical standards have continued to rise, they are based on past climate probabilities and are not necessarily a guide to the future. Sustaining gains in safety, particularly in developing countries, is extremely important. Less predictable or more extreme weather could increase delays, cancellations, and airport closures, which are costly to both operators and passengers. Climate change could affect the distribution of tourism and thus demand on certain routes. Travel to snowless ski destinations, drought or heat-stricken summer destinations, and places experiencing extreme weather is likely to decline. Dry spells can threaten visibility and safety by creating conditions ripe for wildfires and dust or

\(^8\) TRB (2008).


sand storms. Climate change in the deserts of Iraq, causing die-off of vegetation and lower river flow, has produced dust storms that reach further and more intensely than usual into Iran.\textsuperscript{92} This has in many instances—and more often in the past 15 years—prevented aircraft from landing at the Ahwaz and Abadan airports. Flights have been forced to return to the departure airport or land elsewhere, wasting fuel and increasing costs for both airlines and passengers.

\textbf{2.1.2.3. The Effect on Supply of - and Demand for -Transport}

With more frequent, intense, and variable extreme weather events, the role of transport in minimizing disaster loss and enabling recovery becomes even more crucial—even as transport infrastructure and services themselves are increasingly threatened by climate extremes (box 2.2).

After a disaster rescue workers and survivors must have a rapidly deployable communications network. But disasters in developing countries often occur where there is little or no infrastructure, or the disaster may have shut down what infrastructure there was. Without network redundancy, the first precious hours must focus on restoring transit routes for affected populations. The functioning (or failure) of transportation networks after a disaster is a strong determinant of total damage, both direct and indirect, and the ultimate cost of recovery (box 2.3)

\textsuperscript{92} Tajbakhsh and others (2010).
Box 2.2. The 1997–1998 El Niño and Transport and Reconstruction in Kenya, Peru, and Ecuador

Climate change may already be altering the patterns of El Niño, although research has yet to confirm this. In any case, El Niño weather extremes offer insight into the possible impact of severe weather caused by climate change. The particularly severe El Niño of 1997–1998, felt around the globe, offers an example.

Kenya: The 1997–1998 El Niño rains devastated the transportation sector. Floods and landslides destroyed several bridges and an estimated 100,000 km of roads. Damage was estimated at $670 million. Flooding disrupted aviation and shipping. Poor visibility and submerged navigational equipment and runways halted scheduled and chartered flights; flooded docks made it impossible to off-load merchandise from ships. Floodwaters, fallen trees, and collapsed buildings destroyed electrical equipment, interrupted electricity supplies, destroyed communication lines, and severely disabled underground cable channels and telecommunications. The energy sector did experience one positive benefit, however: hydroelectric dams were completely recharged, electricity production was enhanced.

Peru: The 1997–1998 El Niño had a direct negative impact on Peru’s highways and roads, which extend for 75,000 km (only a third of Peruvian highways are gravel or asphalt). Highways and roads carry 80 percent of Peru’s merchandise. Transportation companies and merchants were hit hard by the highway system’s vulnerability, but most affected were towns and villages, several of which were isolated by El Niño without adequate food or supplies.

Ecuador: The economic losses associated with the 1997–1998 El Niño in Ecuador have been estimated at $2.9 billion, or about 15 percent of Ecuador’s 1997 GDP. Sixty percent of Ecuador’s population was affected, with the coastal and southern provinces suffering most. Damage to manufacturing represented 53 percent of total damage, and damage to transport 28 percent. Ecuador’s GDP growth rate in 1998 declined about 1.2 percent from the projection without El Niño. According to the National Institute for Census and Statistics, El Niño had a heavy impact on the country’s coastal and island populations, which together make up 50 percent of Ecuador’s inhabitants. Approximately 34 percent of those affected were younger than 15. Most of the flooded cities sustained damage to water supply, sewage, and infrastructure. Even though the affected urban population was larger, the rural populace suffered more. Flooding not only cut them off from the highways, bridges, and roads that are their lifelines to the cities but also destroyed their agricultural products, raising market prices.

1 Basic information on possible links between El Niño events and climate change is available from the Max Planck Institute for Meteorology: http://www.mpimet.mpg.de/en/aktuelles/presse/faq/das-el-nino-southern-oscillation-enso-phaenomen/beeinflussung-el-ninos-durch-den-anthropogenen-treibhauseffekt.html. Publications investigating the topic include Trenberth and Hoar (1997); Collins and others (2004); Philip and van Oldenborgh (2006); Paeth and others (2008); and Collins and others (2010).

Source: Adapted from Glantz (2001); see also CEPAL (1998).
Box 2.3. Minimizing the Costs of Extreme Events: The Role of Transport

Extreme weather can result in both direct and indirect losses. Direct losses consist of the monetary value of physical assets destroyed or damaged, such as housing, infrastructure, crops, and plants. Indirect losses are the opportunity costs of reconstruction delays, including immobilized productive capacities (both machines and workers) and empty housing. Together direct and indirect losses account for actual losses. Poor logistics in developing countries multiply these losses.

One study defines total cost as the sum of direct and indirect losses. Another draws a relationship between direct costs and total costs through the empirical coefficient of the economic amplification ratio (EAR), defined as the ratio of the overall production loss (total costs) to the direct costs that are associated with an extreme event. The paper’s non-equilibrium modeling shows strong nonlinearity with the capacity to conduct reconstruction after each disaster. Given short-term constraints on spending money productively after a disaster, there is a bifurcation value of direct losses beyond which total costs increase dramatically. Thus the EAR can be significantly higher than unity and it increases with direct costs.

Empirical studies of the aftermath of the 2004 and 2005 Florida hurricanes suggest that the surge in demand for reconstruction and repair along with supply shortages—in qualified workers, carrying capacities of reconstruction materials, and so on—pushes up prices for reconstruction (up to 60 percent in some regions) after an extreme event.

This all make the case for focusing on restoring transport infrastructure to minimize reconstruction delay opportunity costs and help production mechanisms return to optimal functioning.


In many developing countries lack of strategic planning undermines infrastructure resilience—efforts are essentially reactive after a disaster. Perverse in road maintenance and construction incentives increase the cost of extreme events to taxpayers.93

Reactive strategies usually lead to the building of similarly inadequate infrastructure that has to be significantly refurbished every few years—a process known as the “reconstruction of vulnerability.”

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93 Solberg and others (2003).
2.1.3. Why the Impact of Climate Change Is Different

Engineers, policymakers, and project designers may see nothing new in the impacts described. In making decisions that take into account climatic, hydrological, geological, and usage factors, they have always had to consult building and maintenance standards in choosing, for instance, how much clearance to allow below a bridge, how securely to attach a deck to a substructure to withstand high winds, how often to repave a surface, or whether to use riprap or extensive gabions to protect abutments from scour. They have always weighed probabilities and risks against costs and made locally appropriate choices based on a combination of physical factors, risk tolerance, and budget constraints. So what is all the fuss about? Why should investments not continue to be made as they always have been?

First, there is the increase in variability. Variability itself is not new. What is new is the projected increase in both intra- and interannual variability in temperature and precipitation. Greater intra-annual variability means that, even though total annual rainfall in a location may remain unchanged, rainfall that used to be spread out, say, 40 percent/60 percent across two six-month periods may instead be clustered with 20 percent in one six-month period and 80 percent in the other. Thus, infrastructure and operational procedures will need to deal both with drier and with wetter conditions. This will very likely raise costs, for even if it were no more or less costly to build, maintain, and operate transport infrastructures in a dry climate or a wet climate, it is more costly to build, maintain, and operate assets to withstand both.

Interannual variability also complicates decision making, since it can be difficult to distinguish between a change in the mean trend and oscillation about a stable mean. How can local authorities know if their region is really becoming drier on a multidecadal average, or if it is only that the variation around a stable mean has increased, with the past few dry years likely to be followed by a few wet years? Coming to the wrong conclusions, and relying on those conclusions when making investments in infrastructure intended to last for many decades, can be extremely costly.

Changes in infrastructure maintenance and operations, though not easy to implement, might be achieved on a shorter time scale without enormous loss in sunk costs. But rebuilding—or in more extreme cases, entirely relocating transport facilities away from coasts vulnerable to sea-level rise—before the end of the intended life of the infrastructure would be very costly.

Even if transport providers did have the data and tools to analyze probabilities and respond accordingly, many private users of transportation do not. For example, variable rainfall might make driving more dangerous than predictable rainfall, even if actual average road conditions are unchanged. Car drivers tend to drive more slowly 94 Burton and Lim (2005).
and carefully the day after a storm. If rain yesterday is not a good predictor of rain tomorrow, then people are slowing down unnecessarily. More troubling, if clear skies today are an even less reliable predictor of the absence of fog or rain tomorrow, drivers will be even less likely to slow down when they should.

Second, climate change also introduces **deep uncertainty** about future climate, making current information and methods inadequate for decisions that have long-term implications. Future weather—be it tomorrow's forecast peak temperature or a seasonal estimate of rainfall—has always been uncertain. But past data have, until now, provided a guide to climate-sensitive decisions based on probabilities and averages. However, climate change invalidates past averages and probability distributions. And the real challenge is that the new probability distributions are unknown.

Climate has always varied, but in the past the variation has been within a fixed envelope, around a fixed mean. Infrastructure design and planning, insurance pricing, and numerous private decisions have long been based on stationarity, the idea that natural systems fluctuate within an unchanging envelope of variability. With climate change, stationarity is dead. Models of climate change cannot assign probabilities to the projections they generate—and certainly not at the fine temporal and geographic scale that transportation decision makers require. What was once uncertain but could be reasonably predicted with past data is now characterized by deep uncertainty—the phrase used when no underlying probability is known.

### 2.1.4. Drivers of Vulnerability and Resilience

The impact of climate change on transport will not be the same everywhere. Overall vulnerability is a function of both exposure to climate hazards and change and the sensitivities and adaptive capacity of the transport sector, broadly defined to include both providers and users (figure 2.1). Further, there are drivers of vulnerability, other than the climate itself, both within and outside the transport sector. There is intense debate and numerous studies on how to define and measure components of vulnerability and how to link them to related concepts even beyond the area of climate change (for example, disaster risk reduction and social protection). These debates are beyond the scope of this report, which will use the bare-bones Intergovernmental Panel on Climate Change (IPCC) framework commonly used by many sources, which is sufficient for understanding drivers of vulnerability.

The concept of exposure is straightforward: “it is determined by the type, magnitude, timing, and speed

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95 Leigh (2009); Eisengberg (2004); Road Research Laboratory (1954).
96 World Bank (2010).
97 Milly and others (2008).
99 For a review of the literature, good starting points are Füssel (2007) and Janssen and Ostrom (2006).
of climate events and variation to which a system is exposed (for example, changing onset of the rainy season, higher minimum winter temperatures, floods, storms, and heat waves).”

However, it is difficult to characterize exposure, either quantitatively or qualitatively, in a way that is useful to decision makers. Characterizing the exposure of a locality or a transport network depends ultimately on local capacity, which is not necessarily constant over time. But in all cases, qualitative understanding of current challenges and projected trends, however uncertain, will be the first step of several (boxes 2.4 and 2.5).

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100 Fay, Ebinger, and Block (2010).
The sensitivity of a system comprises its structural characteristics. Some characteristics are more sensitive than others—for example, engineered dirt or gravel roads are more likely than are paved roads to become impassable during heavy rains—and poorly maintained assets of any type are more sensitive than better maintained assets. In addition to basic engineering specifications (for example, standard versus porous paved surfaces), location also matters. Settlements, and thus transport assets, are often concentrated in coastal zones, where climate hazards are particularly challenging.

An example of a system’s sensitivity and exposure is a paved two-lane coastal road in a mountainous area. It could be exposed to sea-level rise; higher storm surges; hotter, longer, and more frequent heat waves; more frequent or more intense storms; and alternating dry spells and more intense rainfall. Sensitivity could include location on the coast or at the bottom of a slope, nearby slopes that are increasingly unstable because of deforestation and unplanned settlement, and poorly maintained drainage around the road that impedes the flow of water from the hillside to the sea. These variables combine to determine the potential impact of climate change on the road: intense rainfall could destabilize the slope, provoke mudslides, or even wash out the road; hot spells could soften and cause ruts in the pavement, making it less safe for drivers; and higher tides and increased buffeting by storm surge could greatly weaken the subgrade and destabilize the road.

How potential impacts translate into actual impacts depends not only on
climate phenomena and sensitivity but also on the system’s adaptive capacity—its resources for coping with impacts and mitigating damage. In the coastal road example, adaptive capacity could include the extent to which operators could close the road and reroute traffic with minimal delay; the capacity to foresee the need to maintain drainage and pavement surfaces, including the power to mobilize funding and ensure that the work gets done; and the ability of transport and land-use planning bodies to work together to ensure that new infrastructure is not sited in areas exposed to hazards.

As noted, nontransport factors such as poor drainage, deforestation, or bureaucratic blunders can increase transport vulnerability. While the adaptation options discussed below relate to the transport sector, an overarching recommendation is to consider risks and vulnerabilities, as well as opportunities for cooperation, beyond the sector so as to increase general economic, social, and transport resilience.

The exposure-sensitivity-adaptive capacity approach can help planners to identify combinations of factors that amplify or reduce the impact of climate change and to distinguish exogenous factors (exposure) from those amenable to local policy action (adaptive capacity—hence, future sensitivity).  

2.2. Preserving Resilient and Least-cost Transport as the Climate Changes

With the many uncertainties of climate change, technologies, and policy regimes, there has been no clear agreement yet on how to adapt transport infrastructure to climate change. Priorities differ by country and there are diagnostic tools to identify these (boxes 2.4 and 2.5). There are, however, at least four recognized adaptation measures:

1. Raising engineering standards: infrastructure should be built more sturdily to make it more resilient to severe weather events.
2. Routine road maintenance, often neglected in developing countries (figure 2.2). Higher standards would require countries to invest more in roads and better maintain them. Without timely maintenance, road deterioration accelerates with time and severe weather.
3. Traffic rules, which should address such issues as speeding and overloading, both of which damage road surfaces, particularly under adverse weather conditions.
4. Broader adaptation measures in other sectors, such as urban planning, infrastructure location, creation of redundancy in logistics, accumulation of inventory, and preparation of disaster and emergency systems.

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101 Fay, Ebinger, and Block (2010).
Box 2.4. Starting the Adaptation Process: Asking the Right Questions

It is recommended that transport officials, national and local, consider the following questions, developed by the Transportation Research Board:

- Which projected climate changes are most relevant for the region?
- How are climate change hazards likely to be manifested (for example, flooding and storm surge coupled with a rise in sea level)?
- Which transportation assets may be affected?
- How severe must a hazard be before action is required? Can thresholds be identified?
- How likely is it that a projected hazard will exceed the threshold? When and where?
- How much risk can be tolerated? In other words, what infrastructure performance level is tolerable?
- What level of investment (capital and operating) is needed to maintain different levels of service?
- Can acceptable performance standards for all modes of transportation be established?
- Are there critical levels of service needed to protect health and safety?
- Who is empowered to make these judgments and decisions?
- What are the risks of adverse impacts or consequences if no action is taken?
- If action is necessary, how will investment priorities be determined?
- Who will make the necessary investments, and how will they be funded?


Box 2.5. Advancing the Adaptation Process: Assessing Risk and Defining a Strategy

A qualitative risk assessment requires the following steps:

1. Establish context and objectives. Formulate the issue and the scope of the assessment: define its objectives and the general context; identify climate scenarios; and define the affected geographic region and the stakeholders (government, sector, and community) or the targeted audience.

2. Inventory assets. Identify the components of the transportation infrastructure and their vulnerabilities, taking into account past challenges, both related and unrelated to climate.

3. Identify and analyze hazards. Identify hazards, especially what could happen with different climate scenarios. Structured brainstorming by stakeholders (for example, policymakers and experienced specialists), such as the “Structured What If Technique” (SWIFT), can help identify hazards. Consider each, with any safeguards or controls.

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102 SWIFT screens hazards by considering deviations from business-as-usual operations, using checklists to support brainstorming. It allows for a systematic team-oriented approach but relies heavily on the quality of the expert team. For more details, see http://rmd.anglia.ac.uk/uploads/docs/SWIFT.doc or HSE (2001).
including policy and management responses, and assess the likelihood of various consequences given such controls. Determine the level of risk.

4. Rank the risks. Screen out minor ones and prioritize major ones for further analysis. Describe the uncertainties of each risk and the sensitivity of the analysis to a variety of assumptions.

5. Identify and appraise options to manage risks. Identify climate conditions that represent benchmark levels of risk or thresholds between tolerable and intolerable risk.

6. Draft an adaptation plan. Prioritize the action plan based on options identified to manage risk, with a review of the costs and associated benefits of each. Discuss the risks of under-, over-, or maladaptation. Ensure that plans account for not only changing climate averages but also increased variability and extremes.

7. Take action. Decide whether to build on and update legal and regulatory frameworks, institutions, policies, strategies, and emergency and disaster management plans or to adopt new ones altogether. Determine current institutional capacity and what is needed to support implementation. Assess financing needs and sources. Identify data and information gaps and how to address them, such as through research and development.

8. Evaluate progress on the action plan. Establish monitoring and evaluation—a feedback loop—to periodically reevaluate risks and priorities as information becomes available or new events occur.

Source: Fay, Ebinger, and Block (2010); TRB (2008).

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103 Australian Government (2006); HSE (2001, 2006); New Zealand Climate Change Office (2004); and UKCIP (2003) provide good examples of risk matrices and their application. See below for a further discussion of decision making related to uncertainty.
2.3. Standards and the Resilience of Transport Infrastructure

The nuts-and-bolts, engineering-centered approach to adaptation consists of components like building stronger bridges, paving dirt roads, increasing drainage system capacity, and building higher sea walls (table 2.2). New technologies and materials are necessary—for example, paving that can withstand extreme heat or allow drainage through its surface. Some technologies are still being studied, but advances in materials science (including nanotechnologies), sensors, computer processing, and communications could significantly alter infrastructure design and operation. Many known potentially helpful measures are not yet being applied.

Such proactive engineering measures, however, can be costly when they entail nonmarginal modification of infrastructure or result in “maladaptation”—measures that increase vulnerability. The greater the uncertainty about local climate, the greater the risk of maladaptation. Vulnerabilities and risks, therefore, must be carefully assessed before any building standards are revamped.

Roads with thicker pavements and better drainage are more resilient. Dirt and unsealed roads, though cheap, can lose surface to traffic and rainfall. In developing countries generally, more than half the roads are still unpaved; in Latin America, the Caribbean, and sub-Saharan Africa, only 15 percent of roads are paved (figure 2.3).
Higher-standard roads can reduce vulnerability and thus increase mobility and welfare, particularly in rural and remote areas. In Nepal, rural roads are operational only during the dry season. An estimated one-third of the nation’s 24 million people live at least two hours walk from the nearest all-season road that has public transport.\textsuperscript{104} Although costly,\textsuperscript{105} upgrading dry-season-only roads to meet all-season standards with gravel and Otta seal, a low-cost paving option,\textsuperscript{106} would increase both rural mobility and road resilience.\textsuperscript{107}

Advanced technologies that would, e.g., enable airports, railways, and ports to withstand storms and blasts can improve resilience. In the Philippines, the number of accidents is closely related to the frequency of typhoons. Thousands of people are killed or injured in maritime accidents each year (JICA 2007).\textsuperscript{108} Navigational aid facilities, such as lighthouses and lighted buoys, need to be upgraded. A promising technology being developed for rail systems is a gust prediction system using weather forecasting and Doppler radar.\textsuperscript{109}

Another powerful recipe for increasing resilience is simple: do not build in

\textsuperscript{104} Nepal Public Finance Management Review (2007).
\textsuperscript{105} Average road upgrading cost is estimated to increase by $3,688/km based on the original estimate of $18,173/km.
\textsuperscript{106} Project appraisal document, Nepal Rural Access Improvement and Decentralization Project (No. 31624-NP).
\textsuperscript{107} An interim survey of the project indicates that personal mobility increased by more than 20 percent and travel time plunged from 2.6 hours on average to 32 minutes (Project Paper on Nepal Rural Access Improvement and Decentralization Project, 2009 (No. 50766-NP)).
\textsuperscript{108} JBIC (2007); Ex-Post Evaluation Report on ODA Loan Projects FY2007.
\textsuperscript{109} JR East (2009).
harm’s way. Transport infrastructure should be located based on accurate mapping of climate risks and vulnerabilities and incorporated into the broader land-use strategy (see below). For example, capacity aside, a culvert should at least be located so that “the flood waters are able to easily overtop the road near the culvert and re-enter the stream on the other side of the road causing only local damage to the road fill. Preferably the culvert should be at a low point in the vertical profile of the road ensuring all flood water is directed back into the channel and not allowed to run down the drainage ditches.”110 In other words, if all other design aspects fail, the right location will minimize disruption, destruction, and loss.

Realigning roads from flood-prone areas to high ground is another example. In Peru, El Niño caused massive flooding that submerged roads. In response, the government rebuilt the highway between the capital and the port city of Piura in the northeast on a higher embankment, rerouting it around a lagoon-prone area that had been completely submerged by the 1983 El Niño. Similarly, better road design as well as construction management in Ecuador could have avoided some of the 1997–1998 El Niño damage (box 2.6).111

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110 COWI Ethiopia
111 Solberg and others (2003).
Box 2.6. Failures and Successes in Disaster Recoveries

Inadequate technical solutions to infrastructure failures: In Peru highways cross a multitude of riverbeds that are normally dry but in an El Niño year can channel avalanches of water and mud across the highways. In response, highway engineers have built pontoons across the riverbeds, but these still often overflow during an El Niño, eroding the highways. This explains television images during an El Niño showing a line of trucks traveling single file over severely eroded highways that have become a thin shred of asphalt.

When rebuilding leads to “reconstruction of vulnerabilities”: In Ecuador, a section of highway of about 60 km from Quito to La Virgin Papallacta has often been washed out or made impassable. A major landslide in 2000 near Cuyuga closed the road for nearly a week. An audit by the Government of Ecuador Controller’s Office found that the reconstruction and rehabilitation funds invested in this roadway over the years could easily have financed a high-quality, all-weather road. Problems included low-quality engineering, no contract supervision, and a faulty incentive scheme: the same construction firm fails to do maintenance but gets paid to clean up after the landslides and keep the road open.

A notable reconstruction success based on lessons well learned: In Peru, the 50 km stretch of highway that joins Piura with the port city of Paitais is a triumph of forward thinking. The torrential rains of the 1983 El Niño created a lagoon that had completely submerged it, cutting off Piura from its supply route, causing famine and desolation. Later, the highway was rebuilt on a high embankment and rerouted around the lagoon-prone area. As a result, the highway stayed open during the 1998 El Niño.

Sources: Glantz (2001); Solberg and others (2003).

Though efforts to adapt technical standards to climate conditions have been slow, they are gaining momentum. Major disasters have prompted civil engineers and the construction industry to work to modify building codes and design standards. Although such a reactive strategy takes time, ultimately it should enhance infrastructure safety and reliability. Current design standards represent tradeoffs between performance and cost.112 Some standards have already tried to account for the probability of extremely rare events. Building to higher standards must be weighed against additional costs—one reason adaptation of standards is slow.

Several high-income countries have already started to adapt standards to new climate conditions. Japan has introduced new pavement technology that increases resilience to heat waves (box 2.7). In response to increased precipitation Denmark has changed its drainage capacity. Other possible adjustments would be connecting bridge decks to deck piers so that storm-surge buoyant forces do not lift the decks off their supports or adding a safety margin to existing dikes against

112 TRB (2008)
expected sea-level rise or extreme sea floods.

Upfront investment in higher standards can be cost-effective if the standards will reduce maintenance and operating costs. Severe weather may increase the recurrent costs of maintaining low-standard bituminous-bound roads, for instance, and retrofitting is generally costly.

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**Box 2.7. Standards Updating: Examples**

Drainage systems in Denmark: extension of previous system: In Denmark increased precipitation and flooding overwhelmed drainage. In response, a new policy required a 30 percent increase in drainage capacity.

Use of new technologies: pavement coated with solar reflective technology: The Japanese have developed the innovative “Heat-Shield Pavement,” a spray-on coating that increases reflectivity for near-infrared rays and lowers reflectivity for visible rays. A Heat-Shield surfacing albedo can be as high as 0.57, compared with 0.07 for conventional pavement. This technology also addresses asphalt surface temperature, which can peak in the summer at about 60°C. Coated with Heat Shield, slabs reach a surface temperature of only about 40°C.

Source: PIARC (2010).

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**Box 2.8. Monitoring Corruption**

Illegal side payments—often observed but not easy to verify—pad many contractors’ budgets. When the contractor who offers the largest kickback wins the contract, competition on the basis of quality, price, and reliability is eliminated. In turn, poor quality means the project must be repaired or even redone, wasting time, money, and resources.

A remarkable experiment in reducing corruption in more than 600 Indonesian village road projects produced the following findings:

- By increasing the probability that it would audit a village from 4 percent to 100 percent, the central government audit agency reduced missing expenditures from 27.7 percent to 19.2 percent. If heavier punishment conditional on prosecution were to complement higher audit probabilities, this percentage could improve.
- Giving audit results to the public, who can then use them in making electoral choices, may be a useful complement to formal punishment.
- Grassroots monitoring is most effective with the distribution of private goods, such as subsidized food, education, or medical care, where individual citizens have a personal stake in ensuring that theft is minimized. When incentives to monitor are weaker, such as for public infrastructure projects, using professional auditors may be more effective.
• Grassroots monitoring programs must ensure that they are not captured by local elites.
• Auditors should be rotated often to avoid susceptibility to bribery. The best option may be to combine lower audit probability with heavier punishments.

Even if improved audits can reduce rent capture or bribery, this experiment suggests that there is no single, simple solution to this common problem.

2.3.1. Maintenance and Operations and Vulnerability to Climate Change

Although higher standards and advanced technologies can increase the resilience of transport assets, developing countries must first commit to routine maintenance. In Africa, for instance, an estimated 20 percent of paved roads are in poor condition. Worse, an estimated 42 percent of unpaved roads, which are particularly vulnerable to precipitation and other severe weather, are poorly maintained (figure 2.4).

Figure 2.4. Africa: Roads in Poor Condition
(Cross-country average based on latest data)

Source: AICD database.

All roads deteriorate with time, but potholes or cracks accelerate deterioration by allowing water to infiltrate. Periodic maintenance is needed to keep roads smooth (figure 2.5). In Africa in the 1970s and 1980s, inadequate maintenance led to road loss estimated at $40–$45 billion. Adequate maintenance, in contrast,
would have cost only $12 billion. In Ecuador poor maintenance of highways, secondary roads, and bridges, exacerbated by noncompliance with regulations, contribute to El Niño damage. Enforcement of regulations was particularly low during the presidential campaign of 1996 and in the following troubled political period in early 1997.

Poor maintenance also undermines road safety. Rutting and potholes increase accidents, as does the weather. Precipitation reduces visibility. Water that accumulates in ruts and potholes—generally difficult to see when it is raining or dark—can cause hydroplaning. Slick pavements and adverse weather contribute to about one-fourth of all highway crashes in the United States. Pavement-related road accidents increase by about 30 percent with rain (table 2.3).

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113 Harral and Faiz (1988).
114 Huang and others (2008).
115 Jung and others (2010).
117 Huang and others (2008).
Figure 2.5. Road Roughness and Maintenance Frequency over Time

![Graph showing road roughness and maintenance frequency over time.]

Source: Author’s simulation based on HDM-4.

Table 2.3. Effects of Pavement and Weather on Road Accidents

<table>
<thead>
<tr>
<th>Weather Condition</th>
<th>Estimated Coefficient</th>
<th>Implied Effect of Doubled Rut Depth (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainy</td>
<td>5.209 ***</td>
<td>29.8</td>
</tr>
<tr>
<td>Dry</td>
<td>0.050</td>
<td>0.3</td>
</tr>
<tr>
<td>Both</td>
<td>1.015</td>
<td>5.2</td>
</tr>
</tbody>
</table>

*** indicates the 1 percent significance level.

1 For each weather condition, a negative binomial regression is performed on average daily traffic and rut depth. The coefficient is associated with the rut depth.

2 It is assumed that rut depth increases from 0.05 inch, the sample average, to 0.1 inch.

Source: Author’s calculation based on Huang and others (2008).
Nonroad transport sectors must also be properly operated and maintained. The lack of standard navigational aid systems in developing countries compromises the efficiency and safety of maritime operations. Many victims killed or injured in maritime accidents could have been saved had ordinary infrastructure and equipment been in place. In the Philippines physical damage or poor maintenance shut down 112 of 419 lighthouses and lighted buoys before a maritime safe project was launched (JICA 2007). In Europe and Central Asia in the last two decades the extensive agrometeorological station networks developed during the Soviet era have deteriorated dramatically. While drought-prone Georgia once had 150 stations, today virtually all have ceased to function.118

The importance of maintaining infrastructure in developing countries rises with the demand for transport. In the Philippines, which consists of more than 7,100 islands, marine transportation is the second most important mode after roads. Although the number of vessels entering the country’s ports increased about 10 percent between 1999 and 2005 (figure 2.6), maintenance of the country’s navigational facilities has long been neglected.

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118 Hancock and others (2008).

Figure 2.6. The Philippines: Vessels Entering and Maritime Accidents


2.3.2. Regulations, Traffic Rules, and Climate Change

Transport regulations must also adapt to climate change. Limiting speed is one way. Many countries already reduce speed limits when weather is severe, as in heavy rain or strong winds. Traffic accidents typically increase with speed limits,119 and precipitation substantially increases the risk of road collision and injury—in Canada risk by an estimated 45 percent.120 Lower speed limits also help preserve pavement. In Sweden, for example, estimates for pavement lifetime derive from speed limits and other traffic and road characteristics; the elasticity of pavement lifetime in Sweden is −0.001, a small but statistically significant number.121

In general, good traffic regulations can prevent road deterioration. As noted

119 Jung and others (2010).
120 Andrey and others (2003).
121 Haraldsson (2007).
earlier, in Kazakhstan, truck operations are restricted during the summer period to reduce road deterioration when the asphalt is soft.\textsuperscript{122} Controlling overload, a widespread problem, is also important in developing countries. In Eastern and Southern Africa, for instance, an estimated 10–50 percent of trucks are overloaded (table 2.4). Overloading damages road surfaces significantly because the equivalent standard axle load factor (ESALF)\textsuperscript{123} is typically assumed to follow the fourth or higher power rule (SSATP 2010). In other words, if a truck is overloaded by 20 percent, its axle load factor approximately doubles using an increased load factor of $(1.2)^4$.

Overloading thus increases the axle load factor on roads exponentially, accelerating deterioration (figure 2.7). Overloading by 20 percent shortens the life of roads by several years. The baseline maintenance strategy is to “do the minimum,” meaning pothole patching and edge treatment, but more frequent road maintenance, including major structural overlays, is needed to maintain road surfaces at a reasonable level, for example, at the international roughness index of 4.5 m/km.

Regulations and operational procedures in other transport areas also need to adapt to climate conditions. Weather is a contributing factor in the approximately 10 yearly train derailments in Canada yearly.\textsuperscript{124} About 40 percent of flights cancelled in the United States are weather-related, a percentage that has been increasing in recent years (figure 2.8). Operational regulations need to be updated because new equipment and advanced technologies are inefficient if they cannot be used in real-time operations. While more weather information is becoming available, there is no guarantee that it will be used promptly. A survey in three European and Central Asian countries found that 25–50 percent of respondents did not find out about severe weather until the day it occurred; the comparable figure for the United Kingdom was 6 percent. Equipment to convey station data to headquarters for analysis is often unreliable, labor-intensive, and expensive.\textsuperscript{125} Integrating weather information and operations could make railway, maritime, and aviation operations more reliable.

\textsuperscript{122} Nakat (2008).
\textsuperscript{123} ESALF is defined by the number of applications of a standard 80kN dual-wheel single axle load that would cause the same amount of damage to a road as one application of the axle load being considered.

\textsuperscript{124} Andrey and others (2003).
\textsuperscript{125} Hancock and others (2008).
Table 2.4. Reported Overloading, Southern African Development Community, 2004

<table>
<thead>
<tr>
<th>Country</th>
<th>Percent of All Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Botswana</td>
<td>10–25</td>
</tr>
<tr>
<td>Lesotho</td>
<td>20–35</td>
</tr>
<tr>
<td>Malawi</td>
<td>30–40</td>
</tr>
<tr>
<td>Mozambique</td>
<td>50</td>
</tr>
<tr>
<td>Namibia</td>
<td>20</td>
</tr>
<tr>
<td>South Africa</td>
<td>15–20</td>
</tr>
<tr>
<td>Swaziland</td>
<td>20–40</td>
</tr>
<tr>
<td>Tanzania</td>
<td>20–30</td>
</tr>
<tr>
<td>Zambia</td>
<td>40</td>
</tr>
<tr>
<td>Zimbabwe</td>
<td>5–10</td>
</tr>
</tbody>
</table>

Source: Sub-Saharan Africa Transport Policy Program 2010.

Figure 2.7. Effect of Overloading on Road Roughness

Source: Author’s simulation based on HDM-4.
2.3.3. Climate Resilience of the Economy as a Whole

An infrastructure network has to be considered as an integrated whole. “Network effects”\textsuperscript{126} involve both potential benefits from interconnectedness—as between trade, local development, and transportation speed—and critical interdependences that, if broken, could dramatically disrupt a regional economy. For example, if a crucial node or strategic link,\textsuperscript{127} such as a highway or a pipeline, were cut, there would be significant economic consequences for the region.

This suggests that such institutional aspects as land-use policies, procurement rules, disaster and emergency planning systems, hydrometeorological data collection and management, and circulation of information among transport sector ministries and administration services matter as much as technical issues. Close correlations between the maps of hazard (the exogenous probability of a potentially damaging phenomenon) and vulnerability (the controllable degree of loss resulting from such a phenomenon) disclose more institutional problems than technical or financial ones.

\textit{Creating Redundancy in Infrastructure and Logistic}: Designing redundancies into a network means creating

\textbf{Figure 2.8. Reasons for Flight Cancellations, United States}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2.8.png}
\caption{Reasons for Flight Cancellations, United States}
\end{figure}

\textit{Source}: Research and Innovative Technology Administration, U.S. Bureau of Transportation Statistics.

\textsuperscript{126} Economides (1996).
\textsuperscript{127} Meyer (2007).
alternatives to key bridges or highway segments. Redundancy can diminish disruption to the population and the economy.\textsuperscript{128} Disaster risk management must also ensure accessibility to hospitals to avoid human loss and efficient rubble evacuation. There is much greater potential for creating redundancies in dense urban environments than in rural areas, which may require targeted preventive investments. Public transport could be considered a redundancy; for instance, during the floods in Manila in September 2009, elevated rail and metro transit proved more reliable than cars (box 2.9).

\textsuperscript{128} GTZ 2009.
Creating redundancy in logistics, namely through inventory, could also increase the resilience of the economy to extreme events. Inventory costs represent a significant share of total logistics costs. For Japan, macrologistics costs represent some 10 percent of GDP, and inventory costs account for about 3 percent (table 2.5).\(^{129}\) Obviously, holding more stock is costly enough that it could reduce an economy’s competitiveness. Yet without some inventory an economy would suffer severely if its logistics were disrupted. There is thus a tradeoff between logistics efficiency and reliability.

\(^{129}\) OECD (2002)

### Table 2.5. Japan: Macro Logistics Costs

<table>
<thead>
<tr>
<th></th>
<th>Trillion JPY</th>
<th>Percent of GDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logistics costs</td>
<td>47.1</td>
<td>9.5</td>
</tr>
<tr>
<td>Transport</td>
<td>30.5</td>
<td>6.2</td>
</tr>
<tr>
<td>Stock</td>
<td>14.5</td>
<td>2.9</td>
</tr>
<tr>
<td>Other (managerial)</td>
<td>2.1</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Source: OECD (2002).
Urban and Land-use Planning: The sensible principle of not building in harm's way could come up against politically sensitive land-use policies. These policies drive land prices and require cooperation among different, often opposing, interests: government and public decision makers, real estate developers, and the many people building informal settlements.\textsuperscript{130} Transportation planning seldom considers likely climate change when locating facilities and developing land. The vulnerability of rapidly growing cities in developing countries increases without climate-proofing regulations.

Urban and land-use planning must answer questions like where to locate or relocate infrastructure at risk, and how to enhance the resilience of existing networks to climate. There are two main cases:

Construction of new transport infrastructure: That many developing countries do not currently have much transport infrastructure allows them, at least in theory, to locate new infrastructure out of harm’s way. Climate-smart zoning, limited only by a country’s ability to comply with it, would increase infrastructure resilience.

Relocation, rehabilitation, and retrofitting of infrastructure: Existing transport infrastructure, with marginal retrofits, might work with climate evolution but it might also be totally inadequate. In any case, “path dependency” prevents updating or relocating infrastructure overnight (see Dealing with Infrastructure Inertia in chapter 1). If relocation turns out to be impossible or too costly (as when a whole city is exposed to major climate risks), planners should focus on creating redundancies within the infrastructure that exists.

Although the strategic framework for urban and land-use policies is straightforward, institutional dysfunction and failure to enforce regulations are hurdles in many developing countries.

Disaster and Emergency Planning Systems: This section deals with setting up a strategic agenda to cope with emergency situations following disasters. Each phase of the disaster cycle—response, recovery, and reconstruction\textsuperscript{131}—has a different set of priorities. The preventive building of redundancy into networks as part of a consistent disaster management plan is one option.

Response to the emergency: In this phase, which can last hours to weeks, the priority is to restore basic connectivity and communications and remove all barriers to relief. Redundancy is critical if main roads are impassible. The efficiency of response depends on the preparedness of local authorities.

Recovery: As most roads should be opened by this phase, recovery focuses

\textsuperscript{130} In many countries, public decision makers still consider climate change to be too long-term to be worthy of interest. Short-term political cycles do not match long-term climate policies, which only entail present costs

\textsuperscript{131} GFDRR/ World Bank.
not on transport infrastructure but on providing temporary housing and vital social and commercial activities.

**Reconstruction:** Transport networks are crucial here. If they have been damaged, the first emergency fix must be complemented by restoration that takes into account prior infrastructure vulnerabilities. Unfortunately, given resource shortages, decision makers in developing countries often choose what seems the cheapest solution, one that in fact benefits private companies at the expense of the public. The regulatory aspects are central here: Regulation deals with (i) upgrading building quality standards in the context of possible climate change; (ii) defining sound land-use regulation and urban codes; and (iii) modernizing procurement rules so that perverse incentives to favor cheap short-term infrastructure are translated into efficient incentives that result in long-lasting and robust works. The main goal of the reconstruction phase is to avoid creating new vulnerabilities.

An indefinite period of **preparedness** should follow reconstruction. Among other things, a consistent strategy should include early warning, relief supply, and emergency circulation plans that make the best use of existing networks.

**Linking with Other Sectors:** Ideally, transport adaptation should take into account the environment—the broader system that includes forestry, drainage, farming, and water management. For instance, bridge design should take into account both climate model predictions for increased precipitation and sedimentation from erosion amplified by land use.\(^{132}\)

Good forestry practices—for example, no clear-cutting around infrastructure—can help prevent or soften the impact of extreme events. By contrast, upstream deforestation or informal irrigation channels that turn rainfall into flooding could worsen conditions. Deforestation combined with increased precipitation could shorten the recurrence of flooding, for instance, from an average of every 50 years to every 20 years. An integrated approach, however, battles the usual public policy sectoral focus and would require close coordination between very distinct actors and administrations.

### 2.4. Fundamentals of Transport Adaptation

A comprehensive approach to building resilience means that different stakeholders cooperate to define responsibilities, monitor building standards, enforce land-use regulations, manage uncertainties about climate information, and devise decision tools. Although strategic frameworks are well established, that is less true of practical mechanisms for achieving adaptation. The following section offers guidance in assessing climate information and decision-making tools.

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\(^{132}\) COWI Ethiopia (September 2009), p. 55
2.5. Information

The robustness of transportation infrastructure has typically been calibrated using statistics for such climate variables as precipitation, wind speed, and temperature. Since climate change disturbs trends, past records are no longer reliable indicators. What is needed are updated information from cutting-edge climate modeling and new ways of thinking.

Unlike other sectors, such as agriculture, where stakeholders have long engaged with climate scientists to build mutual understanding, transport and climate specialists must still learn to communicate about how climate information might affect a specific project and what actions to take as a result. Further, local authorities must decide what variables are most important locally. Sometimes this will be obvious: land-locked countries need not consider sea-level rise, nor need low-elevation, low-latitude areas be concerned with changes in freeze/thaw cycles. But because the key variables are not always this obvious, there should be an initial general understanding about which variables need to be examined in detailed quantitative terms.133

Given the limits on the information available, a risk assessment approach should be both qualitative and quantitative to minimize the costs of engineering-based adaptation strategies and loss (box 2.10).

133 For example, see the variables chosen for Ethiopia. COWI Ethiopia (2009; 30–31).
Box 2.10. A Five-Step Risk-Assessment Approach to Infrastructure Design

1. Focus on infrastructure that has a long life (more than 40–50 years); infrastructure designed for a shorter life already has flexibility incorporated into the facility replacement schedule.

2. Identify geographic areas that are particularly sensitive to climate change, such as coastal or low-lying areas.

3. Assign a likely probability of environmental change to these sensitive areas to determine if such changes are likely over the useful life of the facility.

4. Create several designs based on different standards to account as needed for a changing environment. For each design estimate the cost, both replacement and economic, of any disruption.

5. Apply the hazard probability to design components that will be affected by a changing environment. Estimate the likely costs of each in current dollars. Choose the design with the lowest net value cost.

The third step is particularly critical. The accuracy of the predicted probability of environmental change will depend on the reliability of the climate projections. Hence, planners must interpret results with caution, using corridors of values rather than single optimal values.

Source: Adapted from Myer (2007).

Besides raw climate information, sound strategy should map critical infrastructure links—kilometers of railroad tracks or roads, percentage of roads paved or gravel-surfaced, number of bridges or length of subway lines—as well as the physical and institutional context. (This has begun for Ethiopia.134) What is the landscape surrounding the asset? Who has jurisdiction over operations, maintenance, and design—both the original design and future retrofits? Are drainage systems integral? Are they managed by the roads authority or by the urban water and sanitation authority? What standards and manuals provide technical specifications? What is the intended design life? Has it already been, or is it likely to be, exceeded? What climate-related problems have already arisen? What non-climate-related problems?

Knowing the internal state of a structure is also important. Innovative technologies, such as nano-sensors, can monitor how during extreme events infrastructure reacts to water levels and currents, wave action, winds, and excessive temperatures.

2.6. Decision-making Tools

Coping with a less predictable climate requires new decision-making tools tailored to manage deep uncertainty.
and reduce risks. Adaptive management should acknowledge the limitations of the information available and incorporate learning feedback loops.

Decision makers should be open to revising an investment or policy if new information becomes available. A key adaptive strategy therefore is to avoid locked-in technologies or land-use and siting decisions that can be costly to reverse if poorly adapted to future conditions, both climate and nonclimate (such as population growth).

Adaptive decision making means assessing the additional benefits of decisions that allow for fine-tuning or switching to an altogether different option. Additional benefits also accrue from decisions that incorporate options contingent on future states of nature (for example, building roads that can withstand temperature increases, or enacting climate-smart land-use policies for locating new infrastructure). Preserving future choices thus has a value per se, in addition to increasing the ability to adapt to new economic and climate contexts.

There are several practical approaches to increasing robustness and flexibility:

- Pursuing no-regret investment and policy options, which provide benefits regardless of future climate changes
- Promoting reversible strategies, from easy-to-retrofit designs to structured
- Incorporating safety margins that reduce vulnerabilities at manageable cost, which can include buying insurance, building redundancy into systems, or marginal design changes that can have a big impact at low or even no cost
- Identifying soft strategies when vulnerabilities are mainly caused by institutional failures
- Giving preference to strategies that reduce decision-making time by formalizing inclusion of feedback loops and periodic reassessment of initial policy and investment design
- Taking into account conflicts and synergies between isolated investments that should be covered by an integrated strategy; this is particularly important in the transport sector given barriers between modes and the very strong inertia of transport infrastructure (see chapter 1)

A structured tool for increasing adaptiveness and resilience is robust decision making. The Robust Decision-Making (RDM) framework is a formalized approach to evaluating options that recognizes that traditional

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135 Hallegatte (2009); World Bank (2010).

136 For a careful overview of RDM, see Lempert and McCollins (2007) and Lempert and Schlessinger (2000).
decision-making tools, such as the expected utility framework, cannot cope with deep uncertainty. The expected utility framework requires that decision makers know the probability distribution of various climate phenomena and the likely losses or benefits from each—information fundamentally unknowable with a changing climate regime.

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137 Expected utility theory elaborates on the basic expected value framework by incorporating individual or social preferences (or tolerance) for risk. In a process based on expected value alone, for each option the decision maker considers the expected value (the probability of the outcome associated with that option multiplied by the value, in monetary terms, of the outcome being realized, minus the known cost of pursuing the option) and chooses the one with the highest expected value. For example, paving a gravel road costs more than maintaining it; if a flash flood that would wash out the gravel but not the paved road is not very likely, it would not be worth the extra expense of paving. In expected utility theory, the calculation is the same, except that for each option the decision maker considers the expected utility value of each option—wherein the probability is multiplied by the value in terms utility, which captures the decision maker’s risk preferences. Decision makers who are risk-averse will be inclined to choose options that may have lower payoffs (or higher costs) but entail a lower probability of losses. (Monetary damages from a flood, once weighted by multiplying by the low probability of that flood, do not offset the additional cost of paving the road; however, the planner’s attitude toward risk may be such that even the slim possibility of disaster is unacceptable, warranting the extra expense of paving.) It is essential to note that in both expected value and expected utility frameworks, the decision maker must know the probability distribution of the outcomes of choosing various options to assign an expected value or utility to each option.

RDM, by contrast, is designed to cope with deep uncertainty where probability distributions of outcomes are unknown, when low-probability, high-impact events such as climate extremes are projected to increase at unknown speeds, intensities, and precise geographical distributions. Rather than asking the usual “What is the future likely to bring?” decision makers must ask “What actions should we take given that we do not know the future?”

RDM suggests a balancing not of expected utility and immunity to uncertainty under budget constraints but of various levels of “coverage” against uncertainty (analogous to insurance) given a society’s threshold for acceptable versus unacceptable risk and its budget constraints. RDM may not offer complete protection from climate risks, but it does prepare decision makers to face uncertainty and helps them weigh the inevitable tradeoffs between cost of coverage and acceptable risks. Thus, rather than helping decision makers predict what will happen, RDM helps them to better define and select from available choices. In fact, RDM both reduces policy vulnerability and increases policy flexibility.

For transport, RDM could be most useful in guiding long-lived capital investments in new transport infrastructure when decision makers are confronted with both deep uncertainty and a wide array of options for location, capacity, and other design
features. The aim would be to select not the traditionally "optimal" option but the option best suited to generate consensus among stakeholders, some with divergent views about the probability of various impacts, as well as to minimize the impact of adverse climate surprises.

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138 So far, despite its promising new insights, this theoretical framework has yet to be applied to transport projects, though it has been used successfully for long-term water management decisions in California. See Groves, Wilkinson, and Lempert (2008) and Groves, Yates, and Tebaldi (2008).


Ebinger and others (2008).


Janssen, Marco and Elinor Ostrom, eds. 2006. Special Issue on Resilience, Vulnerability and Adaptation, Global Environmental Change 6(3): 268-281


JR East (2009)


Transportation Research Board, 2008, “Potential Impacts of Climate Change on U.S. Transportation”


Transport accounts for 13 percent of total GHG emissions and is one of the fastest-growing sources. Without significant policy action, the increased mobility, motorization, and urbanization that accompany economic development will massively increase carbon emissions.

Some current policies could reduce energy intensity and curb transportation demand without compromising economic growth. But behavior and lifestyles are hard to change. Transport infrastructure is very long-lived. Success will require rapid intervention on many fronts.

Advances in engine fuel efficiency will, of course, pave the way, but new technology is not enough. Economic measures, such as pricing, regulation, and the availability of multimodal transportation systems, are also essential. Soft measures in infrastructure operations could also help—and rapidly. If they are to be effective, all these measures must be integrated into a coordinated sector-wide approach.

Urgent action is needed before economies become locked into high-carbon growth. In the United States, urban settlement patterns and interurban infrastructure established decades ago have led to today’s high transport intensity (figure 3.1), making it difficult to expand mass transit and change behavior despite fossil-fuel price increases.

This chapter discusses how to reconcile development with the need to curb emissions, looking at three sets of instruments. We first discuss new technologies and alternative fuels, limits to their potential in the short term, and their high cost. We then turn to supply-side measures and their limitations: without alternative modes, people have no choice but to rely on road transport. Finally, we look at demand-side policies, such as incentives. Ultimately, we argue that fuel taxation is the most effective and direct way to promote both energy efficiency and mass transportation.

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139 IPCC (2007). The total includes emissions from land-use change and forestry.

140 See, for instance, Lecocq and Shalizi (2009).
Figure 3.1. Paths of Automobile Use


3.1. Technology: Necessary, Promising, but Still Far Off

New technologies are necessary for low-carbon growth, but they vary in their commercial readiness. New road, rail, and aviation engine technologies and biofuels still have relatively little potential for deep emission cuts because of their high cost, even when carbon prices are high.\textsuperscript{141} Significant and accelerated technological development and diffusion are still needed.

\textsuperscript{141} World Development Report (2010a).
3.1.1. Engine Efficiency and New Engine Technologies

Improving the efficiency of internal combustion engines is critical because they are expected to dominate the market for the near future. Cars and trucks account for about 67 percent of total transport emissions (figure 3.2). About 1 billion cars are now on the roads worldwide. Another 2.3 billion are likely to be added by 2050, mostly in developing countries given the expected economic, motorization, and income growth there, and most new cars will still rely on traditional internal combustion engines. Advanced low-carbon engine technologies, such as hybrids, comprise only a small percentage of the market in high-income countries and are very rare in developing countries.

Figure 3.2. World Transport CO₂ Emissions by Vehicle Type (2000)


3.1.1.1. Fuel Economy

Most improvements in fuel economy to date occurred before the mid-1980s (figure 3.3). U.S. fuel economy for passenger cars (sales volume weighted) dropped from 18 liters per 100 km (13 miles per gallon [mpg]) in 1978 to 8.3 liters per 100 km (28.3 mpg) in 2009; in Europe, it decreased from 10 liters per 100 km to 5.7–6.8 between 1975 and 2008.

142 World Bank (2008b).
143 Chamon and others (2008).
The prevalence of diesel vehicles, which emit about 7 percent less CO₂ than gasoline vehicles, partly accounts for Europe’s relatively high fuel efficiency.¹⁴⁵

Some developing economies have therefore favored diesel over gasoline-powered cars, with diesel representing up to 90 percent of domestic markets (figure 3.4).

Fuel economy standards also contribute to engine efficiency, although how much is debatable, especially relative to other interventions, such as fuel taxes. Standards differ by country (table 3.1). The U.S. Corporate Average Fuel Economy (CAFE) program introduced in 1975 requires automobile manufacturers to meet average fuel consumption targets. In 1995 Japan introduced standards to reduce fuel consumption by 19 percent and achieved the target by 2004.

¹⁴⁵ Transport Research Board of the National Academies (2010). Until recently, diesel engines emitted more non-CO₂ pollutants, such as particulates, NOx, and methane, (Defra 2009). These negative environmental effects have become more manageable thanks to advanced technologies, such as diesel particulate filters. However, proper environmental regulations are critical to control these other air pollutants.
A new target set in 2006 aims for another 23.5 percent reduction. In Europe improvements in fuel economy were largely a side effect of air pollutant regulations, although in 1998–1999 car manufacturers agreed with the European Commission (EC) on a voluntary average emission target of 140 grams of CO₂/km for new cars—the 1995 average was 187 grams/km.

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146 METI (2006).
147 Zachariadis (2006).
Figure 3.4. Diesel Share of Total Gasoline and Diesel Fuel Use

![Graph showing diesel share of total gasoline and diesel fuel use across different countries.]

*Source: OECD (2002a).*

Table 3.1. Fuel Economy Standards for Passenger Cars, U.S., EU, and Japan

<table>
<thead>
<tr>
<th>Year</th>
<th>United States</th>
<th>European Union</th>
<th>Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995*</td>
<td>27.5 mpg (standard for 1995) (=8.6 liter/100 km)</td>
<td>140 g/km (voluntary target by 2008) (=6.1 liter/100 km)</td>
<td>6.4 - 21.2 km/liter (target by 2010) (=4.7 - 15.6 liter/100 km)</td>
</tr>
<tr>
<td>2007*</td>
<td>27.5 mpg (standard for 2007) (=8.6 liter/100 km)</td>
<td>120 g/km (expected by 2012) (=5.2 liter/100 km)</td>
<td>7.4 - 22.5 km/liter (target by 2015) (=4.4 - 13.5 liter/100 km)</td>
</tr>
</tbody>
</table>

*1998 and 2009 for Europe.

*Source: Zachariadis (2006); U.S. Department of Transportation; European Commission Environment; METI (2006).*
3.1.1.2. Hybrids

Low-carbon hybrid engines have great potential to reduce fuel input per vehicle-km but are still expensive (figure 3.5). For instance, the Toyota Prius, the best-selling of about 20 hybrid car models, uses 4.7 liters of fuel/100 km (50 mpg) but costs about $21,000. Hybrids have benefited from public programs: New York City aimed to replace all 13,000 taxis with hybrid cars by 2012, the equivalent of removing 32,000 cars from the road.148 Boston, San Francisco, and Seattle are also considering this approach.149 Tax credits and subsidies are often offered as incentives to taxi or bus operators. For instance, the U.S. government allows hybrid buyers tax credits of up to $3,000,150 and since 2002 the Japanese government has subsidized half the price differential between hybrids or electric cars and conventional vehicles.151

149 Seattle Times, March 8, 2010.
Figure 3.5. Estimated Emissions Reduction by 2050 and Costs by Vehicle and Fuel Type

Note: The curves indicate the marginal costs of different technologies and fuels in contributing to CO₂ reductions from light-duty vehicles in 2050. If low-carbon biofuels are used, the marginal costs could be negative, so that those technologies could generate net savings of CO₂ over their lifetimes. The figure shows that most technologies would be developed if oil prices are $120 a barrel and the carbon price is $130 per tCO₂eq, resulting in a savings of 5Gt CO₂ eq a year. But at an oil price of $60 a barrel, more advanced technologies would not be tapped and emissions savings would be 3Gigatonnes CO₂ eq a year. Source: IEA (2009).

But hybrid vehicle use is still limited, especially in developing countries, and wider use will depend on lower prices. The 600,000 hybrid cars sold in 2009, mostly in the United States and Japan (table 3.2), are less than 2 percent of the 51 million cars sold worldwide.¹⁵² With the price differential between a hybrid and a conventional car at 30–60 percent, it would take more than 10 years to pay back the additional cost of a hybrid if gas were $3 a gallon and average yearly mileage 15,000 miles. Ten years is a rather long investment period, particularly given technology and fuel price uncertainties.

Table 3.2. Top Global Hybrid Vehicle Markets (2009)

<table>
<thead>
<tr>
<th></th>
<th>Hybrid Sales (millions)</th>
<th>Total Car Sales (millions)</th>
<th>Hybrid Share (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>265,501</td>
<td>10.4</td>
<td>2.6</td>
</tr>
<tr>
<td>Japan</td>
<td>249,619</td>
<td>2.9</td>
<td>8.5</td>
</tr>
<tr>
<td>Canada</td>
<td>16,167</td>
<td>1.5</td>
<td>1.1</td>
</tr>
<tr>
<td>Netherlands</td>
<td>13,686</td>
<td>0.4</td>
<td>3.5</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>13,661</td>
<td>2.0</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Source: hybridCARS (2010); Global Economic Research (2010); Japan Auto Dealers Association.

3.1.1.3. Electric and Fuel Cell Cars

In recent years several major car manufacturers have begun to mass-produce electric cars. Electric cars emit no CO₂, but whether they reduce emissions depends on the carbon intensity of their electricity, which varies significantly and will continue to do so unless there is major intervention (figure 3.6). If their fuel efficiency does not improve, the advantage of electric cars will remain limited or disappear.

Figure 3.6. GHG Intensity of Electricity Generation, by Region (IEA baseline scenario)

If electricity is reasonably efficient, the emission intensity of electric cars is significantly lower than that of conventional vehicles. A recent experiment in California illustrates the promising environmental benefits of electric school buses: CO₂ emissions were 3.5 kilograms (kg) per mile for a diesel bus and 0.8 kg for an electric bus. Replacing all 475,000 California school buses with electric buses could significantly reduce emissions.¹⁵³ Electric buses also reduce pollutants, emitting 93 percent less NOₓ than diesels.¹⁵⁴

However, electric cars currently cost at least $50,000, up to four times more than gasoline-powered vehicles. In the school bus project, electric buses cost more than one and a half times diesel buses.¹⁵⁵ The much lower operating costs—maintenance costs are lower and electricity costs one-fourth to one-tenth as much as conventional fossil fuel per km (even less if a battery is charged during off-peak hours)—are not enough to offset the high purchase price.

Electric cars will also need a whole new recharging infrastructure. Although electric cars can be charged through a normal household outlet, given the limited driving distance per battery charge there must also be public charge points. Without a minimum network in place, electric vehicle use will be limited. Some developed countries, such as France, Japan, the United Kingdom, and the United States, have begun building recharging stations, but current networks account for less than 1 percent of domestic gas stations.¹⁵⁶ Car manufacturers, power companies, electrical industries, car dealers, and regulators must collaborate to set up a network of charging stations that use standardized charger plugs and management systems.

Another constraint on electric vehicles is battery technology.¹⁵⁷ Batteries are still expensive—$6,000 for plug-in electric hybrids and $16,000 to $20,000 for a fully electric vehicle.¹⁵⁸ In addition, the mass and volume of battery packs are still too large, and driving distance is limited by battery capacity. Most electric cars can travel fewer than 160 km on a single battery charge. Battery charging also takes 7 to 14 hours, depending on voltage. Safety is another concern, particularly for high-speed charger technology. Finally, a finite battery life of 5 to 10 years will necessitate regulations for environmentally safe disposal.

¹⁵³ Based on National Association for Pupil Transportation http://www.napt.org/associations/3103/files/SBIC2007FactSheet.cfm
¹⁵⁴ California ZEBRA Electric School Bus Project; California Air Resources Board (2004).
¹⁵⁵ This was a retrofitting project to repair malfunctioning electric buses. The incremental cost of replacing old batteries and other drive systems with new ones was $70,000 more than for a conventional diesel.
¹⁵⁶ There are 535 electric recharging stations in the United States, compared to 161,000 conventional gas stations (U.S. Department of Energy, http://www.afdc.energy.gov/afdc/fuels/stations_counts.html).
¹⁵⁷ The problems also apply to hybrid vehicles but are an especial concern for fully electric cars.
¹⁵⁸ IEA (2009).
Despite these challenges, in certain conditions electric vehicles have advantages. School or public buses are one of the most promising examples. The driving distance of school buses is typically not long, and buses are usually only used for several hours a day. Thus, there would be time to charge batteries at school bus parking lots. Electric cars are also well suited for urbanites, who typically drive only short distances each day and could charge batteries at home at night. For longer distance travel, they could use mass transit, such as railways.

Fuel cells are attracting increasing attention. A number of materials, such as proton exchange membranes and solid oxide, can be used for fuel cells, though the focus has been on hydrogen because it produces no atmospheric pollutants—water is its only byproduct. Although evolving, fuel-cell technology is still meeting commercial resistance because of its intensive use of expensive catalysts like platinum, the high cost of building hydrogen distribution networks, and the high temperatures and more-than-atmospheric pressures needed to operate it. Finally, current fuel-cell volume and weight need to be downscaled.

In addition, a significant amount of hydrogen has to be produced for fuel cell cars. This is problematic for mitigation. In general, fuel-cell technologies may still be too carbon-intensive even in the long run (figure 3.5). Current production depends on natural gas, coal, or grid electricity, creating significant upstream emissions. Frontier technologies using biomass may be able to reduce lifecycle emissions, but practical use still requires substantially more advanced technology (Transportation Research Board 2010).

3.1.1.4. Jet Engines

Air transport is fuel-intensive, accounting for 12 percent of total transport emissions. For example, a Boeing 747 flying at 900 km/hr uses one gallon of fuel every second. As with vehicle engines, aircraft technology is evolving. Over the past four decades, aviation fuel consumption has declined 60–70 percent with the development of high-bypass ratio engines and aerodynamic efficiency (figure 3.7). The latest Boeing 747 is 20 percent more fuel efficient than the original model (table 3.3). Advanced materials such as aluminum alloys and composites that reduce airframe weight have also improved fuel efficiency. A 1 percent reduction in the gross weight of an empty aircraft can reduce fuel consumption 25–75 percent.

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159 Transportation Research Board (2010).
161 IEA (2000); World Bank (2009).
Figure 3.7. Passenger Aircraft: CO₂ Normalized Energy Efficiency (MegaJoule/available seat km)

*Note:* For each type of airplane, the circles refer to energy efficiency improvements in the engines and the squares to improvements in airframes, such as winglets. Thus, the fuel efficiency of aircraft decreased from 80–90 MJ per available seat kilometer in 1960 to 30–40 MJ in the 1990s, about one-third from engine improvements and two-thirds from airframe improvements.

*Source:* IPCC (1999); reproduced in World Bank (2009).

Table 3.3. Boeing 747 Average Fuel Efficiency

<table>
<thead>
<tr>
<th>Model</th>
<th>Liters / hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>B747-100</td>
<td>14,645</td>
</tr>
<tr>
<td>B747-200/300</td>
<td>13,434</td>
</tr>
<tr>
<td>B747-400</td>
<td>11,865</td>
</tr>
</tbody>
</table>

3.1.1.5. Railway Technologies

Rail contributes as little as 2 percent of total transport emissions because railways are low-carbon emitters and rail networks are equivalent only to about 6 percent of global paved roads. In some major economies, however, railways account for about 9 percent of total passenger-km and 30 percent of total freight ton-km (figure 3.8).162

Railways consume a significant amount of diesel fuel.163 The UN Framework Convention on Climate Change estimates that industrialized countries consume 690,000 Terajoule (TJ), 17,000 million liters for rail. This figure could double if developing countries, where diesel-powered locomotives are often outdated and highly polluting, are included (table 3.4).164 Developing countries may have more opportunities to reduce emissions through improved operations, which are often inefficient, than through new technologies.

Electrifying passenger railways within dense cities and between large cities could greatly reduce emissions. For instance, the EC has been tightening emission regulations for new railway engines since 2004. Railway electricity use could also be reduced through improved operations (see below) and less emission-intensive technologies (box 3.1).

162 EC (2009).
163 Once trains are electrified, the emission issues in the sector translate into the energy-sector efficiency problem (see figure 3.6).
164 UIC (2007).
Figure 3.8. Railway Traffic by Region

Source: Amos and Thompson (2007).

Table 3.4. Railway Diesel Fuel Consumption, Selected Countries

<table>
<thead>
<tr>
<th>Country</th>
<th>Company/Association</th>
<th>Fuel Use (million liters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>Association of American Railroads</td>
<td>16,655</td>
</tr>
<tr>
<td>Canada</td>
<td>Railway Association of Canada</td>
<td>2,209</td>
</tr>
<tr>
<td>India</td>
<td>Indian Railways</td>
<td>2,000</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>Association of Train Operating Companies</td>
<td>600</td>
</tr>
<tr>
<td>Germany</td>
<td>DB</td>
<td>368</td>
</tr>
<tr>
<td>France</td>
<td>SNCF</td>
<td>238</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>EWS (freight)</td>
<td>150</td>
</tr>
<tr>
<td>Kingdom</td>
<td>SBB</td>
<td>77</td>
</tr>
<tr>
<td>Latvia</td>
<td>Romanian Railway Company for Freight</td>
<td>70</td>
</tr>
<tr>
<td>Switzerland</td>
<td>SBB</td>
<td>10</td>
</tr>
<tr>
<td>Netherlands</td>
<td>NS</td>
<td>6</td>
</tr>
</tbody>
</table>

Box 3.1. Rail Companies: Energy Consumers but also Electricity Producers

JR East, a Japanese rail company serving 17 million passengers a day, can generate 3,500 GWh of electricity, 60 percent of the company's electricity consumption. This is roughly equivalent to the total consumption of Albania’s 3 million people or Côte d’Ivoire’s 20 million. Although the company generates a quarter of its electricity from hydropower, it still generates 1.1 million tCO₂ every year.

Figure B.3.1. Energy Production Trends in Japanese Railways

Source: JR East 2009.

3.1.2. Promise and Challenges of Biofuels

Biofuels could complement the modest technological advances in internal combustion engines. Ethanol is produced from food crops, such as sugarcane and maize, and biodiesel can be made from vegetable oil and animal fat. Both have the potential to lower hydrocarbon and carbon monoxide emissions. They are also sulfur-free. Higher octane biofuels allow ethanol-fueled vehicles to run on engines with a higher compression ratio, increasing engine efficiency.

However, the energy intensity of these first-generation biofuels may not be superior to pure gasoline. Ethanol contains about 33 percent less energy than gasoline and biodiesel up to 10 percent less. Total fuel economy, therefore, is expected to improve only a few percentage points.165 Second, if accounting for lifecycle emissions, net emission savings from ethanol may not be large. Estimates differ substantially because of different assumptions and feedstock used.166 In Brazil the savings

165 Kojima and Johnson (2005).
166 Croezen and others (2010).
could reach about 90 percent, including fertilizer production and fuel manufacturing. But in general estimated CO₂ emission savings range from 6 to 28 percent when indirect land use change is taken into account. This would include the cost of expansion to new land for crops that were on land diverted to biofuel crops.

**Biofuel Market:** The biofuel market is growing steadily. Many countries, among them Argentina, Australia, Brazil, Canada, China, Colombia, the European Union (EU), India, Indonesia, Malaysia, Mexico, Peru, the Philippines, South Africa, and the United States, have set biofuel targets. However, the commercial viability of biofuels is questionable. On one hand, with increasing awareness of climate change, the public is more interested in biofuels. A recent survey shows that nearly half the respondents would pay at least 20 cents more per gallon (5.3 cents per liter) for ethanol fuel (figure 3.9); however, another study found that their willingness would depend on the greenness of the biofuel. While the premium for E10 (90 percent gasoline, 10 percent ethanol) is estimated at 12 cents per gallon, for E85 (15 percent gasoline, 85 percent ethanol) it would be 15 cents—30 percent more. In any case, the amounts people are willing to pay are far below the incremental cost of biofuel production, so that the government would have to give substantial support, both direct and indirect, for biofuels to become competitive with gasoline.

**Figure 3.9. Willingness to Pay for Ethanol, United States**

![Figure 3.9](image)

*Source: Solomon and Johnson (2008).*

**Biofuel Production Costs.** Brazil and the United States are the world’s two largest biofuel producers, but currently only Brazil has achieved commercially viable production (figure 3.10). While Brazil produces ethanol mainly from sugarcane and accounts for 42 percent of world ethanol fuel, the United States mainly uses maize to produce 46 percent of global ethanol fuel. The U.S. government subsidizes biofuel consumers and producers at a rate of about $1.44 to $1.85 per gallon (38 to 49 cents per liter) of petroleum equivalent. Brazil has supported its sugarcane-based ethanol industry for 30 years with a wide range of incentives, from price subsidies and tax

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167 Macedo and others (2004).
168 Croezen and others (2010).
169 Searchinger (2009).
170 Kojima (2010).
171 World Bank (2008a).
exemptions to promotion of flexible-fuel vehicles.\textsuperscript{172}

Figure 3.10. Sugar Production Costs as an Input to Ethanol Production (US$/ton)

\textbf{Crop-based Biofuel Weaknesses.} Beyond cost, first-generation biofuels have inherent disadvantages. First, the food crops from which they come often require considerable water, meaning there must be efficient water use, including good irrigation, and close coordination with other water users. Second, biofuel production often has environmentally adverse consequences, such as air emissions and waste water discharge. Finally, it increases feedstock prices, as was seen in the U.S. maize market in 2006. Without significant growth in the agricultural sector, balancing food security and crop-based biofuel production will be difficult.\textsuperscript{173}

\textbf{Potential and Challenges of Cellulosic Biofuels.} Second-generation biofuels that use nonfood crops, such as agricultural residue (e.g., sugarcane waste) and timber and urban waste (e.g., waste paper and tree trimmings), are more compatible with food security and rarely compete for water resources. However, they are still in the initial stages of development, their commercial viability depends on significant economies of scale, and their use requires more efficient waste management systems.

\textbf{Penetration of Compatible Vehicles.} Biofuels require flexible-fuel vehicles that can run on any mixture of fuel ethanol and gasoline. But fleet turnover is generally slow, because vehicles last 10 to 15 years. In Brazil more than 9 million flexible-fuel vehicles are on the road, representing some 20 percent of the country’s registered vehicles.\textsuperscript{174} But it took 15 years after the launch of the National Alcohol Program in 1975 for 50 percent of the fuels used in flexible-fuel vehicles use to be biofuels. In the United States, where the government introduced CAFE credit incentives for the manufacture of alternative fuel vehicles in 1998, about 4 million flexible-fuel vehicles capable of using E85 are on the road—just 5 percent of the country’s vehicles.

\textbf{Biofuel-Related Infrastructure.} Biofuel vehicles require a new network of refueling stations, hybrid mill and distillery complexes, and significant investment in feedstock delivery.\textsuperscript{175}

\textsuperscript{172} Kojima and Johnson (2005).
\textsuperscript{173} World Bank (2008a).
\textsuperscript{174} Brazil Institute (2007).
\textsuperscript{175} Kojima and Johnson (2005).
\textsuperscript{176} Transportation Research Board (2010).
Currently, there is a critical shortage of fuel stations. In Brazil 33,000 gas stations are selling ethanol alongside gasoline, but in the United States there are only about 6,500 alternative refueling sites, of which only about 2,700 offer ethanol or biodiesel; in comparison, there are about 161,000 conventional refueling stations. Incentives for flexible fuel cars have thus not been particularly effective. Potoglou and Kanaroglou (1970) found that Canadian consumers would not choose alternative-fuel vehicles unless fuels were available at more than 50 percent of existing stations.

**Flexibility and Uncertainty.** Technical flexibility is a robust strategy for dealing with climate change and commodity price uncertainty. Hybrid mills and distilleries could allow for easy switching between food and ethanol production. Fuel flexibility allows both producers and consumers to respond to a wider range of economic and climate conditions. For instance, in Brazil an ethanol mandate allows the fuel blending proportion to vary between 20 and 25 percent. In March 2006 after world sugar prices reached a historic high the government reduced the proportion from 25 to 20 percent; raised it several months later to 23 percent; raised it to 25 percent in July 2007; and reduced it back to 20 percent in February 2010.

**Transforming Infrastructure to Low-Carbon Assets**

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177 Brazil Institute (2007).  
179 Kojima (2010).  
180 Anas and Timilsina (2009b).
unnecessary detours. This demands a much broader city management approach, including land-use and transport planning policies.

3.1.3. Supplying Alternative Transport Modes

The modal structure of transport plays an important role in determining carbon emissions, particularly when car ownership is relatively low (box 3.2). Shifting from passenger vehicles to mass transit can significantly reduce emissions (table 3.5). An average public bus emits only half as much CO₂ equivalent per passenger-km as a small petrol-fueled car. Railways, especially between cities that are far apart, are even more ecofriendly. Light-rail emissions are less than or at most equal to average bus emissions. Subways also seem to be less polluting, though this depends on passenger occupancy. For large vehicles, such as public buses, compressed natural gas (CNG) and liquefied petroleum gas (LPG) have an advantage over diesel. ¹⁸¹ Since the late 1990s, 30 major cities in China have implemented the National Clean Vehicle Action program to use more CNG and LPG for public transportation. More than 80 percent of taxis in Shanghai and 50 percent of buses in Beijing use CNG or LPG. ¹⁸²

¹⁸¹ Defra (2009).
¹⁸² Hou and others (2002); Zhao (2006).
Table 3.5. Average CO₂ Emission Factors by Vehicle Type, United Kingdom

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>g CO₂ per Kilometer</th>
<th>g CO₂ per Passenger-Kilometer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petrol car (small)</td>
<td>151.8</td>
<td></td>
</tr>
<tr>
<td>(medium)</td>
<td>187.7</td>
<td></td>
</tr>
<tr>
<td>(large)</td>
<td>260.6</td>
<td></td>
</tr>
<tr>
<td>Diesel car (small)</td>
<td>127.1</td>
<td></td>
</tr>
<tr>
<td>(medium)</td>
<td>158.0</td>
<td></td>
</tr>
<tr>
<td>(large)</td>
<td>215.4</td>
<td></td>
</tr>
<tr>
<td>LPG or CNG car (medium)</td>
<td>188.3</td>
<td></td>
</tr>
<tr>
<td>(large)</td>
<td>260.7</td>
<td></td>
</tr>
<tr>
<td>Average bus (local)</td>
<td>1,014.7</td>
<td>111.5</td>
</tr>
<tr>
<td>(London)</td>
<td>1,122.9</td>
<td>83.9</td>
</tr>
<tr>
<td>Railway (international)</td>
<td></td>
<td>17.8</td>
</tr>
<tr>
<td>(national)</td>
<td></td>
<td>61.1</td>
</tr>
<tr>
<td>(light rail)</td>
<td></td>
<td>84.0</td>
</tr>
<tr>
<td>(London metro)</td>
<td></td>
<td>78.6</td>
</tr>
</tbody>
</table>

Note: Average passenger occupancy is assumed to be 9.1 for local buses and 13.4 for London buses.

Source: Defra (2009).

Box 3.2. How Multimodality Affects Emissions: ASIF Decomposition

ASIF decomposition, defined below, is useful for analyzing the links between transport, fuel consumption, and CO₂ emissions. In this approach, A stands for CO₂ emissions (CO₂ tons) equal to the product of transport activity (passenger-km or ton-km); S for modal structure (the share of each activity by transport mode); I for modal energy intensity (energy use per unit of passenger or freight travel by mode); and F for emission rate (CO₂ emissions per unit of energy consumed).

\[
\text{Emission} = \frac{\text{Passenger km}}{\text{Passenger km}} \cdot \frac{\text{VMT}}{\text{VMT}} \cdot \frac{\text{Fuel consumption}}{\text{Fuel consumption}} \cdot \frac{\text{Emissions}}{\text{Fuel consumption}} = \text{(Activity)} \cdot \text{(Structure)} \cdot \text{(Intensity)} \cdot \text{(Fuel carbon intensity)}
\]
In developed countries, ASIF is an important determinant of emissions (Figure B3.2.1). In Australia, for instance, passenger transport emissions increased by about 61 percent between 1973 and 1995. Even in Japan, which has extensive mass transit, the modal shift to road increased passenger transport emissions by 25 percent, though much of this could be attributed to the country’s rapid economic growth and increased travel. Meanwhile, in most countries the energy intensity effect, which measures a change in carbon emitted per passenger-km, has been insignificant.

There has been a significant modal switch from rail and marine shipment to road in recent decades, reflecting a demand for flexibility and frequency in freight transport and the poor quality of rail services. In developed countries the shift significantly increased transport emissions. However, rail still offers a comparative advantage for long-distance freight and bulk cargo. Coordinating intermodal transportation systems can enhance competitiveness and reduce emissions.

**Figure B3.2.1. ASIF Decomposition, Selected Developed Countries, 1973–1995 (1973=100)**

<table>
<thead>
<tr>
<th>Travel</th>
<th>Freight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>U.S.</td>
</tr>
<tr>
<td>Emissions</td>
<td>119</td>
</tr>
<tr>
<td>Activity effect</td>
<td>148</td>
</tr>
<tr>
<td>Structure effect</td>
<td>101</td>
</tr>
<tr>
<td>Intensity effect</td>
<td>78</td>
</tr>
<tr>
<td>Fuel mix effect</td>
<td>100</td>
</tr>
</tbody>
</table>

*Source: IEA 2000.*
The relevance of particular transport modes depends on city size, density, and other geographic factors. For rapidly growing, densely populated large cities, rapid transit and light rail transit can be best. In Bangkok, for instance, an elevated 23.5-km rapid mass transit system, Skytrain, was constructed in 1999 to relieve congestion. As of 2008 the system was transporting 460,000 passengers a day.183 Another mass transit system, MRT Blue Line, that went into service in 2004 was used in 2007 by more than 170,000 customers a day. Road traffic was reduced along the Blue Line, although only marginally for several reasons.184 Manila’s LRT1 has been a major public transportation mode since it was commissioned in 1985. LRT1 carries about 300,000 people a day. In Tunis, the 32-kilometer LRT, in operation since 1985, was carrying some 294,000 people per day in 2002.185

An increase in the number of rapid transit or LRT passengers can reduce emissions, though of course not all passengers are former users of more polluting transport, such as cars and taxis. The majority of passengers in the Bangkok MRT Blue Line, for example, were former bus users (table 3.6). Nevertheless, over the next 30 years, increased passenger rail use could save some 1.7 million tons of CO₂, as well as reduce such other pollutants as SO₂ and NO₂ (table 3.7).

However, there are enormous costs associated with heavy rail systems. Very high passenger density is needed to justify the investment, and many projects have overestimated demand. For instance, the estimated ridership of the Skytrain in Bangkok was 600,000–700,000, but initial ridership was only 150,000.186 Similarly, the original estimate for the Blue Line was 250,000–430,000 passengers.187 The LRT1 in Manila envisaged 560,000 passengers a day, but the actual number is about half. Reasons for this vary, from mispricing to lack of coordination with other transport policies.

High-speed rail is another alternative. For instance, a Eurostar journey is estimated to emit on average one-tenth the CO₂ emissions of an equivalent airline flight.188 It also saves considerable time for long-distance travelers. In Sweden high-speed trains are the fastest mode of transportation for distances of 100–600 km. For shorter distances, cars are better, and for even longer distances, air has a comparative advantage (figure 3.11). As economies grow, so too does demand for high-speed transportation (box 3.3). High-speed rail technology has responded to this demand, increasing maximum speeds from 200 km/hr to 515 over the past three decades (figure 3.12). However, because high-speed rail is extremely costly, it may be relevant for only a few developing countries with a critical mass of potential users, such

183 Mandri-Perrott (2010); PPIAF Private Sector Participation in Light Rail Light Metro Transit Initiatives (2010).
184 JBIC (2008).
185 Godard (2007).
186 Mandri-Perrott (2010).
Table 3.6. Transport Modes Used Before the MRT Blue Line Opened in Bangkok

<table>
<thead>
<tr>
<th>Mode</th>
<th>Percent</th>
<th>Mode</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus</td>
<td>51.0</td>
<td>Motorcycle</td>
<td>5.5</td>
</tr>
<tr>
<td>Car</td>
<td>14.2</td>
<td>Van</td>
<td>3.7</td>
</tr>
<tr>
<td>Taxi</td>
<td>12.9</td>
<td>Walking</td>
<td>3.5</td>
</tr>
<tr>
<td>Mass transit system (BTS)</td>
<td>8.6</td>
<td>Boat</td>
<td>0.7</td>
</tr>
</tbody>
</table>


Table 3.7. Estimated Emissions Reduction by MRT Blue Line in Bangkok (tons)

<table>
<thead>
<tr>
<th>Fiscal Year</th>
<th>Global Benefits</th>
<th>Local Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CO₂</td>
<td>SO₂</td>
</tr>
<tr>
<td>2004</td>
<td>28,600</td>
<td>27.3</td>
</tr>
<tr>
<td>2005</td>
<td>32,200</td>
<td>32.2</td>
</tr>
<tr>
<td>2033</td>
<td>74,700</td>
<td>71.1</td>
</tr>
<tr>
<td>Total</td>
<td>1,736,000</td>
<td>1,680</td>
</tr>
</tbody>
</table>


as China, Brazil, and Russia (figure 3.13). China is building a 300-km/hr train from Beijing to Tianjin and planning a 1,300-km line between Beijing and Shanghai. Vietnam is also looking at high-speed rail between its two largest cities, Hanoi and Ho Chi Minh, a distance of about 1,700 km.
Figure 3.11. Long Distance Travel Time, Sweden

*Note:* HST = high-speed train; the X2000 is a tilting train introduced in 1990 on the Stockholm-Gothenburg main line.


Figure 3.12. Maximum Speed of High-Speed Trains

Figure 3.13. High-Speed Rail Construction Costs (€ millions/km)


**Box 3.3. Demand for High-Speed Rail**

Demand for high-speed transportation rises with income as the perceived opportunity costs of travel time increase. Thus in Europe introduction of high-speed trains increases passenger rail demand by 8 percent. In Spain the time elasticity of demand for intercity trains is estimated at 2.5, so that a 10% reduction in travel time would increase demand by 25%. People also appreciate the higher frequency and shorter access time of rail compared to air, particularly for business travel.

1 Couto and Graham (2008).
2 Martin and Nombela (2007).
3 Gonzalez-Savignat (2004).

Bus rapid transit may be a more attractive option in small and medium cities, especially where dense corridors are developing. Although it may generate slightly more emissions than rapid transit, it is much cheaper to build (table 3.5). Many cities now have exclusive or separate bus lanes in main corridors. Dublin, Ireland, established Quality Bus Corridors for city buses in peak hours, enabling buses to travel 20 percent faster than before and bringing about a 20 percent increase in the share of bus transportation. Curitiba, Brazil, has successfully implemented an integrated transit and land-use strategy using high-speed bus systems. Combined with land-use regulations, it has permitted Curitiba to boast one of the world’s highest rates of urban mass

189 OECD (2002b).
transit use: 70 percent of the urban population, an increase of 62% since the transit network’s inception in 1974.

In Bogota, Colombia, public bus fares had been set above competitive levels, leading to excess competition and inefficient, fragmented operations. Bus rapid transit, TransMilenio, was substituted for the old bus system and currently supplies 20 percent of daily trips in Bogota, serving 1 million passengers daily. Average public transit travel speeds increased from 15 km/hr to 27, and accidents on service corridors decreased 79 percent. With innovative pricing and land use measures, the system aims to carry 80 percent of the city’s population by 2015.190

Whether bus rapid transit actually reduces emissions depends on the number of passengers and how efficiently it is operated. Without high passenger occupancy, exclusive bus lanes that crowd out other vehicles could increase congestion elsewhere. Proper route planning and other transport measures are important to achieving high occupancy (see below). Successful bus rapid transit systems also need to link with feeder transportation. In Bogota about 50 percent of TransMilenio passengers connect from other bus systems, and roughly half use the feeder system that belongs to TransMilenio. The rest use traditional bus systems, which are energy inefficient and pollutive.192

Without efficient and coordinated operations, hard infrastructure development does not always reduce emissions.

Substituting rail for road freight holds great potential for reducing emissions. Diesel rail, for instance, generates only one-third as many emissions per ton-km freight as a trailer truck, although the net effect depends on the load factor and the size and type of truck, trailer or rigid (table 3.8). In the United States, using rail rather than truck could reduce emissions by about two-thirds per ton-mile of freight transported.193

However, because freight demand is for more frequent and flexible transport, it may be difficult for rail to maintain its share of total freight transportation. In some countries privatization and other reforms have revitalized rail freight operations, but in many developing countries freight rail is marginalized. It may be worth reinvesting in freight rail infrastructure to take advantage of its capacity to significantly reduce not only emissions but also trade, transportation, and logistics costs.

191 Echeverry and others (2005).
193 Transportation Research Board (2010).
Table 3.8. Average CO₂ Emission Factors, Road and Rail Freight, United Kingdom

<table>
<thead>
<tr>
<th>Transport Mode</th>
<th>g CO₂ Equivalent per Passenger-km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road freight</td>
<td>120.4</td>
</tr>
<tr>
<td>Rigid</td>
<td>234.3</td>
</tr>
<tr>
<td>Trailer</td>
<td>86.0</td>
</tr>
<tr>
<td>Rail freight</td>
<td>78.6</td>
</tr>
</tbody>
</table>

Source: Defra (2009).

3.1.4. Wiser Use of Transport Infrastructure

Wiser use of existing infrastructure can reduce both emissions and trade and transportation costs. The efficiency gains are likely to be significant in developing countries where infrastructure tends to be poorly maintained and inefficiently operated. Soft measures are normally cheaper and quicker to implement than hard. Four examples relate to public buses, air, railways, and logistics.

Optimizing Public Bus Operations.
Energy efficiency in public bus operations can be improved dramatically. In Mexico, for instance, bus system optimization could greatly abate emissions (figure 3.14). Restructuring redundant feeder routes and improving bus stops, traffic signals, public information, and the vehicles themselves could reduce emissions by 31.5 megatons (Mt) of CO₂ equivalent/yr.¹⁹⁴ Switching from diesel to compressed CNG could complement such measures.

¹⁹⁴ Johnson and others (2010); Low-Carbon Development for Mexico (2010).
Optimizing Air Traffic. Jet fuel consumption could be reduced by shorter routes, better taxiing, and continuous descent of aircraft. Jet fuel consumption could be reduced by shorter routes, better taxiing, and continuous descent of aircraft. Several airlines have initiated a pilot program to conserve jet fuel that includes single-engine taxiing on departure and arrival, continuous climb and descent, and a tailored arrival. Through this program a B767 flight from Miami to Paris saved about 1,500 lbs of fuel—about 2.5 percent of total fuel consumption between the two cities. A B747 flight from Paris to Miami could save two to three tons of fuel and six to nine tons of CO₂ emissions. One company estimated that total savings on all transatlantic flights could add up to 43,000 tons of fuel a year, reducing costs by about $40 million and CO₂ emissions by about 135,000 tons. These measures not only reduce emissions but also improve air carrier competitiveness, particularly if international fuel prices remain high (figure 3.15). While cost concerns should motivate airlines to undertake these measures, governments can help by publicizing best practices.

Source: Johnson and others (2010).

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195 IEA (2009).
196 It is assumed that B767 consumes 4,700 liter of fuel per hour on average (World Bank 2009).
197 ATW Online (2010).
Modernization of Rail Assets and Operations. Despite the increasing importance of bulk freight, railways in developing countries are often poorly maintained. The expected life of locomotives is more than 40 years. Upgrading and modernizing locomotives and important lines would increase rail capacity and mitigate emissions by attracting more freight from roads and retaining more current rail users. In the Ukraine transporting freight by road produces more than triple the amount of emissions as moving it by rail. A railway modernization project could facilitate a move toward this more fuel-efficient mode. For every million ton-km shifted from truck to rail or retained by rail, 53–55 million tons of CO₂ could be saved.¹⁹⁸

Better rail operations could also improve national competitiveness and economic growth. With high-quality services, freight rail could support bulk exports and imports. In Ghana, because of the poor quality of rail services, cacao beans travel by truck, where they are more likely to be damaged.¹⁹⁹

Subsidies may be needed for rail freight. Road transport is already heavily subsidized because roads are publicly financed and usually used without charge. The United Kingdom partially subsidizes capital investments in rail: since 1975 the government has spent £185 million to support about 250 projects.²⁰⁰ This not only improves railway operational efficiency but also reduces overall transportation costs.

Improvements in Logistics. An estimated 2,800 megatons of CO₂, 5.5 percent of total emissions, are produced by the logistics and transport sector (figure 3.16). Large-scale, consolidated freight transportation is often more efficient and generates fewer emissions than the fragmented small-volume operations that are dominant in developing countries. Trade-related transport costs for landlocked countries are 50 percent higher than for coastal countries.²⁰¹ One of the reasons for high trade costs is inefficiency in freight operations. Up to 60 percent of truck trips in developing countries are done while empty, compared with 26 percent in the United Kingdom.²⁰² Not surprisingly, the higher the empty rate,

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¹⁹⁸ PAD for Railway Modernization Project in Ukraine (52531-UA); World Bank (2010c).
²⁰⁰ OECD (2002b).
²⁰¹ Arvis (2005).
the higher the freight cost and emission intensity (figure 3.17). More efficient routing and higher load factors should help reduce fuel intensity. Transshipment load centers, multimodal facilities, and logistic services are critical.

A study in Odense, Denmark, showed that establishing a city logistics terminal could decrease total freight transport by 2 percent and energy consumption and CO$_2$ emissions by 15 percent. Copenhagen has adopted a similar system. In the United Kingdom the freight industry improved efficiency markedly through better route planning and reducing empty-vehicle travel. Improved truck specifications reduced fuel consumption 20 percent for 1988–1998. An added benefit is that manufacturers were able to reduce their stocks 20 percent, and wholesale and retail sectors saved £11 billion.

---

204 Though, overloading would generate more emissions, because overloading requires more power (see below section 3.3.2.1).
205 OECD (2002b).
Figure 3.16. Emissions from Logistics Activities

*Source: World Economic Forum (2009)*

Figure 3.17. Average Freight Cost and Empty Trip Rate

*Source: Author, based on Londono-Kent (2010).*
Box 3.4. Building Greener Transport Infrastructure

**Street lighting.** Streetlights operate for 9 to 12 hours every day. Bulbs last a year, fixtures more than 10 years. In the City of Rizhao in China, most traffic signals and street and park lights are powered by solar cells.\(^1\) Mexico aims to replace all street lights with energy-efficient high-pressure sodium lamps in the next two decades, which would reduce emissions by 0.9 Mt CO\(_2\) equivalent a year.\(^2\)

**Greener rail stations.** A commuter train station in Tokyo reduced its energy use 30 percent by introducing automatic on-off systems and LED displays and equalizing the levels of illumination on platforms.\(^3\)

**Greener and carbon-neutral airports.** Although technically falling within the commercial building rather than transport sector, an airport can be made more carbon-neutral by combining energy-efficient building technologies, airport design, and air traffic operation. In Brazil, for instance, the first energy-efficiency contract was awarded to Tancredo Neves/Confins International Airport in Belo Horizonte in 1999. Contractor proposals had to include not only costs but also a technical work plan, including energy-saving measures. The price and technical proposals were weighted roughly equally in the evaluation.\(^4\) A five-year contract will save 1 million Brazilian reals to the economy annually.\(^5\) Other airports, among them Gander International Airport in Canada, are promoting the idea of carbon neutrality.

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\(^1\) Suzuki and others (2009).
\(^2\) Johnson and others (2010).
\(^3\) JR East (2009).
\(^4\) Poole (2008); Singh and others (2010).
\(^5\) INFRAERO (2006).
3.1.5. Better Connecting Transport Infrastructure

Having good intermodal connectivity and good integration between transport corridors and feeder systems is crucial to the success of alternative infrastructure. Connectivity is challenging because the demand for transport is dynamic and depends on numerous factors. Transport infrastructure must therefore be analyzed within the broader context of urbanization and economic development.

Compact Cities. A compact city can be designed through complementary land-use and urban planning. Denser cities are generally more energy efficient and less polluting, with lower vehicle miles (figure 3.18). Thus, European and Japanese car drivers travel 30–50 percent fewer vehicle km than those in the United States (table 3.9).206

Regulations can lead to more compact cities. In Curitiba, Brazil, land use and mobility planning were integrated, with the city’s radial (axial) layout designed to divert traffic from downtown. (Three-fourths of city residents use a highly efficient bus system.) The industrial center was built close to the city center to minimize commuting.207 In Denmark, Norway, and the United Kingdom to ensure that shopping can be done locally, large shopping centers cannot be built outside city centers.208

Evidence indicates that people will go without cars if there are good transport connections to their homes. German data show that demand for cars decreases significantly with good access to shopping centers, cinemas, and theaters.209 In the United States, car ownership decreases with the distance to the nearest bus stop.210 In Hamilton, Canada, the number of cars per household decreases as the number of bus stops within 500 meters of residences increases.211 But if household members work more than 6 km from their dwelling, they are more likely to own one or more cars.

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207 World Bank (2010a).
208 OECD (2002b).
209 Woldeamanuel and others (2009).
Figure 3.18. Individual Transport Emissions and Population Density


Table 3.9. Average Vehicle-km Traveled, Selected Urban Areas

<table>
<thead>
<tr>
<th></th>
<th>Los Angeles 1</th>
<th>London 2</th>
<th>Tokyo 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle-km traveled (millions)</td>
<td>63,020</td>
<td>25,401</td>
<td>25,487</td>
</tr>
<tr>
<td>Population (millions)</td>
<td>9.85</td>
<td>7.62</td>
<td>6.45</td>
</tr>
<tr>
<td>Passenger cars registered (millions)</td>
<td>5.86</td>
<td>2.57</td>
<td>3.21</td>
</tr>
<tr>
<td>Passenger-kilometers traveled per capita</td>
<td>6,399</td>
<td>3,334</td>
<td>3,954</td>
</tr>
<tr>
<td>Passenger-km traveled per vehicle</td>
<td>10,755</td>
<td>9,897</td>
<td>7,948</td>
</tr>
</tbody>
</table>

1 Los Angeles County.
2 Greater London.
3 Tokyo Prefecture.
Intermodal Connections for Passengers. It is important to connect complementary mass transit systems because time spent in transit matters to people.\textsuperscript{212} The lack of feeder transportation to the Bangkok Skytrain was a factor in its disappointing initial ridership.\textsuperscript{213} The MRT Blue Line, on the other hand, had feeder buses and commercial facilities around its stations. However, with the delay of other mass transit projects, such as the Red Line, the number of passengers remains stagnant.\textsuperscript{214}

Only 14 percent of Bangkok MRT Blue Line riders are former car users. The park-and-ride facilities at seven stations have been underused. Price incentives, such as discounts for park-and-ride and bus-train transfer passengers, could address this problem. However, a park-and-ride facility could also increase vehicle travel and emissions. For instance, driving distances increased in Osaka, Japan, when a park-and-ride system was built outside the city center; pushing down estimated net CO$_2$ emissions reductions to only 1,400 kg/month.\textsuperscript{215} A combination of policies should address the issue of intermodal facilities for road users.

Nonmotorized Modes. Integrating walking and cycling with mass transit is essential to making a city compact. Such nonmotorized modes, along with low-carbon two- or three-wheel motorized vehicles, have a clear advantage in mitigating emissions, are an important alternative within cities, and are still dominant in individual transportation in developing countries (table 3.10). In Dhaka, Jakarta, and Shanghai, nonmotorized modes account for more than 40 percent of total trips (figure 3.19). In Africa walking still predominates in urban areas; in Nairobi and Dar es Salaam half the trips are entirely on foot.\textsuperscript{216} The use of nonmotorized modes may decline with economic growth, but even in developed countries, they can still represent a significant share of travel if they are well integrated with other transport modes, as in the Netherlands and Denmark.\textsuperscript{217} In addition, new nonmotorized tools are being developed. In China for instance, the electric bicycle (E-bike) is becoming more popular; the market has grown to 21 million in the past decade.\textsuperscript{218}

\textsuperscript{212} Cervero (2007); Holmgren (2007); Takeuchi and others (2007); Anas and Timilsina (2009a, 2009b).
\textsuperscript{213} Mandri-Perrott (2010).
\textsuperscript{214} JBIC (2008).
\textsuperscript{215} OECD (2002a).
\textsuperscript{216} I-ce (2000).
\textsuperscript{217} IEA (2000).
\textsuperscript{218} World Bank (2009).
Table 3.60. Trip Purpose by Bicycle (Percent)

<table>
<thead>
<tr>
<th>Trip Purpose</th>
<th>Accra</th>
<th>Delhi</th>
<th>Leon</th>
<th>Lima</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commuting</td>
<td>31</td>
<td>72</td>
<td>44</td>
<td>46.2</td>
</tr>
<tr>
<td>Business/goods transport</td>
<td>4</td>
<td>10</td>
<td>Little</td>
<td>4.5</td>
</tr>
<tr>
<td>School</td>
<td>8</td>
<td>14</td>
<td>Little</td>
<td>25.2</td>
</tr>
<tr>
<td>Shopping</td>
<td>24</td>
<td>2</td>
<td>High</td>
<td>10.5</td>
</tr>
<tr>
<td>Leisure</td>
<td>33</td>
<td>2</td>
<td>Little</td>
<td>6.8</td>
</tr>
</tbody>
</table>

*Source: I-ce (2000).*

Figure 3.19. Modal Share, Selected Cities in Asia

![Modal Share Chart](image)

*Source: International Road Federation (1998); reproduced by I-ce (2000).*

Table 3.71. Road Users Killed, by Transport Mode

<table>
<thead>
<tr>
<th>City (year)</th>
<th>Pedestrian</th>
<th>Bicyclist</th>
<th>Motorcyclist</th>
<th>Car Driver</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delhi (1994)</td>
<td>42</td>
<td>14</td>
<td>27</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>Thailand (1987)</td>
<td>47</td>
<td>6</td>
<td>36</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Kathmandu</td>
<td>43</td>
<td>9</td>
<td>13</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>Bandung (1990)</td>
<td>33</td>
<td>7</td>
<td>42</td>
<td>15</td>
<td>3</td>
</tr>
</tbody>
</table>

*Source: I-ce (2000).*
Table 3.82. Costs and Benefits, Selected Nonmotorized Modes

<table>
<thead>
<tr>
<th>Test interventions</th>
<th>Total benefits</th>
<th>Benefit components</th>
<th>Total cost</th>
<th>Cost components</th>
<th>B/C ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walk way improvement along corridor in Morogoro</td>
<td>14,400 USD (per year)</td>
<td>Saving travel time</td>
<td>18,000 USD</td>
<td>Repair curvets, Walkway construct</td>
<td>3.4</td>
</tr>
<tr>
<td>Raised zebra-crossing in Dar es Salaam and Morogoro</td>
<td>4,350 USD (per year)</td>
<td>Avoidance cost of accidents</td>
<td>4,500 USD per zebra crossing</td>
<td>Raised zebra-crossing</td>
<td>1.45</td>
</tr>
<tr>
<td>NMT bridge in Dar es Salaam</td>
<td>6,000 USD (per year)</td>
<td>Saving travel time</td>
<td>11,000 USD per bridge</td>
<td>Bridge, Cost reduction because community participation</td>
<td>4</td>
</tr>
</tbody>
</table>


Nonmotorized Modes and Pedestrian Safety. A particular challenge is ensuring the safety of pedestrians and bicyclists, who comprise the majority of road fatalities (table 3.11). Establishing and improving sidewalks and nonmotorized transport bridges can do so cost-effectively (table 3.11) (I-ce 2000).

Intermodal Freight Connections. Although rail freight can reduce emissions by two-thirds or more, the limited extent of railway networks constrain freight mobility. In Ghana, for example, demand for freight transit to neighboring countries, such as Burkina Faso, Niger, and Mali, jumped in 2002 because of political disorder in Côte d’Ivoire, but most freight was carried by truck because of the lack of intermodal facilities, such as storage and handling equipment, at the north end of Ghana’s rail network in Kumasi.219 Thus a significant opportunity to take advantage of railways was missed. Combining more than one transport mode can increase rail attractiveness and improve freight energy efficiency. In Japan, for example, total energy expended for door-to-door 20-km freight transport was lowest when rail was combined with short-feeder road transport. Truck or rail alone would not be as energy-efficient (table 3.13).220

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220 OECD (2002c).
Table 3.93. Energy Consumption, Door-to-Door Transportation (kilocalorie/km)

<table>
<thead>
<tr>
<th>Transport Mode</th>
<th>100 km</th>
<th>200 km</th>
<th>500 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truck only</td>
<td>444</td>
<td>417</td>
<td>396</td>
</tr>
<tr>
<td>Intermodal: rail short</td>
<td>398</td>
<td>363</td>
<td>305</td>
</tr>
<tr>
<td>feeder</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rail only</td>
<td>557</td>
<td>436</td>
<td>363</td>
</tr>
</tbody>
</table>

Source: OECD (2002c).

Regional Integration of Transport Infrastructure. There can be both institutional and physical barriers to good transport connectivity between countries. Institutional barriers include excessive border tolls (legal or illegal) that induce travelers and freight to detour to roads that are longer but quicker to travel. For example, there are two corridors between Greece and Hungary: Corridor X is 405 km with 13 tolls; Corridor IV is 450 km but with only 7 tolls (table 3.14; figure 3.20). Before FYR Macedonia improved Corridor X, much freight was diverted to Corridor IV, which is 10 percent longer but does not require crossing non-EU borders and has fewer toll plazas.

Physical barriers include few or no border-crossing corridors, necessitating detours. For instance, in South East Europe, Corridor VIII could facilitate East-West traffic221 except that rail sections are missing (figure 3.21). Sometimes institutional barriers are the problem. In South Africa and Mozambique for example, the Maputo Development Corridor created after 1995 extends from South Africa’s northern landlocked provinces to Maputo’s deepwater port, but border-crossing costs and delays divert freight to Durban through a corridor 25 percent longer.222

221 Corridor VIII Secretariat (2007).
222 World Bank (2009b). The distance from Johannesburg to Maputo is about 450 km; the distance to Durban is about 570 km.
Table 3.14. Corridors Between Thessaloniki, Greece, and Nish, Serbia, Compared

<table>
<thead>
<tr>
<th>Corridor</th>
<th>Length (km)</th>
<th>Number of Tolls</th>
<th>Number of Border Crossings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corridor X</td>
<td>405</td>
<td>13</td>
<td>2</td>
</tr>
<tr>
<td>Corridor IV</td>
<td>440</td>
<td>7</td>
<td>2</td>
</tr>
</tbody>
</table>


Map 3.1. Corridor IV (Thessaloniki–Sofia–Hungary) and Corridor X (Thessaloniki–Skopje–Belgrade–Hungary)

*Source: World Bank (2007).*
3.2. Demand-Side Transport Policies for Mitigation

3.2.1. Pricing Incentives

In addition to technology and infrastructure, pricing is not only critical to reducing emissions, it is more effective than regulations.

The price of car use relative to alternative mass transit is central. Price can be adjusted in various ways, e.g., through the cost of fuel and other aspects of car use and through mass transit fares. In developing countries the price of driving seems low compared with developed countries (table 3.15). Among selected major cities, Tokyo’s cost of driving is highest relative to mass transit use because of low rapid transit fares and high gas prices. New York also has high mass transit use because the cost of parking is high. By contrast, in three selected cities in developing countries, the the cost of driving is only 1.21 to 4.15 times higher than mass transit, and is much lower than in developed countries. In those cities parking rates are too generous and mass transit fares set relatively high to cover investment costs quickly.
Table 3.105. Relative Costs of Driving and Mass Transit in Selected Cities

<table>
<thead>
<tr>
<th>City</th>
<th>Rapid Transit Bus</th>
<th>Parking</th>
<th>Gasoline (US$/liter)</th>
<th>Range of Relative Costs of Driving to Public Transit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Washington, DC</td>
<td>$1.75–$4.70</td>
<td>$1.45</td>
<td>$5–$10/ hour, $15–$20 / day</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.37 – 8.77</td>
</tr>
<tr>
<td>New York</td>
<td>$2.25</td>
<td>$2.25</td>
<td>$10/ hour; $25–$30 / day</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.75</td>
</tr>
<tr>
<td>London</td>
<td>£4.00–£10.80</td>
<td>£2.00</td>
<td>£4–£5 / hour; £25–£30 / day</td>
<td>1.44</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.46 – 5.24</td>
</tr>
<tr>
<td>Tokyo</td>
<td>¥160–¥300</td>
<td>¥200</td>
<td>¥600 / hour; ¥2,000–¥2,500 / day</td>
<td>1.42</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.19 – 7.20</td>
</tr>
<tr>
<td>Bangkok</td>
<td>16 Baht–41 Baht</td>
<td>7 Baht–8 Baht</td>
<td>40 Baht / hour</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.21 – 2.48</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manila ²</td>
<td>Php12–Php15 km + Php1.85 per additional km</td>
<td></td>
<td></td>
<td>0.91</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.87 – 4.25</td>
</tr>
<tr>
<td>New Delhi</td>
<td>Rs8–Rs29</td>
<td>Rs2–Rs10</td>
<td>Rs20 up to 10 hours; Rs40 for 10 hours or more</td>
<td>1.09</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.91 – 4.13</td>
</tr>
</tbody>
</table>

¹Public transit assumes a combination of rapid transit and bus. Driving cost is the sum of a daily parking rate and gasoline costs for 10 km of driving (or 0.7 liters of petrol).

²For calculating the relative price, a bus ride of 10 km is assumed.

Source: Author, based on data from Washington Metropolitan Area Transit Authority; Metropolitan Transportation Authority; Transport for London; Tokyo Metro; Toei Bus; Bangkok Metro Public Company, Ltd.; Bangkok Mass Transit Authority; Light Rail Transit Authority; Land Transportation Franchising and Regulatory Board; Delhi Metro Rail Corporation, Ltd.; Delhi Transport Corporation; and GTZ International Fuel Prices (2009).
Changing the relative price depends on institutional feasibility, consumer response, and political acceptability. There are a wide range of policy options, each with advantages and disadvantages (table 3.16).223 Fuel pricing is the best option for reducing emissions. However, while less effective at reducing emissions, other policies have other desirable outcomes. For instance, road use charges raise the marginal cost of car travel, thus reducing congestion by discouraging people from driving.

223 Some studies have more detailed classifications; see, for example, OECD (2002b); Timilsina and Dulal (2009); and NSTIFC (2009). However, these four areas are most important for emissions reduction, and other measures can be considered as variations on these.
Table 3.116. Effectiveness of Major Price Policies in Reducing Transport Emissions

<table>
<thead>
<tr>
<th>Policy</th>
<th>Reducing Vehicle Miles Traveled</th>
<th>Increasing Fuel Economy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Best policy option:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel pricing</td>
<td>Effective</td>
<td>Effective</td>
</tr>
<tr>
<td><strong>Alternative policies:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>If charging on mileage traveled:</td>
<td>Effective</td>
<td>Not effective</td>
</tr>
<tr>
<td>Toll road pricing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>If charging on individual car use:</td>
<td>Partly effective</td>
<td>Not effective</td>
</tr>
<tr>
<td>Cordon pricing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parking prices</td>
<td>Not effective</td>
<td>Partly effective</td>
</tr>
<tr>
<td>If charging on car ownership:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Registration/inspection fees</td>
<td>Not effective</td>
<td>Effective</td>
</tr>
<tr>
<td>If subsidizing new car ownership:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cash for clunkers program</td>
<td></td>
<td></td>
</tr>
<tr>
<td>If subsidizing alternatives:</td>
<td>Effective</td>
<td>Not effective</td>
</tr>
<tr>
<td>Lower mass transit fares</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.2.1.1. Fuel Pricing: Best Policy Option

Fuel pricing is unique in its ability to both discourage people from using cars and increase fuel economy. First, higher fuel prices normally correlate with low car use over the long run (figure 3.20). Second, high prices should induce people to buy more fuel-efficient vehicles, thus reducing vehicle-fuel intensity (figure 3.21).

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Figure 3.20. Passenger Car Travel, Fuel Economy, and Average Fuel Prices (1998)


Figure 3.21. Passenger Car Use and Average Fuel Prices (1998)


Fuel taxes vary significantly by country225 (figure 3.22). The 20 developing countries that most subsidize energy spent some $310 billion on subsidies in 2007.226 From an environmental standpoint, these subsidies should be replaced with a fuel tax, but that is politically difficult227 because it could affect the economy.

225 Delucchi (2007); Chamon and others (2008).
226 World Bank (2010a).
negatively. Certainly, low fuel prices help domestic businesses and citizens in the short run, but they also are financially unsustainable, reduce competitiveness, and harm long-term growth.

Figure 3.22. Fuel Taxation by Country (Percent of Retail Gasoline Price)

How much and how quickly consumers respond to fuel price changes depends on the price elasticity of demand. Estimates of price elasticity vary widely and depend on the functional form used, the estimation technique, the period of estimation, and the country. The literature indicates that the price elasticity of automobile fuel demand would range from –0.03 to –0.4 in the short run and –0.6 to –1.1 in the long run. Highly volatile prices affect fuel consumption, as they did during the oil crises in the late 1980s (figure 3.23). Although price elasticity was surprisingly low in the United States in the early 2000s, it has increased since 2005. Expecting fuel prices to remain high, consumers have begun to change their behavior.

Source: Chamon and others (2008).

228 Chamon and others (2008); Hughes and others (2008); World Development Report (2010).
229 Hughes and others (2008).
230 Park and Zhao (2010).
Low price elasticity may result from a strong "rebound effect," in which as fuel economy improves and the cost of driving declines, people drive more. This can partly offset fuel reductions associated with higher prices. One study estimated the short-run rebound effects at 4.5 percent and the long-run effects at 22.2 percent\textsuperscript{231}; another reported even larger rebound effects of 58 percent\textsuperscript{232}. Behavioral inertia also helps keep price elasticity low; it takes time to change people’s preferences and perceptions. Price elasticity has been particularly low in the United States, where fuel prices historically have been low.\textsuperscript{233} Europe nearly 90 percent of passenger cars are four- or two-door sedans.\textsuperscript{234} In the United Kingdom and Germany, where fuel prices historically have been two to three times higher than the United States, price elasticities are also about twice as high.\textsuperscript{235} European economies also offer more transport options, meaning fuel prices can be more elastic because people can more easily switch to other means of travel.

One popular option is to subsidize cleaner and renewable energy sources. In many countries, diesel fuel is consistently cheaper than gasoline.\textsuperscript{236} This encourages the use of diesel-powered vehicles, which with appropriate filters are less polluting. Biofuels need to be 20–30 percent cheaper than gasoline because their

\textsuperscript{231} Small and van Dender (2007).
\textsuperscript{232} Frondel and others (2008).
\textsuperscript{233} Hughes and others (2008).
\textsuperscript{234} OECD (2002a).
\textsuperscript{235} Frondel and others (2008); Bonilla and Foxon (2009); Frondel and Vance (2010).
\textsuperscript{236} GTZ (2009).
energy content is lower than that of gasoline, but subsidizing biofuels simply adds to their development cost.

3.2.1.2. Road User Pricing

Road user pricing is the second-best solution. Toll roads and cordon pricing are typical examples. Road pricing is less effective than fuel pricing because road charges do not affect consumer choice of vehicle unless charges are based on vehicle emission class. Road pricing is, however, more effective than other vehicle-based charges because it closely—though not perfectly—relates to fuel consumption and thus emissions. This is distinct from car ownership charges, which are not linked to driving distances or the amount of fuel used.

Tolls, which are charged according to miles traveled, are more effective than cordon pricing, which charges for entry into an area and lacks the link between pricing and emissions. But cordon pricing can reduce congestion.

Although road pricing generates extra revenue, it is still not in wide use, although at least 46 countries do operate toll facilities. In the United States there are 277 toll roads, bridges, and tunnels. They total about 5,000 miles, but that is only 2 percent of total roads and 5 percent of federal-aid highways. Toll revenue accounts for less than 10 percent of total highway funding, though in some countries, such as Indonesia, Mexico, and Argentina, highways are nearly 100 percent tolled. In general, however, there are still plenty of opportunities globally to charge road users, especially those driving on highways and at peak times.

Historically, road pricing—both tolls and cordon pricing—has been highly effective in urban areas in reducing not only congestion but also emissions. Road user charges discourage people from driving on toll roads or through toll zones. When the Republic of Korea introduced congestion charges at the southern edge of Seoul, traffic declined by 11 percent within two years, and speed increased by 50 percent. In 1975 Singapore introduced the Area Licensing Scheme, the first comprehensive road pricing scheme anywhere. People had to pay an area license fee of $3 or $1.25 a day to enter the central business district during peak hours. The results: the number of vehicles entering the restricted zone declined by 73 percent, and average speed in that zone increased 10–20 percent. The decreased traffic and congestion clearly mitigated emissions.

Road pricing can target polluting vehicles specifically by differentiating tolls according to vehicle type. For cordon pricing, Milan, Italy, introduced Ecopass, which in 2008 began charging heavily polluting vehicles to reduce congestion and emissions. It was expected to reduce incoming traffic by 10 percent. In 2008 London

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237 Kojima and Johnson (2005).
240 NSTIFC (2009).
243 Prasad and others (2009); Rotaris and others (2010).
Chapter 3 | Integrating Sector-wide Reforms for Mitigation

introduced the Low Emission Zone to deter old, polluting vehicles from driving in the area. Trucks over 12 tons were targeted first, with other vehicles to be restricted over time.\footnote{Prasad and others (2009 ).}

One disadvantage of road pricing is that it may divert traffic to toll-free or unrestricted roads. Narrowly targeted road pricing or poorly coordinated transport policies can be a problem. In Singapore the number of vehicles entering the restricted zone did decline, but the ring road outside the city became more congested.\footnote{World Bank (1978).} London’s cordon pricing—among other reasons—has increased passenger car congestion, though the speed of public transport has increased.\footnote{NSTIFC (2009).} In Bangkok poor coordination has increased emissions and pollutants in the expressway network development project. An 11.5-km, six-lane metropolitan highway from Ramindra to Rama IX IC commissioned in 1996 is carrying less than half the forecast 108,000 vehicles a day. In this case, the government built another six-lane public side road in conjunction with the expressway that was toll-free. More and more people chose the toll-free road, thus limiting the positive effects of road pricing. Emissions and pollutants did not decline significantly.\footnote{JBIC (2003).}

Advances technologies, such as electronic toll collection systems and the Global Positioning System, can make road pricing more effective.\footnote{Advanced road or cordon pricing may also require the significant amount of costs to implement. For instance, the London system initially cost $275 million, and the annual operating costs are estimated at $158 million (NSTIFC 2009).} Singapore replaced the initial Area Licensing Scheme with a more advanced mechanism, Electric Road Pricing Scheme, which is an automatic toll collection system. The price to enter the central business district is optimized by a time-of-use system that varies price according to the time of day, thus better managing traffic flow and speed.\footnote{OECD (2002b).} Using a satellite global positioning system, Germany charges trucks heavier than 12 tons in certain mileage and vehicle emission classes. Initial evidence indicates that direct user charges increase efficiency in the heavy vehicle industry.\footnote{NSTIFC (2009).}

3.2.1.3. Parking Policies and Effective Urban Land Use

Initiating or raising parking rates in urban areas is another way to raise the cost of car use, although it has no bearing on the distance people drive. The experience of Perth, Australia, is interesting: in 1998 it replaced traditional license fees for residential car ownership with charges on all nonresidential parking in the Perth Parking Management Area. It used the
revenues to provide free public transport in the city center.\textsuperscript{251}

Parking policies also help promote effective urban land use. Most urban streets have one or two parking lanes that typically take up 20–30 percent of their width. In developed countries roads account for about 20 percent of total urbanized areas. Parking policies are not always enforceable, however, thus aggravating city traffic congestion. Thus, a significant portion of urban areas is devoted to on-street parking, with serious implications for urban planning.\textsuperscript{252}

Parking charges help reduce car use. In Singapore’s city center, monthly parking fees were increased by 30–50 percent, which, along with other measures, significantly reduced traffic.\textsuperscript{253} In Copenhagen in 1990 and 1991 new parking fees were introduced in most of the city’s public parking areas. The number of cars parked dropped 25 percent, and traffic to and from the area declined 10 percent. The 1997 Lloyd District program in Portland, Oregon, that introduced on-street parking charges reduced drive-alone commuter traffic by 7 percent.\textsuperscript{254}

Parking availability also affects household decisions about car ownership and use. Parking costs are the most important determinant of car use in the Seoul metropolitan area.\textsuperscript{255} Households are less likely to own cars if they have difficulty parking them.\textsuperscript{256} By contrast, if parking spaces are provided at work, car use and demand for fuel increase.\textsuperscript{257}

Successful parking policies need the participation of both the public and the private sector. In Singapore private operators were required to set the same fees as public parking areas.\textsuperscript{258} Parking cash-out is another option: in the United States this allows employees to exchange their parking space for its cash equivalent and use alternative transportation.\textsuperscript{259}

3.2.1.4. Charges on Individual Car Ownership and Car-Maker Competitiveness

Another option is charging taxes and fees, such as annual and one-off charges on car purchase, registration, and inspection. However, that may not be enough to reduce car use and emissions. Moreover, without other policy measures, these charges may motivate car owners to travel more in the belief that expensive ownership costs have already been sunk—especially when fuel demand is inelastic. Higher sales taxes and new registration fees may also discourage people from replacing old cars with new fuel-efficient cars.\textsuperscript{260}

Emission-based charges and car scrapping programs could lead to more low-carbon vehicles and make the industry more competitive. If they do

\textsuperscript{251} OECD (2002b).
\textsuperscript{252} Litman (2005).
\textsuperscript{253} World Bank (1978).
\textsuperscript{254} OECD (2002b).
\textsuperscript{255} Sohn and Yun (2009).
\textsuperscript{256} Woldeamanuel and others (2009).
\textsuperscript{257} Cervero 2007; Frondel and Vance (2010).
\textsuperscript{258} World Bank (1978).
\textsuperscript{259} OECD (2002b).
\textsuperscript{260} OECD (2000).
not adopt low-carbon technologies, car companies will eventually lose market share. In 2009 about 600,000 hybrid cars were sold globally, most of them the Toyota Prius. More and more manufacturers have begun to produce hybrid and electric vehicles. Major vehicle industries are concentrated in developed countries and some emerging economies, such as Brazil, China, India, and South Africa. Since it is important that developing countries introduce low-carbon technologies quickly, multinationals should promote international technology transfers.

**Emission-Based Vehicle Taxation.** In 2001 the United Kingdom introduced an excise duty for new cars based on CO$_2$ emissions. Cars are assigned to one of four categories, and the category determines the duty.$^{261}$ Many countries already tax heavy vehicles and trucks more than light. In the United States a 12 percent federal sales tax on trucks and trailers weighing more than 33,000 lbs generates more than $2.5 billion annual revenue.$^{262}$

**Car Scrapping Programs.** Subsidies for fuel-efficient vehicles, including a sales tax exemption, are another powerful tool.$^{263}$ As in other developed countries, such as France and Norway, the United States recently implemented the Car Allowance Rebate System (CARS) or “cash for clunkers” program, which paid up to $4,500 for each energy-inefficient car (18 or fewer mpg) that was replaced with a more efficient one. The price incentives worked; the number of consumers applying for the program was much higher than expected. In all, $3 billion was allocated for trade-ins of 690,000 vehicles. In France the 1994 vehicle retirement program offered a 5,000-franc subsidy, which shortened the average duration of car holding by 3.3 years.$^{264}$ In Spain two cash-for-clunker programs in 1994 and 1995 promoted diesel engines. The replacement of any vehicle more than 7 or 10 years old earned €600; in the 1990s the market share of diesel-powered cars gradually increased from 13 to 50 percent.$^{265}$

Car-scrapping programs, however, are limited by their high cost. In recent U.S. experience, only 30 percent of total passenger cars were traded in, at a cost of $3 billion. Car scrapping thus cannot be the only solution for fleet turnover.

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$^{261}$ OECD (2002a).
$^{262}$ NSTIFC (2009).
$^{263}$ Potoglou and Kanaroglou (2007).
$^{264}$ Yamamoto and others (2004).
$^{265}$ Miravete and Moral (2009).
Box 3.5. Information and Consumer Vehicle Choice

Reasons for vehicle choice are complex because they are affected by economic, social, cultural, and psychological factors. Car safety and fuel economy are important determinants, but people tend to discount future fuel prices and buy cars based on size, speed, and appearance rather than fuel economy. It has been found that car ownership and use are closely related to “symbolic” and “convenience” motives and may be affected by neighbors’ behavior. Thus, the more people use new vehicle technologies, the more others will follow.

In addition to financial incentives, people need information. People are not always familiar with low-carbon vehicle options (figure B3.5.1). To raise public awareness, Singapore launched the Climate Change Awareness Program in 2006, showing the public simple ways to save energy and money and reduce emissions. The Philippines has implemented similar programs. Eco-labeling can significantly affect consumer vehicle choice, although psychological factors and prior choices are also important. In 2005 the United Kingdom introduced a new green car label in connection with the Vehicle Excise Duty rating. The U.S. Environmental Protection Agency also provides two emission ratings: the Air Pollution Score and the Greenhouse Gas Score.

Nonmonetary incentives can help. For instance, people in California—the largest hybrid car market in the United States—buy hybrid cars so that they can use high-occupancy vehicle (HOV) lanes when driving alone. Californians are twice as likely to purchase a hybrid car as are New Yorkers (table B3.5.1). While incentives clearly work, however, traffic conditions, local socioeconomic conditions, and consumer behavior can affect them. In Hamilton, Canada, the effect of HOV lanes is insignificant because such lanes are not common in that country.
Figure B3.5.1 United Kingdom Respondents Familiar with New Vehicle Technologies


Table B3.5.1. Hybrid Markets in the United States

<table>
<thead>
<tr>
<th>Top Five U.S. Hybrid Markets</th>
<th>(a) New Hybrids purchased (December 2009)</th>
<th>(b) 2008 Population (millions)</th>
<th>(a) / (b) (percent)</th>
<th>2008 Median Household Income (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>California</td>
<td>55,553</td>
<td>37.0</td>
<td>0.150</td>
<td>61,021</td>
</tr>
<tr>
<td>New York</td>
<td>15,348</td>
<td>19.5</td>
<td>0.079</td>
<td>56,033</td>
</tr>
<tr>
<td>Florida</td>
<td>14,949</td>
<td>18.5</td>
<td>0.081</td>
<td>47,778</td>
</tr>
<tr>
<td>Texas</td>
<td>14,632</td>
<td>24.8</td>
<td>0.059</td>
<td>50,043</td>
</tr>
<tr>
<td>New Jersey</td>
<td>11,367</td>
<td>8.7</td>
<td>0.131</td>
<td>70,378</td>
</tr>
</tbody>
</table>

Source: U.S. Census Bureau; hybridCARS.

2 World Bank (2010a).
3 Sohn and Yun (2009).
4 Mau and others (2008); Axsen and others (2009).
5 Coad and others (2009).
6 Anable and others (2006), prepared for the U.K. Department for Transport.
7 Prasad and others (2009).
8 Anable and others (2006).
9 Teisl and others (2008).
10 Sangkapichai and Saphores (2009).
3.2.1.5. Alternative Mass Transit Pricing

Lowering mass transit prices increases the relative price of car use and thus induces more people to use public transportation. The price elasticity of public transport demand is generally about –0.3 but can vary considerably from almost zero to more than one.\(^{266}\)

The price elasticity of bus rapid transit demand is estimated at –0.26 based on data from 44 bus systems around the world.\(^{267}\) In Spain price elasticity is –0.61 for train and –0.49 for bus.\(^{268}\) In Bangkok it is much higher, –2.2 to –2.5, because buses are more popular, with 40 percent of households using buses only.\(^{269}\) In Beijing price elasticity is low, –0.01 to –0.12, and depends on income; in other words, the lower the income share of transport expenditure, the lower the price elasticity. The rich continue to use their cars regardless of public transit fare changes.\(^{270}\)

The relative prices of public transit systems also affect consumer choice. In Mumbai reducing bus fares had more impact on modal shift than reducing rail prices. The cost of traveling by rail is much cheaper than bus. While the one-way rail cost of commuting 20 km is Rs. 90 per month, less than Rs. 4 per day, the bus fare for 20 km is about Rs. 20 per day. Price elasticities are thus estimated at –0.35 to –0.45 for bus and –0.07 to –0.08 for rail.\(^{271}\) In contrast, in São Paulo rapid transit and trains were found to be better able to attract passengers by lowering prices\(^{272}\); buses were price-inelastic because the majority of households had little alternative but to use public buses and trolleys at the time of the survey in 1987.\(^{273}\) A later study in São Paulo found that public transit fares had more influence on people's modal choice: a 1 percent reduction in public transit fares could reduce car use by 4–32 percent.\(^{274}\) In that case, the rich seemed more responsive because cars were not an option for the poor regardless of public transit fares.

An integrated transit and parking system may be especially effective. Bremen, Germany, achieved high public transit use by ensuring that transit prices were never greater than car use plus parking charges. Half of all trips into the city center are on mass transit and one-quarter on bikes.\(^{275}\) In developing countries mass transit is more expensive than in developed countries.

In addition to pricing, service is important. If passenger comfort level is low, the effect of pricing is limited. People prefer air-conditioned rapid transit over a crowded bus without air conditioning. Travel time is also part of service quality. In Gran Canaria, Spain, demand for buses is more sensitive for those who found the experience less

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\(^{266}\) Holmgren (2007).
\(^{267}\) Hensher and Golob (2008).
\(^{268}\) Martin and Nombela (2007).
\(^{269}\) Dissanayake and Morikawa (2010).
\(^{270}\) Anas and Timilsina (2009a).
\(^{271}\) Takeuchi and others (2007).
\(^{272}\) The elasticity was considered to be small, however, because of its small modal share at that time.
\(^{274}\) Anas and Timilsina (2009b).
\(^{275}\) OECD (2002b)
People who are not satisfied with service are more likely to be price-sensitive; if prices go up, they shift to alternative modes. In the United States public transport demand is highly elastic to service quality—about 1.05. The German Mobility Panel data indicate that household car ownership would decrease significantly if there were access to good quality urban rail.

3.2.2. Importance of Regulations for Emissions Mitigation

Price incentives, though important, cannot predict emission reduction. People may not choose to purchase fuel-efficient vehicles or use alternative mass transit, regardless of supply and pricing. Fuel taxes and road pricing can be difficult to implement because of political sensitivities. In such cases, direct quantitative intervention may make more sense, although among other drawbacks it can be more expensive. Regulations should be considered complementary to pricing incentives.

There are at least four regulatory approaches to capping car emissions (table 3.17): (1) setting fuel economy standards at the production level; a corollary to this would be periodic emissions inspections, which would be especially important in developing countries; (2) restricting the number of cars on the road; while rare, this is obviously a very strong measure; (3) imposing road-use conditions to reduce traffic volume—high-occupancy vehicle (HOV) lanes are an example; (4) change driving behavior.

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276 Espino (2007).
277 The price elasticities are –0.03 to –0.07 for those who are satisfied with the services and –0.26 to –0.37 for those who are not.
278 Holmgren (2007).
279 Woldeamanuel and others (2009).
280 OECD (2000); Clerides and Zachariadis (2008).
Table 3.17. Major Quantitative Regulations for Emissions Mitigation

<table>
<thead>
<tr>
<th></th>
<th>Vehicle Energy Intensity</th>
<th>Number of Vehicles</th>
<th>Driving Behavior</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel economy standards/ used car import policy/ inspection and maintenance programs</td>
<td>Effective</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Private car ownership restriction</td>
<td>Effective</td>
<td>Effective</td>
<td></td>
</tr>
<tr>
<td>Conditioning on road use</td>
<td>Partly effective</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road traffic rules and regulations</td>
<td></td>
<td>Effective</td>
<td></td>
</tr>
</tbody>
</table>

3.2.2.1. Choice of Regulatory Interventions

**Fuel Economy Standards for New Vehicles.** The U.S. CAFE standards introduced in 1975 aim to reduce new vehicle fuel consumption. Over the past 30 years, fuel economy has improved from 20 mpg to 32 for passenger cars (figure 3.24). If they fail to achieve the standards, manufacturers pay a considerable penalty ($50 per car for each mpg below the standard).  In 1995 Japan introduced standards to reduce new car fuel consumption by 19 percent, which it had achieved by 2004; its new reduction goal is 23.5 percent.  In Europe there is no regulation of fuel consumption, but in 1998 and 1999 car manufacturers agreed on a voluntary emission target of 140 grams of CO\textsubscript{2} per km for new cars, compared with a 1995 average of 187 grams. This was intended to be extended to 120 by 2012.

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281 OECD (2002a).
282 METI (2006); Clerides and Tachariadis (2008).
Trade and Inspection Policies for Imported Used Cars. For most developing countries, trade policies and inspection of imported used cars are more important than regulating the fuel economy of new vehicles. The global used car market is huge, estimated at more than 5.5 million.\textsuperscript{284} Japan alone exported 380,000 used cars around the world, though the United States exported only 120,000.\textsuperscript{285} In addition, the global used-car component industry is significant, estimated at about $60 billion. Some countries prohibit used cars for safety and environmental reasons. Others allow only old cars to avoid competition with domestic new car dealers (table 3.18). But imported used cars may be cleaner than a developing country’s fleet of older vehicles.\textsuperscript{286} Because the average lifetimes of new vehicles may be short in some countries, such as Japan, trade liberalization could introduce more fuel-efficient vehicles into other domestic markets.

Border vehicle inspection is critical. In general, older cars emit more CO\textsubscript{2} and other pollutants. In California 10-year-old vehicles emit about twice as many pollutants as the newest cars (figure 3.25). Until recently, Mexico imported more than a million used cars annually, many of them 10 to 15 years old. In 2006 about 20 percent of these cars exceeded the 2 percent CO\textsubscript{2} threshold. Reinforcing border vehicle inspections could reduce 11.2 Mt of CO\textsubscript{2} equivalent every year.\textsuperscript{287}

\textsuperscript{284}IEA (2009).
\textsuperscript{285}Pelletiere and Reinert (2006).
\textsuperscript{286}OECD (2004); Timilsina and Dulal (2009).
\textsuperscript{287}Johnson and others (2010).
Table 3.18. Prohibitions on Imported Used Cars and Tires

<table>
<thead>
<tr>
<th>Country</th>
<th>Motor Vehicles</th>
<th>Tyres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Bolivia</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Brunei</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Canada</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Chile</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Dominican Rep.</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Ecuador</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Egypt</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Ghana</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Maldives</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Mozambique</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Nicaragua</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Nigeria</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Peru</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Salvador</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Thailand</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Venezuela</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>


Figure 3.225. Total Vehicle Emissions by Base Year

Source: Parry and others (2007).
Inspection and Maintenance Programs. Most developing countries have yet to introduce fuel economy standards, although many have emission standards.\(^{288}\) China, for instance, adopted European emission standards in 1999 that required all new light-duty vehicles to meet Euro I standards by 2000 and Euro II standards by 2004.\(^{289}\)

It is debatable whether inspection and maintenance programs are effective in controlling emissions. They entail high compliance costs for car owners, including time spent on the inspection and for repairs,\(^{290}\) but a well-designed inspection and monitoring program can be effective.\(^{291}\) Enhanced inspection and maintenance in Southern California is expected to reduce light-duty vehicle emissions by 14–28 percent.\(^{292}\) Despite some disadvantages (see below), consumers should be motivated to switch to fuel-efficient cars, and overall vehicle energy inefficiency should eventually improve.\(^{293}\)

Restrictions on Private Car Ownership. This is a direct measure to control the number of vehicles on the road. In 1990 Singapore introduced a vehicle registration quota; each year the government fixes the maximum number of vehicles to be newly registered. The right to register is put out to tender among people who want to buy a new car. The initial quota system divided vehicles into seven categories (table 3.19). In 1999 categories one and two were merged, as were three and four. Each category has a premium value determined by a sealed-bid, uniform-price auction.\(^{294}\) The system is thus a strong quantitative intervention with a quasi-market mechanism. Supply and demand determine the premium. Before the 1999 recategorization, premiums tended to be larger for luxury than for smaller cars, consistent with reducing emissions. However, after recategorization, the premiums of the two new categories, renamed A and B (figure 3.26), converged. Nonetheless, the quota system has successfully controlled the growth of cars on the road.

\(^{288}\) Timilsina and Dulal (2009).

\(^{289}\) Zhao (2006).

\(^{290}\) Merrell and others (1999).

\(^{291}\) Yamamoto and others (2004); Ribeiro and Abreu (2008).

\(^{292}\) Eisinger (2005).

\(^{293}\) An inspection program may initially have a negative effect on emissions reduction, because it helps car owners to use their vehicles longer. Inspected cars are expected to generate fewer emissions than non-inspected cars but may generate more than brand-new vehicles (Yamamoto et al., 2004).

\(^{294}\) See Tan (2001) for further detail.
Table 3.19. Vehicle classification of Singapore’s quota system

Category 1: Small cars with engine capacity of 1,000 c.c. and below;
Category 2: Medium-sized cars with engine capacity of 1,001 to 1,600 c.c., and taxis;
Category 3: Large cars with engine capacity of 1,601 to 2,000 c.c.;
Category 4: Luxury cars with engine capacity of 2,001 c.c. and above;
Category 5: Goods vehicles and buses;
Category 6: Motorcycles and scooters; and
Category 7: “Open”.

Figure 3.26. Singapore: Quota Premiums for Passenger Cars

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Conditioning on Road Use.

Automobile-restricted zones are a strong quantitative regulation, but public transport and bicycle paths must also be available. Aalborg, a city of 120,000 in northern Denmark, closed roads in the city center, introduced energy-efficient buses, and extended pedestrian areas and bicycle paths. Car traffic was reduced by an estimated 750,000 km annually.295

Highway HOV lanes reserved for public buses, carpools, and vehicles with two or more occupants are common in North America and some European countries. On the San Francisco-Oakland Bay Bridge, four HOV lanes carry two-thirds of travelers, with 18 mixed-flow lanes carrying the other third.296 About 60 percent of respondents to a carpool survey cited the availability of HOV lanes as

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295 OECD (2002b),

296 This is a relatively successful case; most U.S. HOV lanes are underused, as will be discussed below.
important to their decision to carpool.\textsuperscript{297} HOV lanes also have revenue potential. In recent years, excess capacity on HOV lanes has been sold to solo drivers who want to use the express lanes (high-occupancy toll—HOT—lanes), as in the vehicle registration quota system. A pilot project in San Diego, California, found that people were willing to pay a fee of $0.50 to $8 per trip, possibly generating more than a million dollars a year. Several states have converted HOV lanes to HOT lanes.\textsuperscript{298}

\section*{Enforcement of Traffic Regulations.}

Regulations should be adopted and enforced that address certain driving activities, such as overloading, that increase emissions. In India the primary long-distance goods carrier is a two-axle, nine-ton truck, which is often overloaded with 14–20 tons, especially on outward-bound trips.\textsuperscript{299} Overloaded trucks not only emit more CO\textsubscript{2} they also wear down road surfaces. In 2005 Albania eliminated a user charge for three-axle trucks because multi-axle trucks damage pavements less than overloaded two-axle trucks do.\textsuperscript{300}

Emissions increase with traffic speeds (figure 3.27). In the United States, for every one mile-per-hour reduction, a heavy truck traveling at 60 to 65 miles per hour can improve fuel efficiency by 0.8 percent.\textsuperscript{301} A study in Japan found that if environmental externalities are taken into account, current speed limits on national highways in rural areas are 10 km/hr higher than the socially optimal limit.\textsuperscript{302}

Speed limits are also conducive to safety. Traffic accidents are usually associated with speed limits.\textsuperscript{303} The elasticity of total fatal accidents may exceed unity: a 1 percent increase in the speed limit increases fatal accidents by more than 1 percent (see the next section). Enforcing speed limits not only reduces emissions, it also saves lives.

\begin{table}
\centering
\caption{Emissions Increase with Traffic Speeds}
\begin{tabular}{|l|l|}
\hline
Speed Limit & Emissions Increase \tabularnewline
\hline
55 mph & 10% \tabularnewline
60 mph & 15% \tabularnewline
65 mph & 20% \tabularnewline
\hline
\end{tabular}
\end{table}

\textsuperscript{297} OECD (2002b).
\textsuperscript{298} NSTIFC (2009).
\textsuperscript{299} World Bank/ESMAP (2002).
\textsuperscript{300} World Bank (2006).
\textsuperscript{301} IEA (2009).
\textsuperscript{302} Thanesuen and others (2006).
\textsuperscript{303} Houston and others (1995); Scuffham (2003); also see the next section for further details.
3.2.2.2. Drawbacks of Hard Regulation

Regulatory measures can increase the certainty of emissions reduction because they impose emission ceilings regardless of consumer preferences. However, past approaches have faced four difficulties: mistargeting, misquantification, enforceability, and costs of implementation.

**Mistargeting.** Good regulations have to be targeted correctly, leaving no room for them to be bypassed. This is not always easy. An example is the U.S. dual CAFE standards, which have a fairly modest fuel standard for "light trucks." The problem is that household cars, such as SUVs and minivans, also fall into this category. Although the standards were slightly tightened in 2004 and in 2006, manufacturers’ efforts to improve fuel economy are diluted by consumer preference for large vehicles with greater acceleration and towing capacity—half the U.S. passenger cars now fall in this category. In the next two decades, however, energy efficiency is expected to improve by 50 percent.

Targeting also fails when traffic bypasses a regulated area. After Switzerland imposed a stringent limit of 28 tons on all trucks traveling through the country and required that heavy freight be carried by rail rather than road, much of the international road freight traffic simply went through neighboring countries instead. There is always the risk that regulations will be bypassed.

**Misquantification.** How stringent should a regulation be? The U.S. CAFE standard for light trucks may be too loose, but regulations that are too stringent can cause other business and efficiency problems. The U.S. CAFE

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304 Transportation Research Board (2010).
305 National Academies (2002).
experience, for example, raises the issue of safety. The uniform down-weighting of the fleet, including both heavy SUVs and smaller light trucks, means these vehicles are not required to have as much occupant protection as heavier vehicles. Aggressive downsizing in the late 1970s and early 1980s may have contributed to more traffic fatalities in the early 1990s. Mandating a nationwide uniform speed can result in higher than optimal speeds in some areas and lower than optimal in others. In the United States, underused HOV lanes can be seen as pushing solo-occupancy vehicles into mixed-flow lanes.

**Enforceability.** Having a regulation does not ensure that it will be enforced. Not all drivers obey speed limits and other traffic rules. Enforcement is particularly difficult when governance is poor and regulatory capacity minimal, as in developing countries. In Bogota, although operators are required to scrap old buses that were operating in TransMilenio corridors, some continue to use them on routes not served by TransMilenio. Thus, allocating road space to dedicated bus lanes can aggravate congestion and air pollution in other corridors if too few car drivers are induced to switch to mass transit.

Enforcing inspection and maintenance requirements can also be a problem. Emissions inspection for imported used cars in Mexico has been imperfect, and the Californian Smog Check program failed to lower emissions in the 1980s: about a third of cars tested roadside had excessive emissions, whether they drove within or outside the program region. It was thought that inspection stations may have been unreliable or corrupt. In Nepal 31–81 percent of gas-fueled vehicles failed the roadside emissions test, and diesel cars failed at an even higher rate, 64–90 percent. Why? Because many drivers pass the formal emissions inspection by making temporary engine adjustments, reverting afterward to pre-inspection conditions.

Traffic violations are another common problem: In Albania it was estimated that about 40 percent of trucks were overloaded before the heavy-user charges for multi-axle trucks were eliminated.

Of particular note, many environmental regulations related to land use, transit operations, nonmotorized facilities, and parking are local or regional. Thus, if government at these levels is not

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308 National Academies (2002). Another view, however, is that reductions in size may make a vehicle more maneuverable, thereby reducing the potential for collision. The U.S. data contradict this hypothesis: smaller vehicles are actually involved in more collisions (National Academies 2002).

309 Lave and Elias (1997); Thanusuen and others (2006).

310 Echeverry and others (2005).
effective, regulation does not work well, particularly in developing countries.

**Costs of Implementation.** The regulatory approach can be more costly than other options, such as price incentives. For instance, the cost of imposing 10 percent lower CAFE standards is estimated at $3.6 billion, $228 per vehicle, raising prices for consumers and decreasing profits for producers. The costs cannot be ignored when regulations are being enacted.

317 Austin and Dinan (2005).
318 Merrell and others (1999).
319 Lave and Elias (1997).
Box 3.6. Policy Options Compared

There is a wide range of policy options available, and the implementation cost of each varies, as does its enforceability. Also, any policy may change consumer behavior. This comparison is thus based on a complex set of factors.

In comparing fuel taxes with fuel economy standards, one study estimates that a 3-mpg improvement in U.S. CAFE standards would impose welfare losses of about $4 billion to save 5.2 billion gallons of gas annually. The implied carbon price for this is an estimated $317 per tCO₂—far above the current market price, which means that the policy is too costly. An 11 percent increase in fuel taxes, which would cost much less, could both achieve the same emissions reduction and increase revenues (which could be used for mass transit and the like). The implied carbon price is more consistent with the market price. Another study similarly suggests that strengthening the CAFE standards would be too costly.

Comprehensive road user pricing, such as cordon pricing, also seems too expensive if only direct investment costs are considered. However, cordon pricing brought in $237 million in revenue for London and $116 million for Stockholm, easily covering the costs of implementation.

From a cost/benefit perspective, rapid transit is more costly than a bus system. However, the feasibility and scope of these two options fundamentally differ, depending on customer density, geographic and environmental conditions, underlying assumptions, and how and whether other benefits are valued (such as whether the option raises additional revenues).

Table B3.6.1. Fuel Taxes and Fuel Economy Standards: Cost and Emissions Benefits

<table>
<thead>
<tr>
<th>Source</th>
<th>Policy</th>
<th>Welfare Losses or Direct Costs</th>
<th>Savings ¹</th>
<th>Author’s Calculated Carbon Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kleit (2004)</td>
<td>3 mpg increase in CAFE standards in the United States</td>
<td>$4 billion a year</td>
<td>5.2 billion gallons of fuel (= 12.6 million tCO₂ a year assuming emission intensity of 2,421 gCO₂/gallon²)</td>
<td>$317 per tCO₂</td>
</tr>
<tr>
<td></td>
<td>11 cents per gallon increase in fuel tax in the United States</td>
<td>$290 million a year</td>
<td>Same</td>
<td>$23 per tCO₂</td>
</tr>
<tr>
<td>Source</td>
<td>Description</td>
<td>Cost</td>
<td>Emission Reduction</td>
<td>Cost per tCO2</td>
</tr>
<tr>
<td>-----------------</td>
<td>------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------</td>
<td>----------------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Austin and Dinan (2005)</td>
<td>10 percent (3.8 mpg) increase in CAFE standards in the United States</td>
<td>$3.6 billion a year</td>
<td>10 percent reduction in fuel consumption for new cars (= 101.5 million tCO2 on average annually assuming an emission intensity of 2,421 gCO2/gallon,(^2) drives averaging 12,000 miles a year, annual new car sales of 13.3 million(^3) and a fleet turnover of 14 years)</td>
<td>$282 per tCO2</td>
</tr>
<tr>
<td>IEA (2009)</td>
<td>Cordon pricing in London</td>
<td>€ 90 million in direct investment in the system</td>
<td>120,000 tCO2e per year</td>
<td>$1,979 per tCO2 (assume €/$ = 0.8)</td>
</tr>
<tr>
<td></td>
<td>Cordon pricing in Stockholm</td>
<td>€ 5 million in direct investment in the system</td>
<td>43,000 tCO2e per year</td>
<td>$1,976 per tCO2 (assume €/$ = 0.8)</td>
</tr>
<tr>
<td>JIA (2008)</td>
<td>0 km of rapid transit in Bangkok</td>
<td>121 billion bahts in capital investment and 2 billion in annual total expenses(^4)</td>
<td>1,736,000 tCO2 for 30 years, plus SO2 and NO2 reductions</td>
<td>$2,661 per tCO2 (assume baht/$ 40)</td>
</tr>
<tr>
<td>IEA (2009)</td>
<td>84 km of BRT in Bogota, Colombia</td>
<td>$554 million in capital cost and $7.8 million in annual operating costs</td>
<td>247,000 tCO2e per year</td>
<td>$144 per tCO2</td>
</tr>
<tr>
<td></td>
<td>20 km of BRT in Mexico City</td>
<td>$50 million in capital cost and $1.9 million in annual operating costs</td>
<td>18,000 tCO2e per year</td>
<td>$241 per tCO2</td>
</tr>
<tr>
<td></td>
<td>30 km of BRT in Pereira, Colombia</td>
<td>$72 million in capital cost and $2.8 million in annual operating costs</td>
<td>18,000 tCO2e per year</td>
<td>$237 per tCO2</td>
</tr>
<tr>
<td></td>
<td>82 km of BRT in Chongqing, China</td>
<td>$90 million in capital cost and $7.6 million in annual operating costs</td>
<td>18,000 tCO2e per year</td>
<td>$47 per tCO2</td>
</tr>
</tbody>
</table>

\(^1\)Author’s assumptions are in parentheses.

\(^2\)U.S. Environmental Protection Agency assumption.

\(^3\)U.S. new vehicle sales in 2006.

Since countries and cities have different cost structures, a country-specific evaluation may make more sense than a country-to-country comparison. For instance, in Mexico a comprehensive green-growth analysis found that fuel economy standards would not be most cost-effective (figure B3.6.1); optimizing bus and rail freight is preferable.

Figure B3.6.1. Mexico: Expected Net Mitigation Benefits, Various Transport Interventions

Source: Authors.
Note: I&M = inspection and maintenance.

Source: Johnson and others (2010).

1 Kleit (2004).

2 Another interpretation is that the current market price is too low, which is quite possible.

3 Austin and Dinan (2005).

4 NSTIFC (2009).
3.3. Designing Transport Projects from a Broader Point of View

The preceding discussion has important policy implications:

Although technology may be a foundation for significant emissions reduction over the long term, advances are not likely to be dramatic. A broader policy approach should promote and accumulate new technologies. For example, technological transfer and trade liberalization could accelerate adoption of advanced low-carbon engine technologies. New technologies will be needed to make inspections and car repair more effective and regulations more enforceable.

Although appropriate alternative mass transit systems should be provided in a timely manner, they do not guarantee emission mitigation. Infrastructure should be used efficiently; operations and management can be improved without significant capital investment. Connecting different transport modes can make a city compact, so that people do not have to travel long distances. A policy framework that integrates transport, urban planning, and land management is needed.

Supply-side measures must be coordinated with demand-side policies. Pricing can guide people toward a low-carbon economy, with fuel pricing the most important policy tool. Road user pricing and parking policies are less effective but can be useful. Adopting vehicle-related taxes and charges based on emissions or vehicle miles traveled should motivate heavier users to refrain from car use. Subsidies for mass transit and rail freight can mitigate road dependency and emissions.

Regulations can complement price incentives and increase the certainty that emissions will be reduced. But implementation may be too costly.

Finally, the carbon market price may not be high enough to effect mitigation, especially through costly infrastructure investment for multimodality. However, there are other options for mitigation. Road user pricing can discourage people from driving and motivate them to use public transportation. Road pricing also helps reduce costly congestion. Parking policies can change car use and encourage effective urban land planning. A significant portion of urban areas devoted to on-street parking aggravates congestion. Regulating speed limits can reduce vehicle fuel consumption and contribute to safety. Any evaluation of projects to mitigate emissions must account for all these benefits.


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Kojima, Masami, Todd Johnson. 2006. Potential for Biofuels for Transport in Developing Countries. ESMAP Knowledge Exchange Series No. 4.


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NSTIFC (2009)


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Woldeamanuel, Mintesnot, Rita Cyganski, Angelika Schulz, Andreas


4. Climate-Resilient Investment in Transport

Mitigating and adapting transport will require considerable financing. Individuals will pay a large part of the mitigation costs by buying energy-efficient vehicles, but governments must still cover incremental investment for adapting roads. And developing countries face large transport infrastructure deficits regardless of climate change.

Available funding, such as carbon financing and international assistance, cannot cover the adaptation and mitigation costs. Mitigation, including advanced technologies and electric and fuel cell cars, is particularly costly and will remain so for some time.

Factoring in all the benefits of mitigation measures dramatically alters the economics of transport investment. Accounting for negative externalities, such as congestion and pollution, could both reduce emissions and encourage policymakers to allocate more resources to transport.

Some measures, such as fuel taxation and road user charges, could bring in new resources relatively quickly. Minimizing harmful subsidies would also help. Immediate action is necessary; putting new institutions in place takes time, and change becomes more costly once an economy is locked into high-carbon transport.

4.1. Financing Mitigation and Adaptation

Incremental costs for adaptation and mitigation are significant. Although future climate change, technology, and policy regimes may be uncertain, the costs are undoubtedly far beyond the resources of the developing world, even using the most conservative assumptions.

4.1.1. Investment in Mitigation

Few of the models that forecast future energy use and GHG emissions analyze the transport sector in detail. What role transport will play in emission reduction is therefore uncertain, as is the rate at which advanced transport technologies can be diffused. The International Energy Agency (IEA) and the Pacific Northwest National Laboratory (PNNL) have markedly different views. While IEA estimates that transport can reduce emissions by 30 percent, PNNL predicts a 47 percent increase (table 4.1). The IEA model assumes that fuel use and CO₂ emissions/ km by new vehicles could be cut 30 percent worldwide by 2020 and 50 percent by 2050; it also assumes that 50 million plug-in hybrid and electric vehicles will be sold by 2050 and that hydrogen fuel cell cars will be commercialized by 2020 and will
promptly be widely distributed (IEA 2009). Given current progress, those assumptions are optimistic.

The PNNL model assumes more limited technology diffusion, with only the United States adopting advanced vehicle technologies (plug-in hybrids and electric vehicles). Elsewhere, conventional internal combustion engines would remain dominant; their fuel efficiency is assumed to be 35–37 mpg. This model uses a discrete choice analysis\(^\text{320}\) that reflects people’s unwillingness to adopt vehicles that though more efficient are more expensive.

Depending on the model, mitigation costs vary substantially. Few models report sectoral emission reductions, including transport. The IEA estimates incremental investment for transport mitigation at $237 billion annually (table 4.2). This assumes international policies that limit GHG gases to 450 parts per million of CO\(_2\) equivalent. It also accounts for about 45 percent of total additional mitigation investment needed in all sectors (buildings, power plants, industry, and biofuels supply).\(^\text{321}\)

The IEA model assumes that most mitigation investment (figure 4.1) will go into buying hybrid and electric cars. It focuses on changes in car technologies rather than behavior and modal shifts and may underestimate transport’s capacity to reduce emissions (box 4.1). As the cost of low-

\(^{320}\) Clarke and Edmonds (1993).

\(^{321}\) The 20-year cumulative cost to the transport sector is about $4,700 billion, followed by buildings at $2,533 billion, and power generation at $1,745 billion.

\(^{322}\) The requirements are exclusive of OECD member countries.
Table 4.1. Reduction of Energy-Related Emissions by 2050, by Sector

<table>
<thead>
<tr>
<th>Sector</th>
<th>IEA</th>
<th>MiniCam *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>-71</td>
<td>-87</td>
</tr>
<tr>
<td>Building</td>
<td>-41</td>
<td>-50</td>
</tr>
<tr>
<td><strong>Transport</strong></td>
<td><strong>-30</strong></td>
<td><strong>47</strong></td>
</tr>
<tr>
<td>Industry</td>
<td>-21</td>
<td>-71</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>-50</strong></td>
<td><strong>-50</strong></td>
</tr>
</tbody>
</table>

*MiniCam is the PNNL model.

*Source: World Bank (2010).*

Table 4.2. Average Annual Incremental Mitigation Investment by 2030

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$ billion</td>
<td>%</td>
<td>$ billion</td>
<td>%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>525</td>
<td>100.0</td>
<td>563</td>
<td>100.0</td>
</tr>
<tr>
<td>Of which, infrastructure</td>
<td>324</td>
<td>61.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Of which, transport</td>
<td>237</td>
<td>45.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Of which, passenger cars</td>
<td>168</td>
<td>31.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Source: IEA (2009); World Bank (2010a).*
Figure 4.1. Cumulative Incremental Transport Investment by Mode

![Cumulative Incremental Transport Investment by Mode](image1)

**Source:** IEA (2009).

Figure 4.2. Cumulative Incremental Transport Investment by Regions and Sectors

![Cumulative Incremental Transport Investment by Regions and Sectors](image2)

**Source:** IEA 2009.
Box 4.1. IEA assumptions in Estimating Mitigation Investment Needs

The IEA model, which emphasizes changes in car technologies, assumes that the cost of buying more efficient vehicles represents most of the additional mitigation cost. Engine-fuel efficiency standards for CO₂ emissions or fuel consumption per unit of service of passenger light-duty vehicles (fleet averages) for 2030 are assumed to be 80 grCO₂/km for OECD and other EU countries, 90 grCO₂/km for other major economies (Brazil, China, South Africa, Russia, and the Middle East), and 110 grCO₂/km for other countries. The scenario assumes that more efficient vehicles will increase their market share regardless of price: hybrid vehicles to 32 percent by 2020 and 29 percent by 2030, plug-in hybrids to 12 percent by 2020 and 21 percent by 2030, and electric vehicles to 12 percent by 2020 and 17 percent by 2030.

This scenario assumes fuel prices will hold steady, so that increases in fuel taxes would compensate for decreasing demand and downward pressure on fuel prices. It does not account for consumer reaction, regardless of fuel prices, except in terms of choices of vehicle type. Savings in transport CO₂ emissions would be 18 percent compared with the baseline and could slightly increase over time.
4.1.3. Investment in Adaptation

Adaptation costs refer to the incremental investment needed to adapt to climate change. For infrastructure, the cost is calculated by multiplying baseline projections of investment needs by the share of new investment vulnerable to climate change. Because estimates of baseline infrastructure needs vary widely, particularly in developing countries, estimated adaptation costs also vary. With global warming of 2°C Celsius, total investment in transport adaptation for the world economy is an estimated $28–$100 billion a year (table 4.3). The World Bank’s Economics of Adaptation to Climate Change (EACC) study offers two estimates based on different scenarios of the National Center for Atmospheric Research (NCAR) and the Commonwealth Scientific and Research Organization (CSIRO). Both estimates are higher than that of the UNFCCC (2007), which uses a narrower definition of adaptation needs (box 4.2).

Infrastructure represents the largest share of adaptation costs. In the EACC model, infrastructure is 20–30 percent of the total, $14–$30 billion a year; this is consistent with the UNFCCC (2007). Infrastructure is also vulnerable to precipitation and humidity. The NCAR model assumes the wettest weather.

Adaptation needs for transport, mostly roads, are an estimated $7 billion a year for the next 40 years, 8 percent of total adaptation costs. Including maintenance costs raises the number to $10 billion—still much lower than estimated mitigation costs of $237 billion a year.

323 Normally, no retrofitting required for existing infrastructure assets is considered in estimating adaptation costs, but the World Bank EACC model includes incremental operation and costs of maintaining existing assets.
Table 4.3. Average Annual Incremental Adaptation Cost Through 2050

<table>
<thead>
<tr>
<th></th>
<th>World Bank (2010c)</th>
<th>UNFCCC (2007)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NCAR scenario</td>
<td>CSIRO scenario</td>
</tr>
<tr>
<td></td>
<td>$ billion</td>
<td>%</td>
</tr>
<tr>
<td>Total</td>
<td>89.6</td>
<td>100.0</td>
</tr>
<tr>
<td>Of which, infrastructure</td>
<td>29.5</td>
<td>32.9</td>
</tr>
<tr>
<td>Of which, transport</td>
<td>7.2</td>
<td>8.0</td>
</tr>
<tr>
<td>Of which, roads</td>
<td>6.3</td>
<td>7.0</td>
</tr>
</tbody>
</table>

*Source: World Bank (2010c); UNFCCC (2007).*

Box 4.2. Methods of Estimating Adaptation Investment Needs

UNFCCC (2007) does not account for incremental operation and maintenance costs for existing infrastructure. It first estimates gross fixed infrastructure capital formation in 2030 at $22.27 trillion, three times the 2000 investment, based on annual growth of 5–6 percent. It then estimates how much of the new investment is vulnerable to climate change using insurance data on weather-related losses. Insurance company Munich Re counts 0.7 percent of all infrastructure as vulnerable, the Association of British Insurers (ABI) says 2.7 percent. Thus, estimates of vulnerable new investment in 2030 range from $153 billion to $650 billion. The UNFCCC study assumes that climate-proof infrastructure would cost 5–20 percent more, with incremental adaptation costs of $8–$31 billion using Munich Re data or $33–$130 billion using ABI data.

The EACC study takes a different approach. It projects stocks of major types of infrastructure from 2010 to 2050, including roads, rail, and ports. Adaptation cost is computed as the additional cost of constructing, operating, and maintaining baseline infrastructure under the climate conditions projected by NCAR and CSIRO.

The EACC study focuses on price and cost changes for fixed quantities of infrastructure (referred to as a delta-P component) but also calculates costs based on the impact of climate change on infrastructure service demand (delta Q component), including operating and maintenance costs. The NCAR model projects additional cost and maintenance expenditures for all sectors at $36.8 billion annually; the CSIRO model projects $28.6 billion.

*Source: Parry and others (2009); World Bank (2010c).*
4.1.4. Adaptation and Development Deficits

Many adaptation cost estimates, even in the EACC study, ignore the close link between adaptation and development. In theory it is correct to distinguish the incremental cost of new climate-proofing infrastructure investment (the development deficit) from the gap between current infrastructure and projected infrastructure needs to achieve a baseline (the adaptation deficit). In addition, in theory adaptation costs are incremental and not directly related to development deficits. Therefore, most studies report only adaptation deficits.

However, many developing countries still have large infrastructure deficits, especially inadequate roads. Developing countries have only 5–30 percent of the paved roads per capita of high-income countries (figure 4.3). More than half their roads are unpaved, poorly maintained, and vulnerable to weather.

Similarly, many railway assets, including locomotives, need to be upgraded to developed-country standards. In Africa nearly half the railways are in urgent need of rehabilitation. Airports have not yet reached international standards; some countries lack airport infrastructure, facilities, and oversight to enforce compliance with international safety and security standards. According to the U.S. Civil Aviation Safety Assessment, about one-third of developing countries do not meet international standards and practices recommended for aircraft operations and maintenance (table 4.4).

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324 This is also referred to as infrastructure deficit (Parry and others 2009).
325 World Bank (2010c).
327 ADB (2007).
328 World Bank (2005); JBIC (2006); World Bank (2010d).
329 Briceno-Garmendia and others (2008).
330 World Bank (2010e).
331 The U.S. Federal Aviation Administration’s foreign assessment program looks at the ability of the country, not individual air carriers, to adhere to international standards and recommended practices for aircraft operations and maintenance established by the International Civil Aviation Organization (ICAO), the United Nations technical agency for aviation. Data are as of December 2008. http://www.faa.gov/about/initiatives/iasa/
Figure 4.3. Road Network and Population by Region, 2005

![Graph showing road network and population by region, 2005.]


Table 4.4. U.S. Civil Aviation Safety Assessment, 2008

<table>
<thead>
<tr>
<th>Countries</th>
<th>Countries Meeting ICAO Standards</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-income countries</td>
<td>45</td>
<td>43</td>
</tr>
<tr>
<td>Developing countries</td>
<td>62</td>
<td>42</td>
</tr>
<tr>
<td>Upper middle-income countries</td>
<td>27</td>
<td>24</td>
</tr>
<tr>
<td>Lower middle-income countries</td>
<td>27</td>
<td>16</td>
</tr>
<tr>
<td>Low-income countries</td>
<td>8</td>
<td>2</td>
</tr>
</tbody>
</table>

Source: U.S. Federal Aviation Administration.
If development deficits are not taken into account, estimates for transport will be unrealistically low—a major criticism of the current estimation approach.\textsuperscript{332} This could be particularly problematic for poorer countries with enormous development deficits.

Estimates of infrastructure deficits are sensitive to models and assumed goals and vary significantly, from $316 billion a year to achieve the Millennium Development Goals to annual baseline spending of $1,900 billion, which includes nonconventional infrastructure, such as health, education, and urban (table 4.5). For transport alone, including roads, estimated investment needs are $310 billion.\textsuperscript{333} Estimated incremental adaptation costs are $7.2 billion a year, 2.3 percent of total investment.

Regardless of model, the incremental cost of adaptation is only a small fraction of total transport investment needs. A case study using highway development software found that in a “do the minimum” scenario the incremental road adaptation cost would be only 2 percent of total investment and maintenance costs (box 4.3). The case study also shows that regardless of climate change, more frequent road maintenance reduces not only maintenance costs but also eventual adaptation costs. Thus, timely building and maintenance of roads is a robust investment decision that should be a priorit

\textsuperscript{332} Satterthwaite and Dodman (2009).
\textsuperscript{333} World Bank (2010c).
Table 4.5. Annual Adaptation and Infrastructure Deficits

<table>
<thead>
<tr>
<th></th>
<th>Parry and others (2009)</th>
<th>World Bank (2010c) 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Infrastructure 1</td>
<td>Infrastructure 3</td>
</tr>
<tr>
<td></td>
<td>Annual Average Infrastructure Deficit</td>
<td>Infrastructure Adaptation Cost</td>
</tr>
<tr>
<td>Asia</td>
<td>217.5</td>
<td>10.9</td>
</tr>
<tr>
<td>Latin America</td>
<td>37.2</td>
<td>1.9</td>
</tr>
<tr>
<td>and the Caribbean</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Africa</td>
<td>61.6</td>
<td>3.1</td>
</tr>
<tr>
<td>Others</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>316.3</td>
<td>15.9</td>
</tr>
</tbody>
</table>

1 Including housing and infrastructure.

2 Based on the National Center for Atmospheric Research (NCAR) climate scenario.

3 Including health, education, power and wire, road, urban, water and sewage, and other transport infrastructure.

4 Including road and other transport.

Source: Parry and others (2009); World Bank (2010c).
Box 4.3. A Numerical Example of Road Management: Applying HDM-4

The Highway Development and Management Model (HDM-4) version 2 is software that evaluates how climate affects highway development and maintenance. First, climate determines annual road deterioration. Humidity and low temperatures, for instance, quickly wear down road surfaces and shoulders. Second, seasonality and drainage affect road pavement strength, represented by the structural number of the pavement (SNP). SNP is calculated from the thickness of the base or surfacing layer and the depth of each layer from the top of the sub-base. It is reduced by seasonality, which is measured by the length of the wet season: water infiltrates cracks and joints, fracturing the pavement and increasing road roughness. Drainage, determined by the shape and type of drain, functions to reduce the length of the wet season. SNP is therefore a function of not only average temperature and precipitation but also seasonality and drainage.

In the case of a 10-km two-lane primary bituminous road in a tropical area, project life is assumed to be 20 years. The discount rate is 12 percent. There are two strategies. One is to do the minimum with routine pothole patching and edge treatment without major surface treatment until the International Roughness Index (IRI) reaches 10 m/km. The other is to do maintenance more often—before the surface is severely damaged—and assumes structural overlay at a lower IRI of 4.5 m/km, with routine pothole patching and edge treatment.

There are also two climate scenarios. One is the actual tropical condition; the other assumes more precipitation and humidity, which would increase the roughness environmental coefficient (road deterioration rate) from 2 percent to 2.5 percent.

In either scenario frequent maintenance is more cost-effective. Under actual weather conditions, total maintenance savings would be about 4 percent if maintenance were more frequent. Over a longer period, the savings could be even greater. With the alternative weather scenario, savings would be 6 percent (figure B4.3.1).

Climate change would increase road maintenance costs only minimally, especially if the road were maintained properly. In the “do the minimum” scenario, the cost would increase by 2 percent. If the road were more frequently maintained, the cost would increase by only 1 percent. Thus, adaptation costs for roads would likely remain small relative to total investment needs, and additional costs could be minimized by appropriate maintenance.
4.2. Insufficient Financing Available

At present the most important mechanism for financing mitigation and adaptation may be carbon markets. There are also a few other resources available internationally, but these mostly go to areas other than transport.

4.2.1. Carbon Markets

The Kyoto Protocol created three market mechanisms: emissions trading, the Clean Development Mechanism (CDM), and the Joint Implementation mechanism. These offer developed countries an opportunity to buy carbon credits and avoid more costly mitigation measures to meet their emission reduction commitments. They offer developing countries incentives for mitigation, can facilitate funding, and give access to emerging clean technologies. From 2000 to 2005 the CDM, one of the most promising mechanisms, had more than 4,200 projects in the pipeline, with 2,246 of these approved.

However, CDM has only three registered transport projects: the Bogotá TransMilenio (BRT); installation of low-GHG rolling stock in rapid transit systems in Delhi; and the Cable Cars Metro in Medellin. These are expected to reduce emissions respectively by 246,563, 41,160, and 1,729 tons of CO$_2$-eq. Even with fairly high carbon prices, 334

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334 The EU Emissions Trading System is by far the most important carbon market. Others, including the Kyoto Protocol Joint Implementation and international emissions trading Switzerland, New South Wales, the U.S. Regional Greenhouse Gas Initiative, the Chicago Climate Exchange, and voluntary markets, are tiny by comparison and irrelevant for transport. Kossoy and Ambrosi
it is unlikely that the private sector will be induced to adopt sufficient low-carbon transport technologies, which are expensive and difficult to commercialize\textsuperscript{335} (figure 4.4). The limited impact of carbon markets may also be attributable to the current rigid framework for calculating emissions savings\textsuperscript{336}. While mitigation intervention could help the carbon market mechanism, institutional reforms are needed if mitigation is to be significant.

\textsuperscript{335} World Bank (2010a).
\textsuperscript{336} See, for example, the methodology UNFCCC, ACM 0016: Baseline Methodology for Mass Rapid Transport Projects – Version 1, Tool for the demonstration and assessment of additionality and Tool to calculate baseline, project and/or leakage emissions from electricity consumption. http://cdm.unfccc.int/methodologies/PAmethodologies/approved.html.
4.2.2. Other International Funding Sources

Transport claims only a small share of other international funding. The Global Environment Facility (GEF), established in 1991 at the Rio Convention on Sustainable Development, commits about $250 million a year—largely in the form of grants to developing countries that are parties to the UNFCCC—in support of energy efficiency, renewable energy, new clean energy technology, and sustainable transport projects (table 4.6). In the past 20 years, the GEF has approved only 28 transport projects, 3.4 percent of the total; funding has been slightly higher at about 6.4 percent. On average, the GEF grant mechanism has mobilized about $120 million a year for transport, including cofinancing, but the sector needs $240 billion for mitigation and $7–$10 billion for adaptation and it also needs to make up a transport development deficit of $310 billion.


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337 $50–$150 billion for developing countries only.
Table 4.6. Global Environment Facility Funding, 1991–2010

<table>
<thead>
<tr>
<th>Projects</th>
<th>Approved Number</th>
<th>Share Number (%)</th>
<th>GEF grant Share $ million (%)</th>
<th>Cofinancing Share $ million (%)</th>
<th>Total Share $ million (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport</td>
<td>28</td>
<td>3.4</td>
<td>182.4</td>
<td>6.4</td>
<td>2,368.5 11.3</td>
</tr>
<tr>
<td>Other sectors</td>
<td>792</td>
<td>96.6</td>
<td>2,654.7</td>
<td>93.6</td>
<td>18,501.288.7</td>
</tr>
<tr>
<td>Total</td>
<td>820</td>
<td>100.0</td>
<td>2,837.1</td>
<td>100.0</td>
<td>20,869.700.0</td>
</tr>
</tbody>
</table>

Source: GEF project database.

Climate Investment Funds (CIF) is a family of funds devoted to climate change initiatives. Established in 2008, it is hosted by the World Bank and implemented by the Multilateral Development Bank. The CTF is one of the most important funds, providing some grants, concessional loans, and partial risk guarantees of as much as $200 million per project to help countries scale up clean technology initiatives (table 4.7).338 On average, 16 percent of CTF funding has been allocated to transport, although this varies significantly by country; the Colombia investment plan alone accounts for more than 77 percent. Transport is among the priority sectors in half the CTF investment plans.

338 In Indonesia and Kazakhstan transport components may be added later.
Table 4.7. CTF-Endorsed Country Investment Plans

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Transport</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$ million</td>
<td>$ million</td>
</tr>
<tr>
<td>Total investment</td>
<td>36,835</td>
<td>8,458</td>
</tr>
<tr>
<td>CTF funding</td>
<td>3,500</td>
<td>570</td>
</tr>
<tr>
<td>Private investment</td>
<td>7,329</td>
<td>1,983</td>
</tr>
<tr>
<td>Government and MDB</td>
<td>26,006</td>
<td>5,905</td>
</tr>
</tbody>
</table>

Source: CTF Country Investment Plans.

Although the sum of this fragmented funding is small compared with total investment needs, the combination of resources may create synergies sufficient to finance mitigation and adaptation, as in the case of Mexico City (box 4.4). Early in the market’s transformation, the GEF piloted innovative approaches and helped countries to create effective policies and regulations. CTF resources support low-carbon infrastructure investment on favorable terms, helping the market to scale up or move innovation toward maturity. Carbon revenues improve investment profitability and strengthen the financial viability of projects that do not depend on carbon finance.

Different financial sources have different comparative advantages (figure 4.5). Since the GEF’s mandate is to innovate and remove barriers, its limited funds focus on early stages in technology adoption. These are often risk-prone, and resources are rarely sufficient to transform markets completely. CTF funds, by contrast, are technologically conservative and figure relatively little in early phases. They contribute to demonstration, deployment, and transfer of low-carbon technologies. Carbon finance can significantly affect the second stage, improving investment return on relatively new, initially marginal technologies. To initiate a shift to low-carbon development and avoid high-carbon technology lock-in, concessional funding and revenue enhancement are needed. At the mature stage, when carbon finance provides the most significant push into maturing markets, the CTF may still have an important role but GEF resources will be phased out.

339 World Bank (2010b).
Figure 4.5. Climate Funds and Transition to Low-Carbon Technologies

Box 4.4. Blending Carbon Finance Resources in Transport: An Example

Bringing together the agendas of local urban transport, national poverty reduction, and global climate change, the Mexico Municipal Transport Project (UTTP) aims to move urban transport to a lower carbon path. In many cities private cars account for 80 percent of all motor vehicles but just 30 percent of daily passenger trips. The goal is to reduce private trips despite high levels of motorization. The first UTTP phase focuses on improving transport policies and strengthening public transit institutions. The second addresses integrating transit systems, including mass transit corridors and other public transport. The third looks at stimulating the market for low-carbon buses and scrapping inefficient older buses.

Early GEF support of the Climate Measures in the Transport Sector of Mexico City project, the Insurgentes bus corridor, and the testing of bus types helped demonstrate the importance of bus rapid transit systems and the CDM methodology. The UTTP experience in Mexico City can be transferred to other urban areas. The program builds on an International Bank for Reconstruction and Development Sector Investment Loan of $200 million and a CTF concessional loan of $200 million. The Banco Nacional de Obras channels resources, serves as financial intermediary, and lends the funds to participating municipalities. These loans will be combined with up to $900 million from the National Trust for Infrastructure. The private sector is expected to contribute up to $2.3 billion and municipalities up to $150 million. Estimated carbon revenue is another $50 million. Cities that submit Integral Transport Plans are eligible for funding.

Source: GEF webpage, http://www.thegef.org/gef/gef_projects_funding
4.2.3. Domestic Spending on Transport

In theory, domestic sources could address development deficits. Routine transport infrastructure maintenance, for instance, is financed domestically rather than through international funding. Meeting development deficits with domestic resources could substantially reduce additional investment.

In reality, however, securing internal resources has long been difficult for developing countries. Spending on infrastructure is easily marginalized under fiscal pressures, as in Latin American countries during the 1990s. Although developing countries spend hundreds of millions of dollars annually on transport development and maintenance, accounting for several percent of GDP, the amounts are still insufficient. In Africa, for example, most countries have underinvested in transport, with a total of 22 countries together spending only about $11 billion annually on transport investment and maintenance (figure 4.6). About $4 billion was spent on transport projects, although an estimated $8 billion is needed (this is exclusive of South Africa). Thus, at only half of what is needed, fiscal resources cannot close development deficits, let alone respond to adaptation or mitigation needs.

340 It is well known that there is a general bias toward new investment in the international donor community for various reasons. See, for instance, Briceno-Garmendia and others (2008).
341 Calderón and Servén (2004b).
342 Briceno-Garmendia and others (2008).
343 Carruthers and others (2009). The financial requirements are calculated based on the assumptions that the levels of connectivity comparable to those in developed countries would be achieved with all transport assets maintained in good condition. See Carruthers and others (2009) for more details.
344 Other estimates for the whole of sub-Saharan Africa are even larger. For instance, the World Bank (2010c) estimates baseline transport spending at $40 billion a year for sub-Saharan Africa.
4.3. Economics of Climate-Resilient Transport Financing and Mitigation

A narrow view of the costs and benefits of transport helps to keep funding low. If local externalities, such as congestion, local pollution, and safety, are factored into policy evaluations, however, the economics of transport investment change dramatically, supporting more resources for the sector.

4.3.1. The Magnitude of Transport Externalities

Externalities in transport are estimated at 11 cents a mile,\(^ {345}\) about the same as the cost of fuel for a standard passenger car in the United States (table 4.8).\(^ {346}\) In aggregate the cost of externalities would exceed 10–11 percent of GDP in OECD countries (table 4.9).\(^ {347}\) Removing these externalities would thus be beneficial.

Traffic congestion is a major externality. The estimated cost of congestion is 5 cents a mile and adds up to 8.5 percent of GDP. Road congestion is particularly costly in urban areas. In the United States, urban congestion delays increased from 16 hours a year to 47 between 1980 and 2003, pushing up the annual national time loss cost from $12.5 billion to $63 billion.\(^ {348}\) Congestion will increasingly be a problem for developing countries that are urbanizing rapidly. Road congestion that reduces mobility for freight and individual travel undermines city productivity—traditionally the most important growth center in any economy.\(^ {349}\)

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\(^ {345}\) Parry and others (2007).

\(^ {346}\) It is assumed that vehicle fuel economy is 30 mpg and gasoline costs $3 per gallon.

\(^ {347}\) The external costs in tables 4.8 and 4.9 are evaluated based on shadow prices in the United States or OECD member countries, prices that are presumably higher than in developing countries. However, the relative costs to GDP, as in table 4.9, should apply in developing countries as well.

\(^ {348}\) Schrank and Lomax (2005).

\(^ {349}\) World Bank (2009).
Figure 4.6. Actual Transport Spending and Estimated Requirements, Sub-Saharan Africa (US$ millions)

Source: Briceno-Garmendia and others (2008); Carruthers and others (2009).

Table 4.8. Estimated Costs External to Transport, United States

<table>
<thead>
<tr>
<th>Externality</th>
<th>Cents/gallon</th>
<th>Cents/mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central values of marginal external costs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Greenhouse warming</td>
<td>6</td>
<td>0.3</td>
</tr>
<tr>
<td>Oil dependency</td>
<td>12</td>
<td>0.6</td>
</tr>
<tr>
<td>Local pollution</td>
<td>42</td>
<td>2.0</td>
</tr>
<tr>
<td>Congestion, cents/mile</td>
<td>105</td>
<td>5.0</td>
</tr>
<tr>
<td>Accidents</td>
<td>63</td>
<td>3.0</td>
</tr>
<tr>
<td>Total</td>
<td>228</td>
<td>10.9</td>
</tr>
</tbody>
</table>

Source: Parry and others (2007).
Table 4.9. Estimated Costs External to Transport, OECD Averages (% of GDP)

<table>
<thead>
<tr>
<th>Externalities</th>
<th>Road</th>
<th>Other Modes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel time</td>
<td>6.8</td>
<td>0.07</td>
<td>8.5</td>
</tr>
<tr>
<td>Local pollution</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Global pollution</td>
<td></td>
<td>1.0–10.0</td>
<td></td>
</tr>
<tr>
<td>Accidents</td>
<td>2.0</td>
<td>1.5–2.0</td>
<td></td>
</tr>
<tr>
<td>Noise</td>
<td>0.1</td>
<td>0.01</td>
<td>0.3</td>
</tr>
</tbody>
</table>

*Source: Banister (1998); reproduced in OECD (2002b).*
4.3.2. Benefits of Coping with Transport Social Costs

Policies to internalize or mitigate transport externalities could also help mitigate emissions. For instance, traffic congestion clearly increases emissions: cars emit more CO₂ when traffic is moving slowly, and congestion and idling increase local pollutants and noise. Optimizing traffic signals not only alleviates congestion and saves travel time but also increases fuel efficiency. In California, synchronizing traffic signals at 3,172 intersections reduced congestion and lowered fuel consumption by 8.6 percent. Realigning intersections can also reduce congestion. In Tokyo improving an intersection of rail tracks and trunk roads doubled traffic speed, reducing CO₂ by an estimated 12,000 tons per year.

These supply-side measures may be enough to alleviate congestion and some emissions, but demand-side interventions are also needed. For instance, improving traffic flow alone could motivate people to drive more. In Niort, France, traffic signal synchronization improved average speeds, but traffic volume also increased 7 percent and emissions 6 percent. Fuel taxation, road user pricing, parking policies, and vehicle-related charges can all discourage individual car use, thus alleviating traffic congestion and lowering emissions. Particularly promising are high congestion charges during peak periods.

There are also safety benefits. Mass transportation is usually much safer than car travel. In Japan the road fatality rate is eight times that of rail (table 4.10). Road fatality rates are also noticeably different between developed and developing countries. The road injury/fatality rate in high-income countries is 10.3/100,000 a year; in low-income countries it is 21.5/100,000 (table 4.11). Promoting mass transit in large cities could reduce both fatalities and emissions.

Similarly, lower speed limits can reduce fatalities and mitigate emissions. Accidents typically increase with open road speed limits. In New Zealand the elasticity of total fatal accidents is estimated at 1.2. In the United States, the fatality rate—defined as the number of fatalities per billion vehicle miles travelled—would decrease by 5 percent if the speed limit were 55 mph (88 km/h) instead of 65 (110 km/h). Emissions would also decrease.

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350 Davis and Diegel (2004); Anas and Timilsina (2009).
351 OECD (2002a).
352 Scuffham (2003).
353 Houston and others (1995).
Table 4.10. Transport Fatality and Injury, Japan, FY2008/2009

<table>
<thead>
<tr>
<th>Mode</th>
<th>Fatalities</th>
<th>Injured Persons</th>
<th>Fatality Rate per Million Passenger-km</th>
<th>Injury Rate per Million Passenger-km</th>
<th>Passenger-km (Millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road</td>
<td>5,155</td>
<td>945,504</td>
<td>5.7</td>
<td>1,043.7</td>
<td>905,907</td>
</tr>
<tr>
<td>Railway</td>
<td>300</td>
<td>397</td>
<td>0.7</td>
<td>1.0</td>
<td>404,585</td>
</tr>
<tr>
<td>Air</td>
<td>7</td>
<td>10</td>
<td>0.1</td>
<td>0.1</td>
<td>80,931</td>
</tr>
<tr>
<td>Waterborne1</td>
<td>2,414</td>
<td>n.a.</td>
<td>687.7</td>
<td>n.a.</td>
<td>3,510</td>
</tr>
<tr>
<td>Total</td>
<td>7,876</td>
<td>945,911</td>
<td>5.6</td>
<td>678.1</td>
<td>1,394,933</td>
</tr>
</tbody>
</table>

1 Including all marine perils.


Table 4.11. Road Traffic Injury and Fatality Rates (per 100,000 people)

<table>
<thead>
<tr>
<th>Region</th>
<th>High-income</th>
<th>Middle-income</th>
<th>Low-income</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa</td>
<td>32.2</td>
<td>32.3</td>
<td>32.2</td>
<td></td>
</tr>
<tr>
<td>The Americas</td>
<td>13.4</td>
<td>17.3</td>
<td>15.8</td>
<td></td>
</tr>
<tr>
<td>South East Asia</td>
<td>16.7</td>
<td>16.5</td>
<td>16.6</td>
<td></td>
</tr>
<tr>
<td>Eastern Mediterranean</td>
<td>28.5</td>
<td>35.8</td>
<td>27.5</td>
<td>32.2</td>
</tr>
<tr>
<td>Europe</td>
<td>7.9</td>
<td>19.3</td>
<td>12.2</td>
<td>13.4</td>
</tr>
<tr>
<td>Western Pacific</td>
<td>7.2</td>
<td>16.9</td>
<td>15.6</td>
<td>15.6</td>
</tr>
<tr>
<td>Global</td>
<td>10.3</td>
<td>19.5</td>
<td>21.5</td>
<td>18.8</td>
</tr>
</tbody>
</table>

Vehicle inspection and maintenance increase safety and reduce emissions. Spending for vehicle maintenance would reduce fatal accidents, and inspections encourage the scrapping of old cars that do not meet safety standards. Fleet transition to newer vehicles would decrease fatalities. In Rio de Janeiro the state light-vehicle inspection and maintenance program is expected to reduce carbon monoxide by 16–44 percent and hydrocarbons by 9–37 percent.

Potential health benefits from local pollution policies, such as diesel particulate filter regulation, are significant. In sunlight, air pollutants react to form ozone (smog), which affects pulmonary function in children and asthmatics and reduces visibility. Fine particles are small enough to reach lung tissue, and particulate exposure can cause death. Lower-middle-income and low-income countries are exposed to 50 percent more particulate pollution than high-income countries (figure 4.7).

Other antipollution policies also have health benefits and reduce emissions. For instance, converting diesel buses to CNG is a common pollution control measure that has proved effective in Mumbai. Based on observation of passengers, a 5–10 percent increase in bus fares could cover the cost of converting all 3,400 Mumbai buses, which travel 240 million km a year. It would reduce PM10 by 662 tons a year, as well as reduce CO2 emissions. In Madrid, one of the most polluted cities in the EU, a new metro line, Arganda, that came into service in 1999 has reduced a number of pollutants (CO, NOx, SO2, and particulates) by more than 20 percent and also reduced emission intensity. Although the number of vehicles on alternative roads has increased, that increment is smaller, and the slowdown is 2–16 percent less than it would have been without the Arganda.

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354 Houston and others (1995).
357 Schwartz (1994).
358 Takeuchi and others (2007).
359 Zamorano and others (2006).
4.4. Generating New Resources

Addressing negative externalities like congestion and local pollution is good for economies and helps justify funding of transport, but it does not create the additional fiscal space needed for mitigation and adaptation.

4.4.1. Reducing Harmful Subsidies

Removing fuel subsidies can create significant financial resources and be accomplished at fairly low cost. The IEA estimates 2008 fossil fuel subsidies at $557 billion, where the implicit subsidy is the difference between a reference price and the actual end-user price. Oil products received $312 billion in subsidies and natural gas $204 billion, with the rest going to coal.

Thirty-seven developing countries subsidize gasoline and diesel fuel at more than a million dollars a year (figure 4.8), an amount calculated using a price-gap approach where U.S. fuel prices are assumed to be subsidy-free. In many countries, diesel prices are more heavily subsidized not because its carbon content is lower but because diesel affects the movement of goods. Iran could increase revenues by more than $20 billion and Saudi Arabia by more than $17 billion if they abolished all gasoline and diesel subsidies. Many other countries could gain more than a billion dollars a year.

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360 Nash and others 2002.

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361 IEA, OECD, and World Bank (2010).

362 As discussed in chapter 3, it must depend on the price elasticity of fuel. For simplicity, fuel consumption would not change even if the pump price is increased by the abolition of subsidies.
4.4.2. Mobilizing Revenues from Mitigation Measures

A fuel tax is the best way to create fiscal space fairly quickly and motivate people to reduce energy intensity (table 4.12). Fuel tax rates vary considerably by country (see figure 3.22). While many European countries, as well as such countries as Malawi, Mongolia, and Zambia, tax fuels heavily, many developing countries do so at relatively low rates. The transaction costs of fuel taxation are relatively low and applying the carbon price to pump prices can generate significant revenue. A gallon of gasoline contains 0.0024 tons of carbon. Thus a market carbon price of $20, $30, and $300 per ton would translate into 5, 12, and 72 cents per gallon, respectively. While these numbers appear small, carbon pricing could increase annual revenues by about $10 billion, $24 billion, and $145 billion a year, based on U.S. fuel consumption.

Source: Author, on GTZ (2009) and World Development Indicators (2010).

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363 GTZ (2009).
Table 4.12. Emission Reduction: Effect, Benefits and Fiscal Potential of Various Interventions

<table>
<thead>
<tr>
<th>Measure</th>
<th>Primary Benefits</th>
<th>Impact on Fiscal Balances</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Economic:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel taxation</td>
<td>Congestion mitigation</td>
<td>+ +</td>
</tr>
<tr>
<td>Road user charges</td>
<td>Congestion mitigation</td>
<td>+</td>
</tr>
<tr>
<td>Parking policies</td>
<td>Efficient urban land use</td>
<td>+</td>
</tr>
<tr>
<td>Vehicle-related charges</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Cash for clunker programs</td>
<td>Competitiveness of auto industry</td>
<td>–</td>
</tr>
<tr>
<td>Low mass transit fares</td>
<td>Congestion mitigation; safety</td>
<td>–</td>
</tr>
<tr>
<td><strong>Regulatory:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel economy standards</td>
<td>Competitiveness of auto industry</td>
<td>– / +</td>
</tr>
<tr>
<td>Inspection and maintenance</td>
<td>Safety</td>
<td>– / +</td>
</tr>
<tr>
<td>Traffic rules</td>
<td>Safety</td>
<td>– / +</td>
</tr>
</tbody>
</table>

Other economic measures, such as road user pricing and parking policies, can generate revenue, but particularly in developing countries initial transaction costs can be high. In London, cordon pricing generates $237 million annually at an operating cost of $158 million. Subsidies to new vehicle buyers and mass transit passengers can help alleviate transport emissions, but the costs may be too high for the expected benefits. They may still, however, be an acceptable and may not be particularly effective in mitigating emissions. Parking policies are less likely to create fiscal space; violations are widespread, and the cost of enforcement is high in developing countries.

The initial investment of $275 million will thus be paid back relatively quickly (see box 3.6).

The revenue potential of vehicle-related charges, such as registration fees and customs duties, is subject to political acceptability and may not be particularly high in developing countries.

365 NSTFC (2009).
appreciate counterpoint to huge implicit road subsidies.

As long as car users pay transaction costs, regulatory measures are generally fiscally neutral. Of course, inspection fees can be too high, and traffic tickets can also be set very high. Even when they are, though, revenues are relatively small. Regulatory measures are in general very costly.\textsuperscript{366} Therefore, while these measures can help mitigation, they cannot be relied on to generate revenue.

\textbf{4.5. Conclusion}

\textit{Measures to reduce GHG emissions will reduce the costs of congestion, local air pollution, and safety risks. Policies to reduce these social impacts of transport also reduce GHG emissions. They have the potential to make transition to a low-carbon transport sector largely self-financing.} Policies to convey all environmental, safety, and congestion costs to users will reduce the social costs of transport. To give an example, without such policies transport users have no opportunity to learn about the health costs of local air pollution and no incentives to change their behavior to reduce them. The policy deficit in making such costs felt is enormous. The highest social costs are due to

- congestion,
- local air pollution,
- road accidents, and, last but not least,
- GHG emissions.

Efforts to reduce these costs do more to reduce GHG emissions than a narrow climate change agenda.\textsuperscript{367} Moreover, removal of these deficits would create revenues to finance the transition to a low-carbon environment. In addition to the global public good of reducing damages from climate change, this would also provide local political motivation because it creates local benefits in terms of reduced time losses and health costs.

\textit{An obvious reform—one that reduces the social costs of transport and creates fiscal opportunities—is to remove subsidies that give the wrong signals.} Most important in this respect are subsidies for gasoline and diesel. U.S. pump prices for gasoline and diesel are taken to be a good approximation for tax- and subsidy-free consumer prices.\textsuperscript{368} In addition to countries like Iran and Saudi Arabia, poorer countries could also have important savings: Myanmar, for instance, could save more than $300 million in transport fuel subsidies. Iran, Colombia, and other countries are now making major strides toward reducing transport subsidies.

\textit{The most direct way to convey the costs of transport’s contribution to climate change is by setting a price for carbon. A gallon of gasoline contains 0.0024 tons of carbon.}\textsuperscript{369} As already discussed, setting a carbon price of, say, $20 per ton would lead to only a moderate change of 12 cents in consumer prices.

\textsuperscript{366} Austin and Dinan (2005); Merrell and others (1999).
\textsuperscript{367} Parry (2007)
\textsuperscript{368} GTZ (2009)
\textsuperscript{369} Parry, Walls, and Harrington (2007)
If there were no changes in travel behavior, a carbon charge that small could bring in revenues of $10 billion a year in the United States.

The fiscal consequences of charges for local air pollution differ substantially. In some cases they can be very high. For the Los Angeles area, Small and Kazimi (1995) estimated charges to contain the health costs of local pollution of 1 to 8 cents per mile for 2000. Given the number of vehicle miles driven in the area, they would bring in revenues of $40 million to $3.26 billion. Willingness to pay to avoid the health costs will depend on the local context. Functions for how willingness varies with income and household characteristics remove the need to collect primary data in each locality. Applying such functions shows that valuations differ much less than income differences suggest. The health costs for Beijing, for instance, were estimated at $3.5 billion in 2007, equivalent to 3.5 percent of local GDP. Similar estimates can be done for congestion and accident costs. Signaling the true costs of transport to users should open considerable fiscal opportunities. These could be used to address the chronic underfinancing of transport and the incremental costs of climate-related transport policies.

The measures discussed above generate substantial income and welfare benefits. They are designed to maximize the development gains from limiting GHG emissions, local air pollution, costs of congestion, and accidents. They bring net benefits to both consumers (benefits from transport minus the costs of the charges) and revenue. Rough estimates of the revenue potential suggest that it could be even higher than the additional funding required for the low-carbon transition. If so, efforts to increase the efficiency of the transport sector could make it possible to reduce taxes that are harmful to growth and welfare. A broad agenda to make the sector more efficient provides far stronger incentives to reduce GHG emissions than a narrow climate policy program that implicitly assumes that all other inefficiencies have been removed. An efficient transport sector protects the environment and advances development.

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370 For example Loehmann et al. (1997)
371 Creuzig and He (2009)
Studies have looked at measures to simultaneously address the environmental costs of transport, road safety, and congestion for Beijing, Mexico City, and Washington. The following gives an approximation of the fiscal space such measures would earn.

**Beijing.** The most recent transport study for Beijing analyzes optimal policies for containing not only GHG emissions but also air pollution, congestion, and noise. The study assumes a price of $70 per ton of carbon, and an annual social cost of $205 million. It relates concentration levels of PM 10 to cases of chronic bronchitis and asthma and premature death from lung cancer. These health effects are converted to monetary values using a willingness-to-pay function from a study by Deng (2000). The values are corrected for health cost increases, growth in motorization, and reduced emissions per vehicle-km if the fleet were modernized. Health costs were $3.5 billion for 2007, equivalent to 3.5 percent of local GDP. Motorized transport’s share in total emissions is a function of population density and vehicle emission standards.

Accident costs are based on the number of fatalities and severe injuries reported by the Beijing Transportation Research Center for 2005 and have been corrected for underreporting. The study assumes that 25 percent of accident costs are external and not covered by insurance. Values for a statistical life and severe insurance are from the EU handbook. Total external safety costs are valued at $147 million a year.

Time lost in traffic is valued at $3.35 billion a year for car drivers and $853 million for bus riders. By implementing all measures, the most important being those related to congestion and air pollution, the metropolitan area of Beijing could bring in $6.5—$13.56 billion a year in revenue.

Another study analyzed CO₂ emission charges versus congestion charges. A congestion toll in Beijing would earn $5.5 million daily, reducing travel time by about 20 percent and CO₂ emissions by 36 percent. A fuel tax would earn the same amount, reduce time loss even more, and reduce emissions by 45.3 percent. The toll reduces car fuel use by 34 percent and the fuel tax by 43 percent. The toll, however, would have less effect on transport user income. The lowest two income quintiles would benefit most and the highest three quintiles least from a congestion toll and the differential would be even larger with a fuel tax.

The study also compares fuel taxes versus technical standards. Regulations affect user income less because they affect car use less. However, that is without taking into account changes in the prices of fuel-efficient cars or that revenues could contribute to other benefits. It also does not include the combined effect of fuel taxes and per-km charges on government revenue and user well-being. Fuel taxes could lead to

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Maibach et al. (2008)
trips outside the high-price region to refuel vehicles and to even higher transport demand. National carbon pricing would not have this localized problem.

**Mexico City.** Fuel taxes and congestion tolls were similarly compared for Mexico City. Here the optimal gasoline tax to reduce negative externalities would be $2.72 a gallon, much higher than the current excise tax of 17 cents a gallon. Such a tax would increase the pump price by 215 percent, from $2.21 per gallon to $4.76. It would also reduce GHG emissions by 37 percent with high welfare gains, assuming high fuel costs could not be avoided. An optimal average toll on car mileage is 20.3 cents per vehicle mile. At current fuel standards, this is the equivalent of $3.50 a gallon. Current mass transit prices (50 percent of operating costs are subsidized) are roughly in line with optimal prices.

High optimal fuel and congestion charges would increase transport revenue and help shift demand from cars to rail or other mass transit. Microbuses would become less attractive, with an optimal vehicle-mile tax of 34.2 cents a mile and a fuel tax equivalent of $2.67 a gallon. However, high taxes and tolls may not be politically feasible. A more modest fuel tax of $1 a gallon could achieve 60 percent of these benefits. There is still a strong bias toward individual car use: 600 cars are registered in Mexico City every day. Thus, increasing mass transit capacity without demand-side measures risks a mismatch between supply and demand (see chapter 2).

**Washington.** Correcting for the social costs of congestion, air pollution, and road safety is also relevant in developed countries. As an analysis of urban transport in Washington shows, congestion, accident, and local air pollution costs are of far greater economic importance than a charge for GHG emissions (table 4.13).

<table>
<thead>
<tr>
<th></th>
<th>cent/gallon</th>
<th>cents/mile</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fuel-related costs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global warming</td>
<td>6</td>
<td>0.3</td>
</tr>
<tr>
<td>Oil dependency</td>
<td>12</td>
<td>0.6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>18</td>
<td>0.9</td>
</tr>
<tr>
<td><strong>Distance-related costs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Local pollution</td>
<td>42</td>
<td>2</td>
</tr>
<tr>
<td>Congestion</td>
<td>105</td>
<td>5</td>
</tr>
<tr>
<td>Accidents</td>
<td>63</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>210</td>
<td>10</td>
</tr>
</tbody>
</table>

Chapter 4 – References


Houston and others (1995).


Banister (1998); reproduced in OECD (2002b).

OECD (2002a)


TURNING THE RIGHT CORNER
Ensuring Development Through a Low-Carbon Transport Sector