TRANSPORT FOR HEALTH

THE GLOBAL BURDEN OF DISEASE FROM MOTORIZED ROAD TRANSPORT

FOREWORD BY
WORLD BANK GROUP PRESIDENT JIM YONG KIM

GLOBAL ROAD SAFETY FACILITY
THE WORLD BANK GROUP

INSTITUTE FOR HEALTH METRICS AND EVALUATION
UNIVERSITY OF WASHINGTON

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This report was prepared by the Global Road Safety Facility at the World Bank and the Institute for Health Metrics and Evaluation (IHME) at the University of Washington and was based on seven papers for the Global Burden of Diseases, Injuries, and Risk Factors Study 2010 (GBD 2010) published in *The Lancet* (2012 Dec 13; 380). GBD 2010 had 488 co-authors from 303 institutions in 50 countries. The work was made possible through core funding from the Bill & Melinda Gates Foundation. The views expressed are those of the authors. The findings, interpretations, and conclusions expressed in this work do not necessarily reflect the views of the World Bank, its Board of Executive Directors, or the governments they represent.

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Global Road Safety Facility

GBD

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ABOUT THE GLOBAL ROAD SAFETY FACILITY AT THE WORLD BANK GROUP

The Global Road Safety Facility (GRSF), a global partnership program administered by the World Bank, was established to help address the growing crisis of road traffic deaths and injuries in low- and middle-income countries. GRSF provides funding, knowledge, and technical assistance that catalyze further investments through World Bank projects addressing road safety. GRSF also partners and collaborates with other multilateral organizations, the private sector and NGOs, and country-based agencies. To express interest in collaborating with the GRSF, or to receive copies of this publication, please contact the GRSF at www.worldbank.org/grsf.

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The Institute for Health Metrics and Evaluation (IHME) is an independent global health research center at the University of Washington that provides rigorous and comparable measurement of the world's most important health problems and evaluates the strategies used to address them. IHME makes this information freely available so that policymakers have the evidence they need to make informed decisions about how to allocate resources to best improve population health.

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LIST OF FIGURES

LIST OF TABLES

FOREWORD

Transport for Health focuses timely attention on the growing burden that motorized road transport imposes on global health development. By quantifying the burden of disease attributable to both road injury and air pollution from vehicles, the authors have found that motorized road transport deaths exceed those from diseases such as HIV, tuberculosis, or malaria. That is a powerful wake-up call.

Mobility solutions need to address the whole gamut of human needs: transport that is clean and affordable must also be safe for people who want access to jobs, health, and education. Road injuries now rank as the world's eighth-leading cause of death and the number-one killer of young people ages 15 to 24. While the disease burden attributed to ambient air pollution has declined among richer regions such as Western Europe and North America, over the last 20 years we have seen a sharp rise in South Asia and East Asia.

These alarming findings underscore the urgent need to spread improvements in transport pollution and safety across world regions. Building the institutional capacity to address this challenge, by mobilizing expertise across health and transport sectors, is also crucial. It is a matter of life, death, and equity: approximately 90% of all road crashes now happen in low- and middle-income countries; yet they own only half of the world's motor vehicles. More than half of global deaths are among pedestrians and operators of motorized two-wheeled vehicles. Rates are higher in the world's poorest regions. These losses are tragic and needless. Families often lose their breadwinners or have to pay for expensive medical treatment. Many are plunged into poverty as a result.

Road crashes cost an estimated 1% to 5% of GDP in developing countries, undermining efforts to reduce poverty and boost shared prosperity. In the coming years, the World Bank Group, our partners through the Global Road Safety Facility, the international donor community, and governments worldwide need to scale up efforts to save millions of lives and avoid serious injuries, as mandated by the United Nations Decade of Action for Road Safety 2011-2020.

The work conducted by the Institute for Health Metrics and Evaluation to update the Global Burden of Disease (GBD) dataset is particularly valuable. These findings will help us sensitize policymakers to the staggering cost of current and future health trends, and to mobilize appropriate responses to transport and health challenges in an increasingly urbanized and motorized world.

Facts in hand, I am convinced we can achieve safer, cleaner, and more affordable transport solutions that benefit the poor, create resilient economies, and save millions of lives.

Jim Yong Kim

President
The World Bank Group

FOREWORD

This report summarizes the findings of a long and meticulous journey of data gathering and analysis to quantify the health losses from road deaths and injuries worldwide, as part of the path-finding Global Burden of Disease (GBD) study. It is important, first, to acknowledge the profound contribution made by the lead authors and global team of injury prevention professionals to estimate the disease burden of road trauma, before absorbing their findings and recommendations. Without their dedication and tenacity, the way forward would be less certain. The first GBD study, published nearly two decades ago, signaled an emerging road safety crisis in developing regions of the world. It triggered a remarkable program of global advocacy that culminated in the United Nations Decade of Action for Road Safety and Global Plan to bring road safety outcomes under control in these regions by 2020. However, limited investment has been mobilized so far to implement the UN initiative. The second GBD study, and related analyses presented in this report, confirm the importance of road safety as a global development priority and the urgency with which it must be addressed.

The report's findings highlight the growth in road deaths and injuries globally, and their substantial impacts on maternal and child health, despite sustained reductions over the last three to four decades in high-income countries. Combined with the deaths arising from vehicle pollution, the road transport death toll exceeds that of, for example, HIV/AIDS, tuberculosis, malaria, or diabetes. This statistic further reinforces the call for global action. Without these GBD estimates we would not have a clear picture of the true situation because official country data in the developing world vastly understate the scale of road transport health losses.

The report's findings also underscore the policy complexities of managing the adverse health impacts of increasing road vehicle travel. These include premature death and disability arising from road crashes, air pollution, diminished physical activity, and greenhouse gas emissions. While estimates of road crash injuries have been improved, and conservative estimates of the disease burden attributable to road vehicle pollution have been made, the adverse health impacts of reduced physical activity and greenhouse gas emissions resulting from increased road vehicle use are yet to be reliably estimated. Nevertheless, it is clear from the evidence presented that the potential is substantial for safer active transport facilities to reduce the growing burden of non-communicable diseases and climate change impacts.

The issue remains of how to best use the report's findings. A strong case is made for improved data collection and more robust accounting of adverse health impacts within a sustainable development framework. Multisectoral collaboration, strengthened institutional management capacity, and the development of more comprehensive transport evaluation tools will be integral to this desired shift in practice. Above all, the report's findings make it clear that the economic benefits of reducing the health losses accruing to road transport are too huge to ignore. In the case of road safety and air quality improvements, they have proved to outweigh their costs – as demonstrated by the experience of high-income countries over the last four decades – and the business case for integrated action is compelling.

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PREFACE

Two decades ago, the first iteration of the Global Burden of Disease study brought attention to the growing toll of premature death and disability from road injury. Since that time, deaths from road injuries increased to become the eighth-leading cause of death worldwide in 2010. Road injuries are a universal threat to population health across rich and poor countries alike and disproportionately impact the most economically productive age groups in society.

The increasing use of vehicles over time has led to more air pollution, which also negatively impacts health. This report marks the first effort to quantify both the burden of disease attributable to road injury and the burden linked to air pollution from vehicles. While the consequences of road injury tend to be immediate and severe, air pollution from vehicles is more insidious and can lead to ischemic heart disease, stroke, chronic lung diseases, and lower respiratory infections. To strengthen our understanding of this health risk, we need to improve the data available on vehicle pollution and the methods for estimating its contribution to disease burden. If this challenge can be met, it will allow researchers and policymakers to monitor progress in reducing the burden from vehicle emissions.

Ministry of health officials are typically viewed as the chief stewards of countries' population health, but reducing the disease burden from motor vehicles requires action from multiple sectors. As economies grow and demand for cars and roads increases, the transport sector plays a vital role in designing, building, and maintaining an infrastructure and regulatory system that will encourage economic growth while minimizing health loss. Policymakers can improve health by implementing measures shown to effectively reduce disease burden from transport, such as vehicle safety and emissions regulations, seatbelt and helmet requirements, and speeding and drunk-driving laws. These regulations are only as effective as they are enforced legally, requiring investment to ensure compliance with these laws.

The success we see in high-income countries, where premature death and disability from road injuries have dropped, shows us it is possible to reverse this growing problem. The United States reduced its burden of road injuries by 16% between 1990 and 2010, despite a significant increase in population and vehicles on the road. Many Western European and high-income countries in the Asia Pacific region reduced their burdens even more dramatically. Japan reduced its disease burden from road injuries by 42% between 1990 and 2010, and Sweden lowered its burden by 30%. Case studies of interventions, policies, regulations, and institutional capacity to deliver them in these high-achieving countries could help elucidate key lessons that other nations can follow to reduce the burden of road injuries.

Annual updates of the Global Burden of Disease will allow decision-makers to continually monitor the impact of road injuries in their countries as they implement new policies and design programs to address this important health problem. By collaborating across sectors, replicating effective policies carried out in other countries, and making an ongoing commitment to improve data and research, we can get closer to realizing a world where everyone enjoys the benefits of safe transport and lives a long and healthy life.

Christopher J.L. Murray

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EXECUTIVE SUMMARY

Rapid improvements in road transport have helped many nations make progress toward their development goals. Transport is often one of the most highly funded sectors in development bank lending portfolios due to ongoing demand from borrowers as well as its role in stimulating economic growth and competitiveness. At the same time, the global development community is increasingly concerned about the social costs of growth in road transport, particularly the impacts on human health due to the rise in road traffic injuries and impacts on non-communicable diseases via emissions and decreased physical activity.

This report quantifies, for the first time, the global health loss from injuries and air pollution that can be attributed to motorized road transport. It combines estimates of the global burden of road injuries based on a large pool of new data from the most information-poor regions with estimates of the health effects of pollution from vehicles. The results of this analysis show the following:

- Motorized road transport imposes a large burden on population health, resulting in more than 1.5 million deaths and 79.6 million healthy years of life lost annually. Deaths from road transport exceed those from HIV, tuberculosis, or malaria. Injuries and pollution from vehicles contribute to six of the top 10 causes of death globally.
- Road injuries have a substantial impact on maternal and child health. Health loss attributable to motorized road transport exceeds that from key risk factors affecting children, including childhood underweight and suboptimal breastfeeding. Road injuries rank among the top 10 causes of death after the first year of life through age 59. In addition, road injuries are a top-10 cause of death among women of childbearing age and are the fourth-leading cause among women aged 15 to 29 years.
- The burden due to motorized road transport is growing. Over the last two decades, deaths due to road crashes grew by 46%. Deaths attributable to air pollution, to which motor vehicles are an important contributor, grew by 11%.
- Health loss resulting from the combined effects of road injuries and pollution from transport is substantial in all regions. While the deaths from road transport are dominated by road injuries in poorer regions, such as sub-Saharan Africa, health loss due to pollution from vehicles tends to be highest among richer regions, such as Western Europe.
- Injuries are responsible for most of the burden of motorized road transport, accounting for 95% of the healthy life years lost. Road crashes result in 1.3 million deaths annually and 78.2 million nonfatal injuries warranting medical care.
- Pedestrians alone account for 35% of road injury deaths globally and over 50% in East and Central sub-Saharan Africa.

- Pollution from vehicles is the cause of 184,000 deaths globally, including 91,000 deaths from ischemic heart disease, 59,000 deaths from stroke, and 34,000 deaths from lower respiratory infections, chronic obstructive pulmonary disease, and lung cancer.
- Official government statistics substantially underreport road injuries. Estimates based on Global Burden of Disease 2010 data suggest, for example, that road injury deaths are more than twice the official statistics in India, four times those in China, and more than six times the official numbers in parts of Africa.

KEY CONCLUSIONS AND RECOMMENDATIONS

This report reaffirms the need for safe and clean transport for achieving global health and development goals. It calls for a multisectoral collaboration that includes the transport, health, and urban sectors, among others, to help achieve beneficial and sustainable development. In particular:

- Road injuries are a major contributor to the Global Burden of Disease. Thus, rapidly scaling up road safety programs alongside the expansion of transport is vital for saving lives while promoting development. Mitigating the health risks requires a long-term investment strategy to build the capacity of national institutions so they can actively manage safety and mobility performance through targeted interventions. This is necessary given the multisectoral complexity of road safety and demands a systematic approach rather than isolated efforts with specific interventions.
- While malnutrition, diarrhea, and many infectious diseases occur in settings of extreme poverty, the health burden associated with road transport spreads with economic growth and rapid motorization. This need not be the case, provided countries, aid agencies, and donors develop comprehensive and country-specific policy frameworks for investing in the health and well-being of populations. It took developed countries 70 years to reverse negative health trends from road transport, but developing countries can accelerate this process through strategic investments and collaboration across sectors.
- Due to limitations of available data and methods, we have likely underestimated the effects of pollution from vehicles. Additional research is needed to obtain more detailed geographic information on human exposure to air pollution in rapidly motorizing regions and to better understand the health effects of exposure to traffic-related pollutants. In addition, a comprehensive accounting of the burden of road transport requires research to quantify the loss of physical activity due to motorization, which is not possible with currently available data and methods.
- There is an urgent need for better tracking of the health impacts of road transport. Statistical systems need to be expanded and improved to collect key indicators to monitor and evaluate these effects. The absence of reliable accounting of health impacts not only endangers effective multisectoral action, it can waste government resources or lead to development aid funding being targeted at ineffective solutions.

INTRODUCTION

MOTORIZED ROAD TRANSPORT POSES A GROWING THREAT TO POPULATION HEALTH

International and national development agencies have long viewed building roads as a key strategy for driving economic growth and improving the health and well-being of people. Providing reliable transport infrastructure can stimulate economic development in several ways. For instance, foreign direct investment is attracted to regions that provide high-quality road infrastructure to facilitate efficient logistics.[1] Within a country, road infrastructure connects remote areas with centers of trade and connects centers of industry to global markets, spurring the growth of trade and reducing costs by improving access to goods and services.[1]

Since 2000, the Millennium Development Goals (MDGs) have been the central focus of global development. While the MDGs did not explicitly address the transport sector, roads have been viewed as crucial for successfully achieving several of the MDGs. In 2005, the African Union and the United Nations (UN) Economic Commission for Africa wrote a report[2] calling for widespread infrastructure improvements, stating, "The significance of transport services to each of the MDGs means that effective pursuit of the latter requires priority attention to those transport services, which are relevant to each." Roads bring people closer to health care facilities and educational opportunities. In particular, rural connectivity helps reduce maternal mortality through better access to maternal care.[3] Rural roads have impact on increasing the enrollment of girls in school.[3] In addition to being an end in itself, education of girls is important to population health as it helps reduce fertility rates and improve maternal and child health, among other mechanisms.[4] Similarly, roads facilitate access to food markets and can promote better nutrition.[3]

Motorized road transport has grown briskly in recent decades, especially in regions with the most rapidly growing economies. In the last two decades, China has built a highway system that, by Chinese government estimates, rivals that of the United States, and it plans to further develop the network substantially over the next decade.[5] In India, rapid expansion of the highway infrastructure is currently underway because insufficient road transport is viewed as a key impediment to industrial growth and has been viewed as a reason for the country's failure to achieve the full benefits of economic reforms.[6] In sub-Saharan Africa, where most people do not have access to all-weather roads, road transport is seen as a key solution to providing basic services, reducing poverty, and driving economic growth.[3]

However, motorized road transport is also closely linked to several threats to human health and well-being that have not been previously assessed in a comprehensive manner. These harms include the direct health effects of road injuries and vehicular emissions, the indirect health effects of sedentary lifestyles resulting from frequent use of motorized transport, and the threat of catastrophic environmental damage through climate change, to which vehicular emissions are a key contributor. Each of these issues is increasingly receiving attention. Our knowledge of global road safety has substantially improved in recent years due to several epidemiological studies such as the Global Burden of Diseases, Injuries, and Risk Factors Study 2010 (GBD 2010), which is the basis of this publication. While the Global Burden of Disease due to ambient air pollution has also been characterized, the contribution of emissions from vehicles has never been estimated. In this report, we estimate these for the first time. Although studies to estimate the global burden of physical inactivity have become increasingly sophisticated, the contribution of motorization to physical inactivity has not been measured and represents an important gap in our assessment of the health impacts of motorized road transport. Finally, although action to address climate change is urgently needed, the connections between transport, climate, and health have been extremely difficult to quantify.[7]

Despite these numerous limitations, the systematic and comprehensive assessment of the health effects of motorized road transport presented in this publication can help guide decision-making in the transport sector for a safer and more prosperous future.

NEED FOR A MULTISECTORAL APPROACH

Since the identification of road injuries as one of the top 10 causes of death and disability by the original GBD study in 1993, substantive global efforts have been undertaken to establish road safety as a development priority. In May 2011, the UN Decade of Action for Road Safety 2011-2020 was launched in more than 100 countries with the goal of preventing 5 million road traffic deaths and 50 million serious injuries. The launch was a culmination of substantial efforts by international and national agencies. These included the release of the 2004 *World Report on Road Traffic Injury Prevention* by the World Health Organization (WHO) and the World Bank, multiple UN and World Health Assembly resolutions calling on governments to improve road safety, and the first Global Ministerial Conference on Road Safety in 2009.[8] Numerous co-sponsoring country governments, key UN regional agencies, and multilateral development banks have endorsed the call for the Decade of Action and its goals.

At the same time, non-communicable diseases, which are linked closely to motorized transport through the health effects of air pollution and physical inactivity, have emerged as a major health problem. In September 2011, the High-level Meeting of the UN General Assembly adopted the Political Declaration on the Prevention and Control of Non-communicable Diseases.[9] It is now considered likely that non-communicable diseases will figure prominently in the post-MDG era beginning in 2015.

A multisectoral approach for addressing the health impacts of transport is key for maximizing public health improvements. For example, promoting active transport, such as walking and biking, has emerged as a guiding vision among public health professionals. However, people tend not to walk, bike, or take public transport unless these activities are safe.[10] In fact, a growing body of literature shows that such programs are most successful when they employ an integrated approach that includes providing safe infrastructure such as sidewalks and bike lanes, supportive land use planning, and advocacy and education.[11]

Providing infrastructure that makes active modes of travel safe, secure, and convenient is particularly important, making the transport sector the key enabler for the multisectoral goal of healthy development. Major international institutions, such as development banks, are attempting to reframe their development agenda to be consistent with these principles of sustainable transport and development.[12] Commitments for sustainable transport growth, as seen at the 2012 Rio+20 Summit,[12] although small, are important steps toward this broader vision.

PURPOSE OF THIS REPORT

This report is the first attempt to assess the combined direct global health loss that can be attributed to motorized road transport. Specifically, we quantify the health impacts of motorized road transport from 1) injuries due to road traffic crashes over the last two decades, and 2) air pollution generated by motorized road transport ("pollution from vehicles").

We did not estimate indirect health impacts, such as physical inactivity, and distal impacts, such as climate change, because we lacked sufficient epidemiological data to construct estimates of these effects at a global scale. Finally, we discuss the implications of our findings for transport and health policy.

METHODS

Our estimates of the health losses due to motorized road transport are based on GBD 2010, which is a systematic, scientific effort to quantify the comparative magnitude of health loss due to 291 diseases and injuries, 1,160 sequelae (direct consequences of disease and injury, also known as complications), and 67 risk factors for 20 age groups and both sexes in 1990, 2005, and 2010. GBD 2010 produced estimates for 187 countries and 21 regions. GBD 2010 generated estimates of the burden of road injuries as well as the burden that can be attributed to outdoor air pollution from all sources. For the first time, we estimated for this report the amount of premature death and disability that is attributable to air pollution from motor vehicles ("pollution from vehicles") and combined that with the burden of road injuries to construct estimates of the total health loss due to motorized road transport. This chapter provides a synopsis of methods. For more details, see Annex 1 and associated GBD 2010 publications.[13]

ESTIMATING THE BURDEN OF ROAD INJURIES

As part of GBD 2010, we accessed and assessed all empirical measurements of population health that could inform estimates of the incidence of fatal and nonfatal road injuries. These included data from vital registration systems, verbal autopsy studies, mortuary/burial registers, household surveys, hospital databases, and prospective studies of disability outcomes following injuries. Prior to analysis, these data sources were systematically cleaned and standardized. Next, we estimated road injury mortality in all countries using Cause of Death Ensemble Modeling (CODEm), which is an analytical tool used in GBD 2010 that tests a wide variety of possible statistical models of causes of death and creates a combined "ensemble" model that provides the best predictive performance. We assessed the burden of nonfatal road injuries by first calculating the incidence of nonfatal crashes using population-based data (e.g., household surveys), then estimating the complications from crashes using hospital data. Next, we estimated the duration of disability based on prospective follow-up studies, and finally, estimated health loss by applying disability weights (a number on a scale from 0 to 1 that represents the severity of health loss associated with a health state).

ESTIMATING THE BURDEN OF VEHICULAR EMISSIONS

We estimated human exposure to annual average levels of fine particulate air pollution ($PM_{2.5}$) from road transport in two steps. First, we developed a database of geo-referenced, annual average $PM_{2.5}$ measurements from surface monitors in 2005, combined with estimates of $PM_{2.5}$ derived from satellite-based observations and estimates of $PM_{2.5}$ from a global atmospheric chemical transport model (TM5). Thus, we estimated $PM_{2.5}$ levels at a grid resolution of 10 x 10 square kilometers across the globe for the year 2005 and extrapolated it to 1990 and 2010 based on observed trends. Second, we estimated the contribution of road transport to overall $PM_{2.5}$ for 2010 in all countries using a global air quality source-receptor model that links emissions of pollutants within a given source region with downwind impacts. We estimated the country-specific burden of disease attributable to total $PM_{2.5}$ exposure using nonlinear functions for the leading global causes of death and disability associated with outdoor air pollution: ischemic heart disease, stroke, lung cancer, chronic obstructive pulmonary disease, and acute lower respiratory tract infections in children. These risk functions were used in GBD 2010 to generate country-level estimates of the burden of disease attributable to exposure to ambient $PM_{2.5}$. We then estimated the country-specific burden of disease attributable to $PM_{2.5}$ from road transport by multiplying the country-specific total $PM_{2.5}$-attributable burden by the region-specific (country-specific for some large countries) proportion of ambient $PM_{2.5}$ from road transport.

We report burden of disease using the following standard metrics of population health loss:

- **Years of life lost (YLLs):** This is the number of years of life lost due to premature death. It is calculated by multiplying the number of deaths at each age by a standard life expectancy at that age.
- **Years lived with disability (YLDs):** Years of life lived with any short-term or long-term health loss, adjusted for severity.
- **Disability-adjusted life years (DALYs):** This is the sum of YLLs and YLDs. DALYs are also defined as years of healthy life lost.

GLOBAL HEALTH LOSS DUE TO INJURIES AND POLLUTION FROM ROAD TRANSPORT

MOTORIZED ROAD TRANSPORT AND HEALTH LOSS

Injuries and air pollution generated by motorized road transport were associated with six of the top 10 causes of death and five of the top 10 causes of premature death and disability, also known as disability-adjusted life years (DALYs), in 2010 (Table 1). In fact, the top three causes of death, premature mortality (YLLs), and premature death and disability are diseases that are linked to air pollution, which is closely associated with motorized road transport. Overall, injuries and air pollution from road transport caused 1.5 million deaths globally, representing 2.9% of deaths from all causes. Together, they were the sixth-leading cause of death in 2010, with a death toll exceeding those from HIV/AIDS, tuberculosis, malaria, and diabetes. They were responsible for 79.6 million healthy life years lost, or DALYs, which is 3.2% of the total global burden of disease and injuries.

Table 1: Leading causes of death worldwide, associated DALYs, and burden attributable to motorized road transport, 2010

		Global burden of disease		Burden attributable to motorized road transport	
Rank	Cause	Deaths	DALYs	Deaths	DALYs
1	Ischemic heart disease	7,029,270	129,795,464	90,639	1,909,563
2	Stroke	5,874,181	102,238,999	58,827	1,148,699
3	COPD	2,899,941	76,778,819	17,266	346,376
4	Lower respiratory infections	2,814,379	115,227,062	5,670	489,540
5	Lung cancer	1,527,102	32,405,411	11,395	232,646
6	HIV/AIDS	1,465,369	81,549,177	–	–
7	Diarrheal diseases	1,445,798	89,523,909	–	–
8	Road injury	1,328,536	75,487,102	1,328,536	75,487,104
9	Diabetes mellitus	1,281,345	46,857,136	–	–
10	Tuberculosis	1,195,990	49,399,351	–	–
	All other causes	24,207,527	1,682,995,639	–	–
	Total	**52,769,676**	**2,482,258,070**	**1,512,333**	**79,613,928**

Note: In the "burden attributable to motorized road transport" column, emissions from road transport contribute to deaths and DALYs from ischemic heart disease, stroke, COPD, lower respiratory infections, and lung cancer. Road transport accidents contribute to deaths and DALYs from road injury.

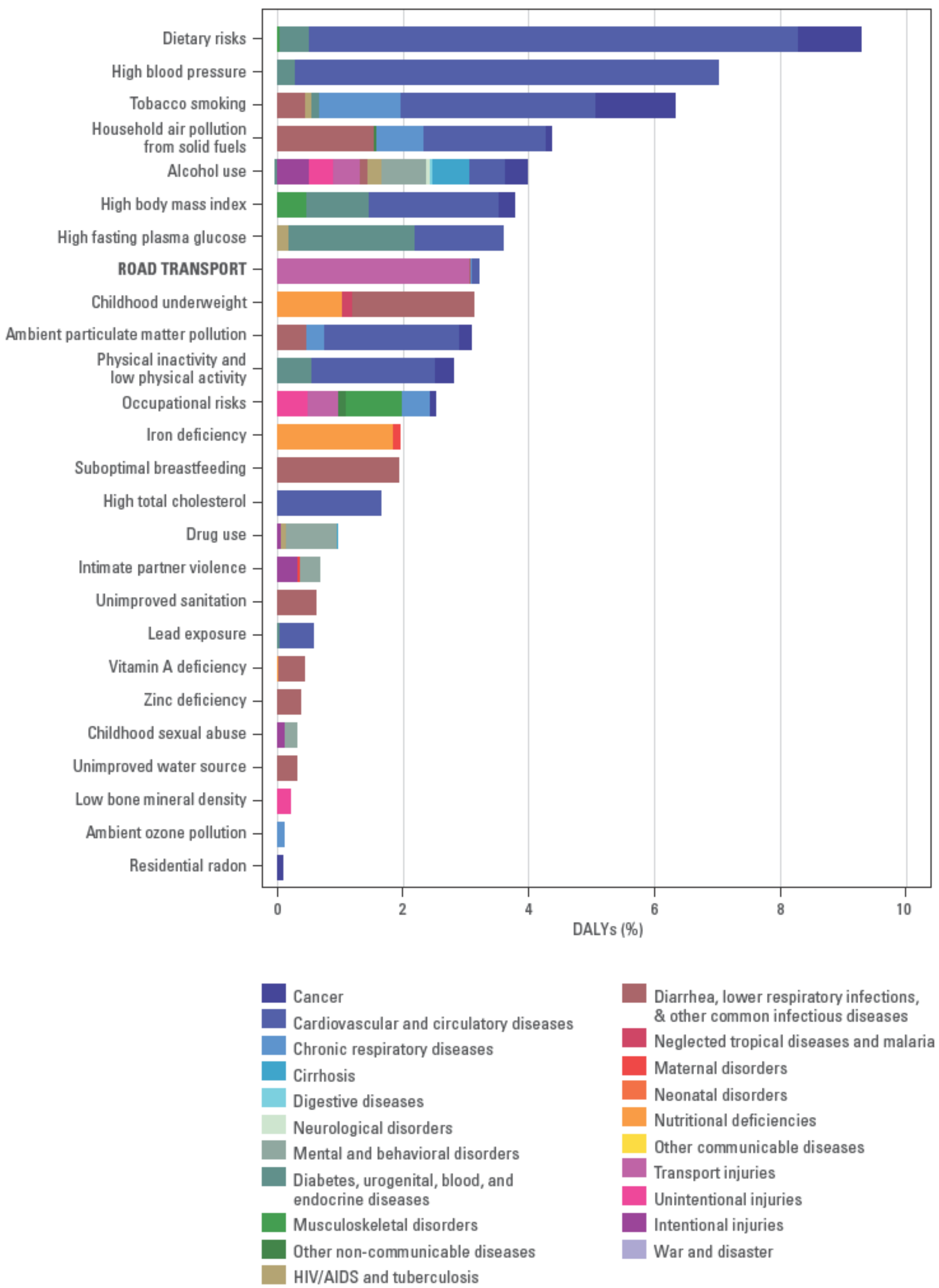
Injuries resulting from road crashes account for 95% of the combined burden of ill health from motorized road transport. Road injuries killed 1.33 million people globally in 2010 and were the eighth-leading cause of death, accounting for 2.5% of all global deaths. The road injury death toll exceeded that from diseases such as tuberculosis and malaria that receive substantial attention in the global health research and development community. They were the 10th-leading cause of healthy life years lost, contributing 3.0% of the total global health burden. They were also the eighth-leading cause of premature mortality.

In addition to injuries, pollution from vehicles causes a broad range of acute and chronic health effects, ranging from minor physiologic disturbances to death from respiratory and cardiovascular diseases. In 2010, we estimate that exposure to pollution from vehicles, in terms of particulate matter pollution ($PM_{2.5}$) derived from vehicular emissions, resulted in 184,000 deaths globally. This includes 91,000 deaths from ischemic heart disease, 59,000 deaths from stroke, and an additional 34,000 deaths due to lower respiratory infections, chronic obstructive pulmonary disease (COPD), and lung cancer combined. As explained in Annex 1, we expect that these results underestimate the health loss attributable to pollution from vehicles.

While this report was being prepared, the International Council for Clean Transportation (ICCT) completed an analysis of the mortality attributable to ambient $PM_{2.5}$ from motor vehicles, using similar methodology but some different input datasets.[14] Overall, the results of this analysis were similar to ours. The ICCT estimated 230,000 deaths per year in 2005, compared to the 184,000 deaths per year in 2010 that we estimate. As in our analysis, the ICCT found that the greatest disease burden attributable to air pollution from motor vehicles was observed in East Asia, followed by Western Europe, South Asia, and North America. In both our work and the ICCT analysis, mortality rates attributable to ambient $PM_{2.5}$ from motor vehicles were highest in Western, Central, and Eastern Europe, high-income Asia Pacific countries, and North America.

Figure 1 compares the combined burden of injuries and air pollution from motorized road transport with other leading risk factors. In 2010, road transport ranked eighth, with a burden comparable to alcohol use, which is also a key contributor to the burden of road injuries. It ranked ahead of important global health risks such as childhood malnutrition and risks faced in the workplace.

Figure 1: Percentage of global health loss that can be attributed to motorized road transport compared with other leading risk factors, 2010

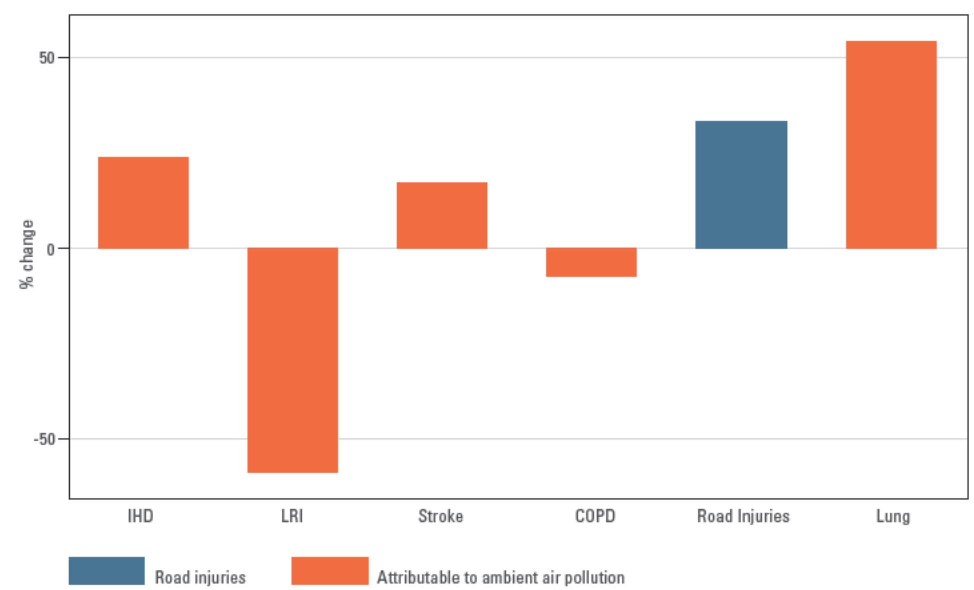


THE BURDEN OF DISEASE FROM ROAD TRANSPORT IS GROWING IN RAPIDLY MOTORIZING COUNTRIES

GBD 2010 estimates show that over the last two decades, the Global Burden of Disease has transitioned from communicable, maternal, neonatal, and nutritional disorders toward non-communicable diseases and injuries. Similarly, the contribution of risk factors has shifted from those that cause communicable diseases among children to risk factors that lead primarily to non-communicable diseases and injuries among adults.

In this report, we have estimated the health effects of pollution from vehicles only for the year 2010. However, it is important to note that overall ambient air pollution, of which air pollution from vehicles is a component, contributed to increases in premature death and disability from certain diseases as shown in Figure 2. The figure illustrates changes in the proportion of the burden attributable to overall ambient air pollution estimated in GBD 2010 and to road injuries between 1990 and 2010. Although disease burden from lower respiratory infections attributable to ambient air pollution declined and COPD has remained relatively stable, there have been large increases in disease burden from ischemic heart disease, stroke, lung cancer attributable to ambient air pollution, and road injuries.

Figure 2: Global shifts in healthy years lost due to road injuries and ambient air pollution from all sources, 1990 to 2010

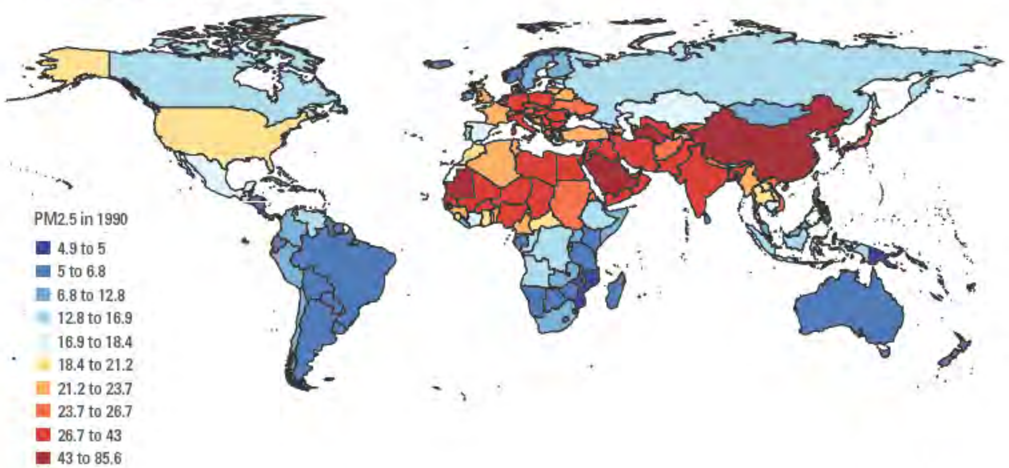


Note: This figure illustrates time trends of health effects from all sources of air pollution estimated in GBD 2010. In this report, we assess the health effects of pollution from vehicles for only one year, 2010. IHD: ischemic heart disease; LRI: lower respiratory infections; COPD: chronic obstructive pulmonary disease.

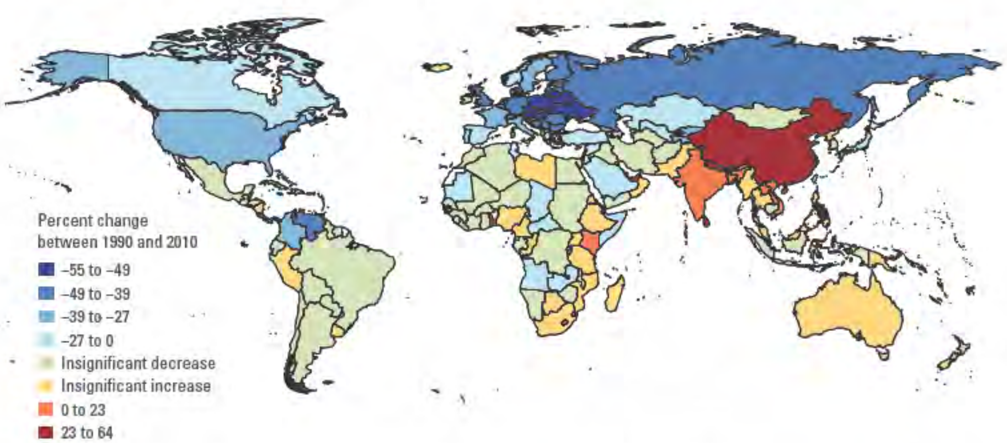
Figure 3 illustrates the vast differences across regions and countries in overall ambient air pollution and the changes over two decades. These results are broadly consistent with other reports. (Brauer et al.[15] provide a detailed review.) Although pollution levels were relatively high in 1990 in many countries in Western and Central Europe, these regions have seen considerable declines over 20 years. Declines in air pollution have also occurred in North America. In contrast, ambient pollution levels in South Asia and East Asia were already high and have increased further during this period.

Figure 3: Overall ambient air pollution levels ($PM_{2.5}$), 1990 (a), and change in ambient air pollution levels ($PM_{2.5}$), 1990 to 2010 (b)

(a) Air pollution in 1990



(b) Change in air pollution, 1990 to 2010

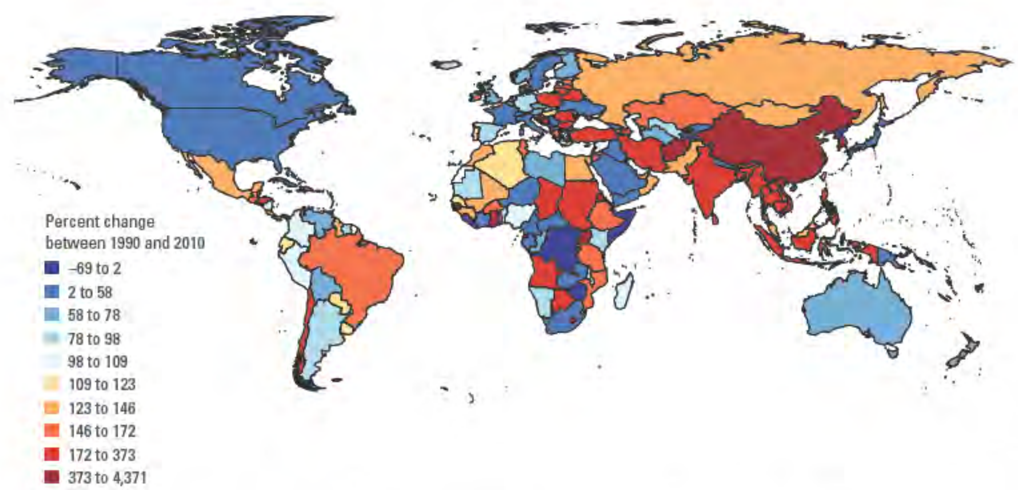


Note: These figures illustrate estimates and change in all sources of air pollution. All estimates are adjusted for population size.

Although we are unable to assess trends in pollution from vehicles with the currently available epidemiological information, a comparison with growth in motor vehicle fleets is instructive. Figure 4 illustrates that while motor vehicle fleets have grown in all countries, many of the countries with the largest increases (including China and India) are the same as those with rapid increases in overall air pollution. However, it should be noted these regions would have also experienced concomitant growth in other sources of air pollution, notably from industrial sources.

Aside from changes in motor vehicle ownership rates, regional trends in overall air pollution are partly explained by efforts to reduce pollution from vehicles in many high-income regions, including Western Europe and North America. For example, a recent analysis projected a reduction of nearly 40% in deaths attributable to air pollution from transportation (of which about 50% is due to road transport) in the US from 2005 to 2016.[16]

Figure 4: Change in motor vehicle ownership per capita, 1990 to 2010



Note: Vehicles per capita are shown. National vehicle fleet was an input used in the GBD 2010 study and was estimated based on analysis of data from multiple sources including the International Road Federation's World Road Statistics Database.

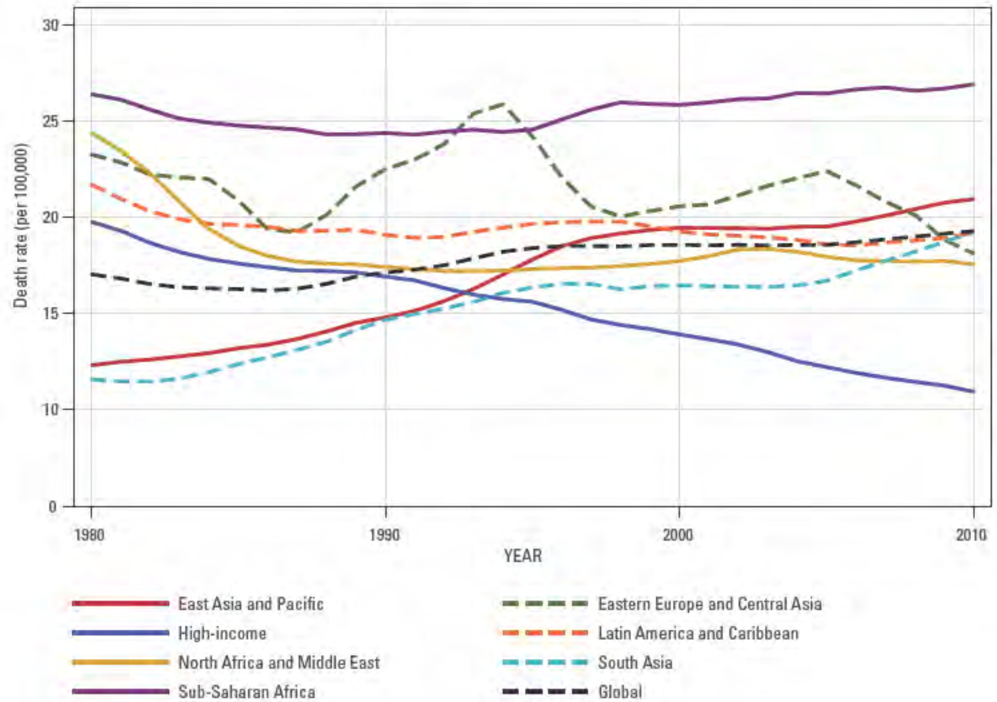
The trends in road injuries have strong parallels with trends in overall air pollution (Figure 5). Since 1980, road injury death rates have steadily declined in most high-income countries. Improvements in road safety in these regions have been well documented.[17] This progress began in the early 1970s, when most high-income countries established national road safety agencies, which instituted a wide array of programs promoting more stringent safety standards for vehicles, roads, and road users. Many middle-income regions succeeded in stemming the growth of road injury death rates. In Central Latin America, road injury death rates have declined by 28% since 1980. In Central Europe and Eastern Europe, road injury death rates have declined by 30% and 20%, respectively. Although the pace of improvement has been slower than that witnessed in high-income regions, these declines occur at a time when motor vehicle ownership rates in these regions have continued to increase.

In contrast to successes seen in other areas of the world, East Asia and South Asia, the two most populous regions of the world, have witnessed the highest increases in road injury death rates (Figure 5). In East Asia, which includes China, road injury death rates have grown by 77% since 1980. Similarly, in South Asia, which includes India, death rates grew by 66%. These regions have also witnessed among the fastest growth in motor vehicle ownership (Figure 4) and highway infrastructure, highlighting the urgent need for better safety management in regions undergoing rapid growth in motorized transport. Unless the death rates in these regions decrease, the goals of the UN Decade of Action for Road Safety will likely not be achieved.

Globally, rates of death from road injury have risen slowly over the last two decades, and this general trend appears to be continuing (Figure 5). This finding differs from the WHO's 2013 *Global Status Report on Road Safety*, which reported that road deaths have plateaued since 2007. The report suggested that "interventions to improve global road safety have mitigated the expected rise in the number of deaths." However, our analysis shows that it is difficult to draw such conclusions from currently available data.

The WHO report based its findings on a cross-sectional analysis of the WHO Mortality Database and national official statistics in 2010, and a comparison of these estimates with another cross-sectional analysis for 2007 conducted previously. The report did not account for uncertainty in the two estimates. In contrast, we have used substantially more data spanning longer time periods and employed statistical models that predict cause of death trends more accurately than other methods. Our analysis (Figure 6) shows that although the GBD 2010 mean estimate of road injury deaths for 2010 is 7% higher than for 2007, the uncertainty in this change is too large (95% confidence interval [CI]: -23, 37) to draw conclusions about short-term trends.

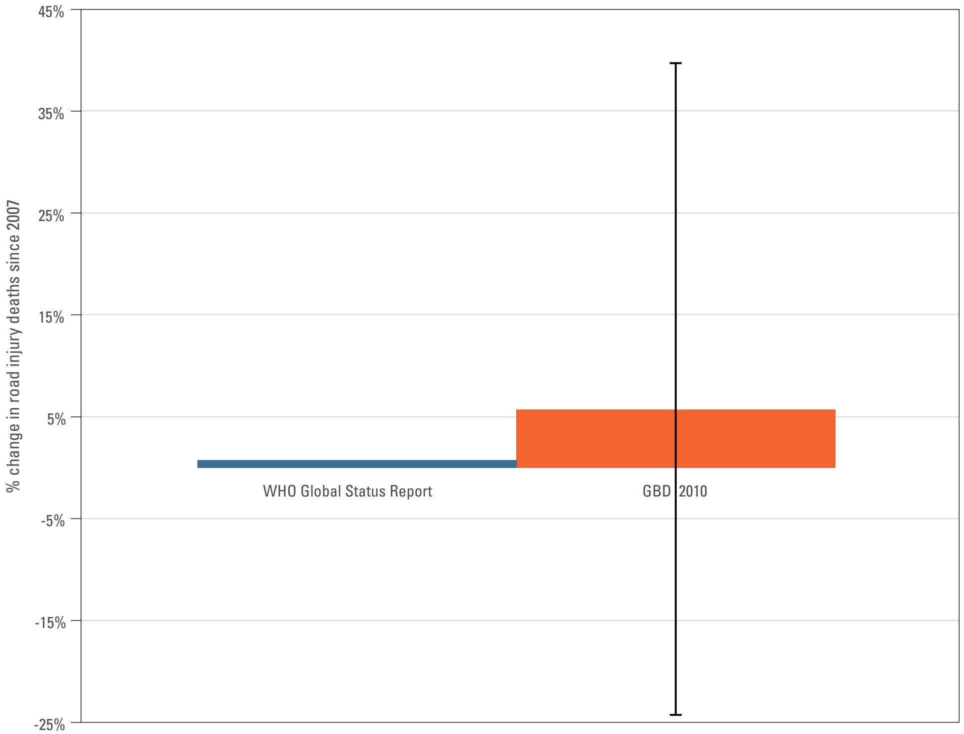
Figure 5: Trends in road injury death rates, 1980 to 2010



Region	% Change from 1980 to 2010
Global	13.21
East Asia	77.23
Southeast Asia	53.90
Oceania	35.79
Eastern Europe	-20.49
Central Europe	-30.14
Central Asia	-12.04
Western Europe	-54.97
High-income Asia Pacific	-32.86
High-income North America	-44.18
Australasia	-58.10
Southern Latin America	-0.23
Caribbean	-4.46
Central Latin America	-28.45
Tropical Latin America	8.19
Andean Latin America	-9.94
North Africa and Middle East	-28.07
South Asia	66.24
Central sub-Saharan Africa	-26.40
Eastern sub-Saharan Africa	-8.79
Southern sub-Saharan Africa	29.78
Western sub-Saharan Africa	15.18

There is an urgent need to make all relevant data available and comparable to reduce the uncertainty in monitoring health impacts of transport. In particular, WHO and the World Bank have in-country networks with access to rich data on health outcomes and transport covariates. Pooling these together can create an unprecedented dataset to assess global injury metrics. GBD 2010 has already made substantial advances in developing the tools to combine data from a wide range of sources into coherent global health metrics. Further efforts to make transport and related health data available could narrow the existing gaps in our knowledge about global road safety.

Figure 6: Percentage change in global road deaths since 2007



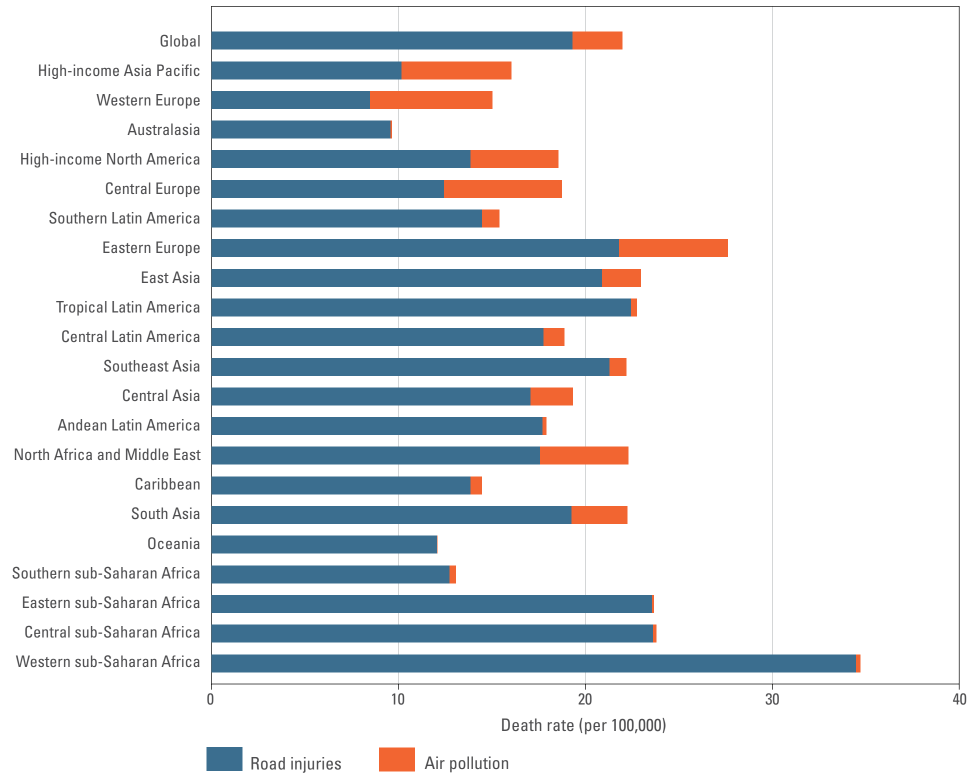
Note: Vertical lines represent the uncertainty interval surrounding the estimate.

COMPARISONS OF BURDEN OF DISEASE FROM ROAD TRANSPORT ACROSS REGIONS

Figure 7 shows death rates from motorized road transport across different regions in 2010. The figure shows considerable variation in the relative contribution of pollution and injuries by region. The general pattern suggests that in the poorest regions of the world, deaths from road transport are dominated by road injuries. For example, injuries accounted for approximately 99% of total deaths attributable to road transport in sub-Saharan Africa. In contrast, in Western Europe, pollution from vehicles contributed nearly half the burden (44%). These variations are caused by a wide range of factors. These include the relative success or failure of different regions in reducing road injuries and controlling pollution from vehicles. In addition, they reflect differences in ages across regions because road injuries tend to affect young adults, while air pollution has a greater impact on young children and older people.

The importance of a risk factor for population health depends on its ranking relative to other risk factors for premature death and disability. Figure 8 ranks the leading risk factors according to their contribution to disease burden in each region. Color-coding is used to indicate how high a risk factor ranks in a region. The leading risk

Figure 7: Death rates from injuries and air pollution due to motorized road transport, 2010



factors are shown in red and orange. Figure 8 illustrates that the burden due to motorized road transport is a leading risk factor in most global regions. It is among the top 10 risk factors in 18 of 21 global regions and is among the top five risk factors in two regions, West sub-Saharan Africa and Andean Latin America.

Figure 8: Ranking of health loss (DALYs) attributable to injuries and air pollution due to road transport compared with leading risk factors in global regions, 2010

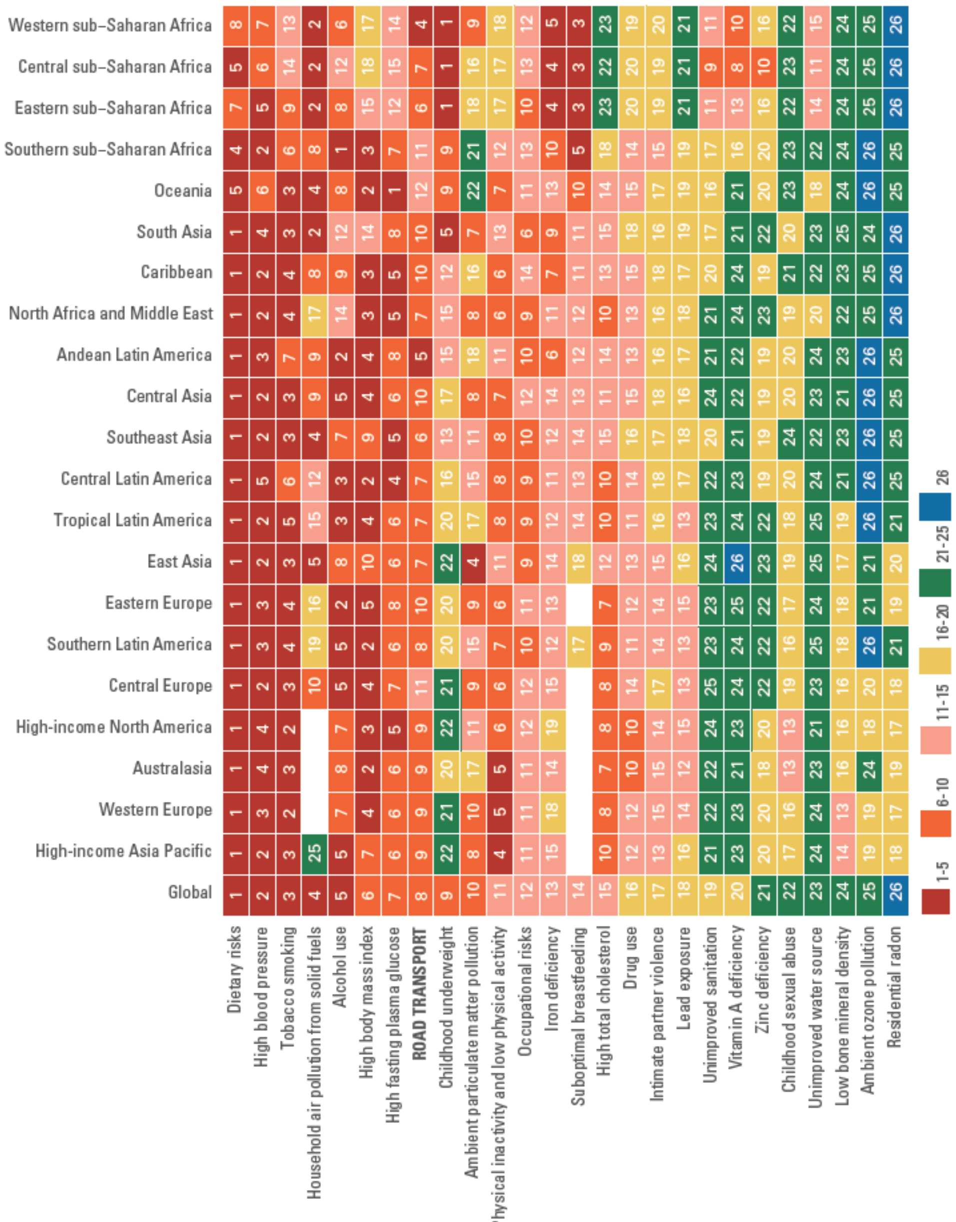
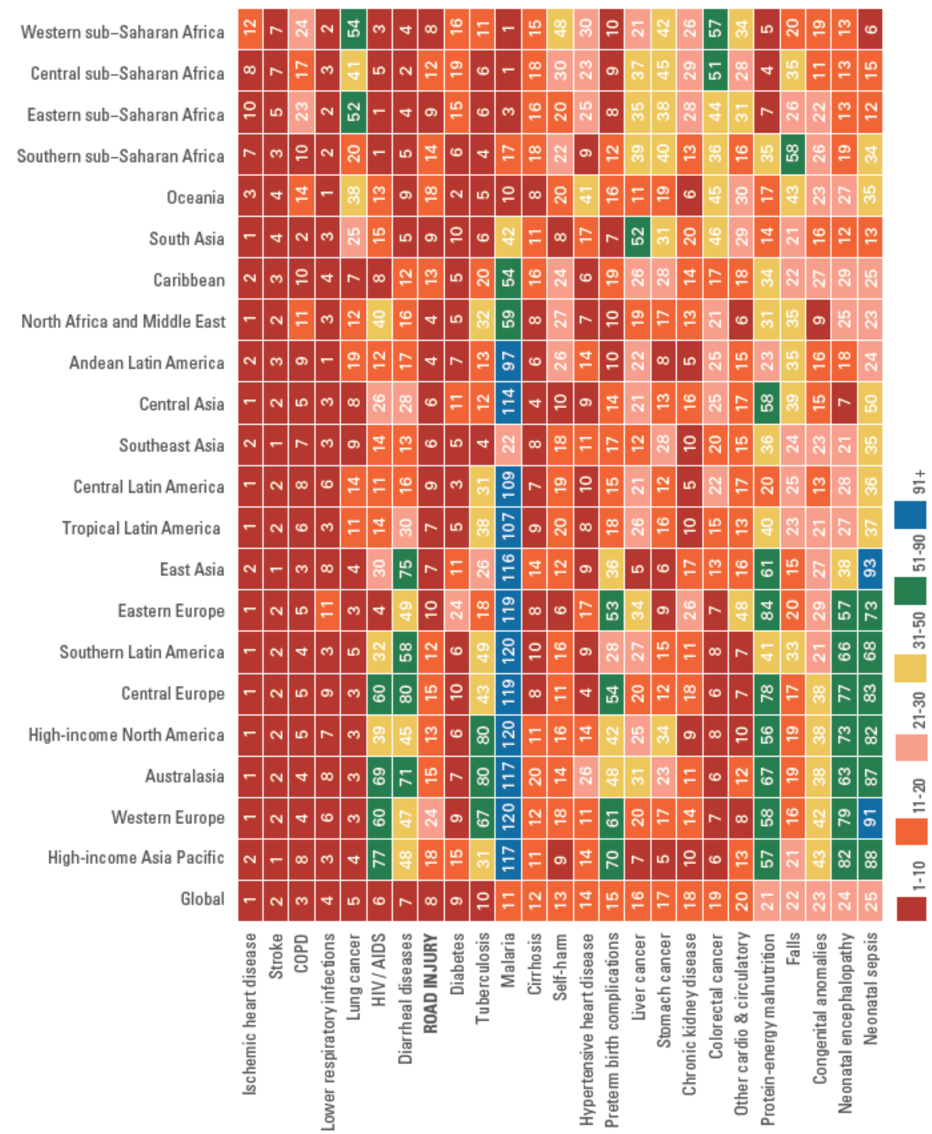


Figure 9 shows the ranking of road injuries as a cause of death independent of pollution from vehicles. Other leading causes of death are also shown. Among the 21 global regions, road injuries ranked in the top 10 causes of death in 11 regions in 2010 (Figure 9). In general, road injuries ranked lowest in the richest regions (such as Western Europe and high-income Asia Pacific). However, as illustrated in Figure 7, low road injury death rates in these regions are accompanied by a relatively high burden from pollution from vehicles. Diseases for which air pollution is a risk factor

Figure 9: Ranking of the top 25 global causes of deaths and their ranking in different regions, 2010



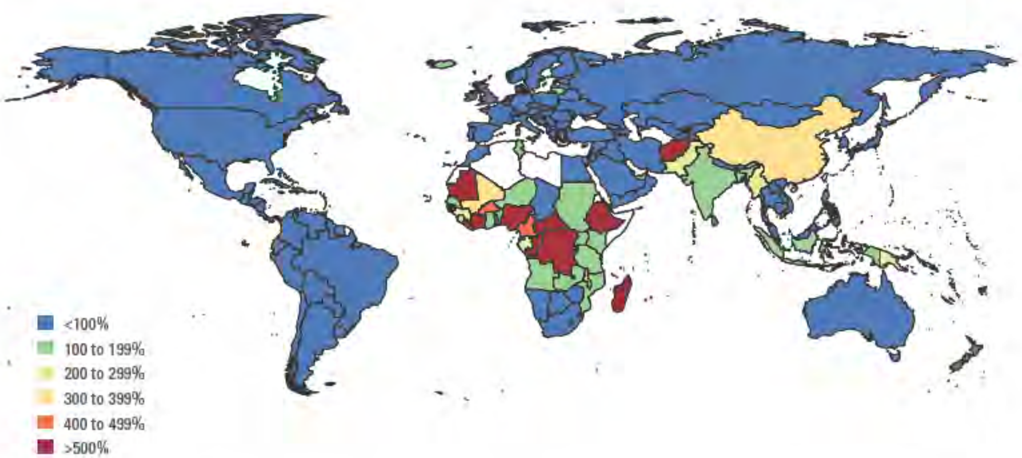
are the top three causes in each of these regions. In general, diseases linked to air pollution are two of the top three causes in most regions, except in sub-Saharan African regions, where communicable diseases, such as HIV, malaria, and diarrheal diseases, dominate the top three causes of death.

ROAD INJURIES ARE UNDERREPORTED IN THE POOREST REGIONS

Figure 10 compares our estimates of road injury death rates by country with those reported in official government statistics. It shows that underreporting of road deaths in many countries exceeds 100%. In some of the poorest parts of the world, such as certain countries in Eastern, Western, and Central sub-Saharan Africa, underreporting exceeds 500%. In general, countries with high death rates have high levels of underreporting. Although underreporting of nonfatal injuries is well documented, even in high-income countries, researchers have usually assumed that deaths are more accurately estimated in official statistics. However, our results illustrate pervasive underreporting even in death counts.

Such large discrepancies cannot be explained by the use of different definitions of road traffic deaths by police across countries. Depending on the country, police databases may report only deaths that occur within one day, one week, or one month of a crash. This issue of different definitions across countries receives substantial attention among international researchers and policymakers seeking to harmonize statistics across countries. For example, WHO recommends countries use a 30-day definition. When using a 30-day definition, all deaths resulting from a road traffic crash that occur within 30 days of the crash should be included in official statistics of road traffic injury mortality. WHO's 2013 *Global Status Report on Road Safety* highlights progress toward countries adopting this standard.

Figure 10: Underreporting of deaths from road injuries in official government statistics, 2010



Notes:

- *Percent underreporting is calculated as 100 x (Our estimate - official statistics)/(official statistics).*
- *Official statistics are the 30-day adjusted country reported statistics from the 2013 World Health Organization's* Global Status Report on Road Safety.

Our report, however, shows that the lack of standardized definitions has a comparatively small effect when compared to the overall magnitude of underreporting of road traffic deaths. In the worst case, when police count only deaths that occur within one day of a crash, they are expected to miss approximately one-fourth of the true death toll. In contrast, our estimates of national road injury deaths are often more than six times the national official statistics, and that is after the official statistics have been corrected to the 30-day reporting standard (Figure 10). Further, these results show that underreporting of deaths from road injuries in official statistics is highest in the poorest regions. In most of these countries, official statistics are derived from crashes reported to traffic police, who likely do not know about most deaths from road injuries.

However, underreporting is a major problem that extends beyond the poorest regions of the world. Compare the official statistics for road traffic deaths in China and India, the two most populous countries, with our estimates (Table 2). While the official statistics for China are furnished by the national traffic police, China also operates a nationally representative sample registration system (the Disease Surveillance Points [DSP] System) that uses verbal autopsy to monitor causes of death and a national death registration system. Our estimates of road traffic deaths rely heavily on the DSP system and are four times greater than the official statistics. The DSP system is used extensively by health researchers and national planners. Our estimates suggest that China ranks 120th globally in road safety. However, if their official statistics based on police-reported road deaths were correct, it would be the 15th-safest country in the world.

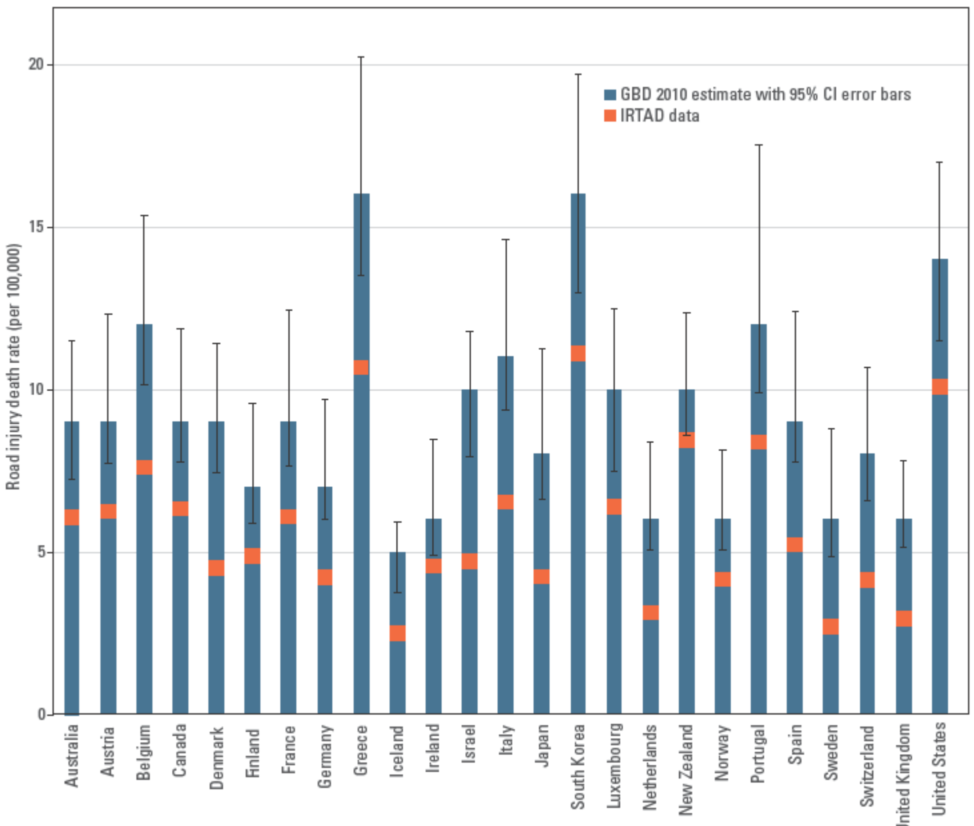
Table 2: Underreporting in official statistics of road traffic deaths in China and India, 2010

China	India
Official national statistics: Data source: traffic police records Reported road death toll: 65,225	**Official national statistics:** Data source: traffic police records Reported road death toll: 130,037
Other national data sources: Disease Surveillance Points System Vital registration statistics	**Other national data sources:** National Sample Registration System
GBD 2010 estimate: 283,000	**GBD 2010 estimate:** 274,000
Underreporting: 334%	**Underreporting:** 111%

Similarly, official government statistics in India are sourced from national traffic police. However, the Registrar General of India operates a Sample Registration System (SRS), which monitors cause-specific mortality using verbal autopsy in a nationally representative sample. Our estimates of road deaths, which are influenced strongly by the SRS, are more than twice the official statistics. The DSP system in China and the SRS in India are widely accepted by health researchers as the best sources of unbiased population health metrics in these countries because the systems are designed to be representative of the population and to allow explicit corrections for completeness of reporting. However, governments in both China and India continue to rely on police-based data instead of using the DSP and SRS systems as their official source for national road traffic injury statistics.

Figure 11 compares GBD 2010 estimates of road injury deaths with official statistics from high-income countries that report to the International Road Traffic Accident Database (IRTAD), which is the database of the Joint Transport Research Center of

Figure 11: National road injury death rates estimated by the GBD 2010 study compared with official national statistics from high-income countries that report to the International Road Traffic and Accident Database, 2010



the Organisation for Economic Co-operation and Development (OECD). On average, GBD estimates are 58% higher than official statistics in these countries. This is explained by differences in definitions and data sources. IRTAD typically relies on police reporting, while GBD relies primarily on death registration data in these countries. Furthermore, IRTAD only includes those deaths that occur within the first 30 days of a crash and excludes motor vehicle-related deaths that do not occur in traffic. In contrast, our estimates provide a more comprehensive estimate of the impact of motor vehicles on population health.

Table 3 ranks countries based on their road safety performance in 2010. With the exception of El Salvador, all 10 of the worst-performing countries are in sub-Saharan Africa and North Africa and the Middle East. Nigeria has the world's highest road injury death rate of about 50 per 100,000. In contrast, road injury death rates in the best-performing region, Western Europe, are more than five times lower (Figure 7). In fact, the best-performing countries in Western Europe (Sweden and Iceland) have death rates that are less than one-tenth of that of Nigeria.

In the least-safe countries of the world, road safety routinely ranks among the top five causes of death, especially for countries in North Africa and the Middle East. In Oman, it is the second-leading cause of death, with only 11% fewer deaths than the leading cause of death, ischemic heart disease. In Iran and Saudi Arabia, it is the third-leading cause of death behind ischemic heart disease and stroke.

Table 3: Countries with the highest death rates due to road injuries among those with at least three epidemiological measurements of road injury mortality, 2010

Rank	Country	Death rate	Deaths	Cause of death rank
1	Nigeria	52.4	74,548	5
2	Oman	47.3	1,090	2
3	Mozambique	46.7	7,154	7
4	Saudi Arabia	42.8	9,128	3
5	Iran	41.0	27,486	3
6	Ethiopia	37.3	21,520	9
7	Sudan	33.3	10,278	6
8	Zimbabwe	33.2	3,527	10
9	Zambia	30.8	2,798	12
10	El Salvador	29.0	1,589	7

Notes:

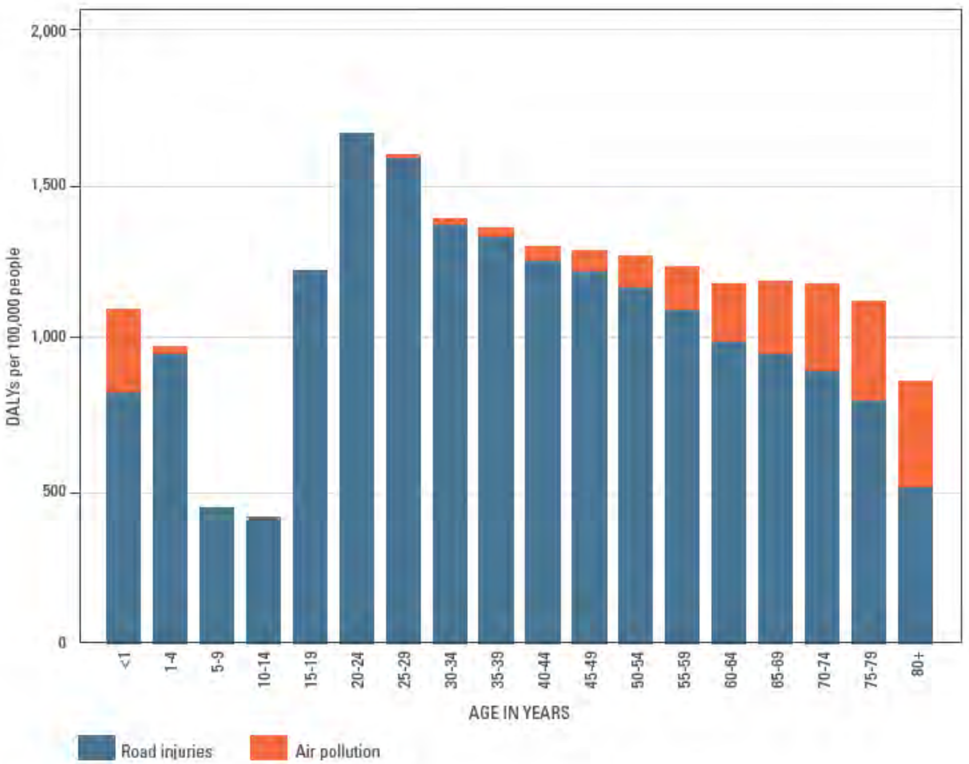
- *Death rates are age-standardized and per 100,000 population.*
- *In these rankings of national road safety performance, we have only considered the 125 countries for which GBD 2010 had access to at least three epidemiological measurements of road injury mortality.*
- *Our estimates for each country are shown in Annex 2.*

HEALTH LOSS DUE TO MOTORIZED ROAD TRANSPORT IMPACTS THE ENTIRE LIFE COURSE

Injuries and air pollution from motorized road transport cause substantial disease burden in both sexes and all ages, except for a brief period between the ages of 5 and 14 years (Figure 12) when exposure to road traffic is comparatively lower. Among children aged less than 1 year, the rate of healthy years lost to injuries is relatively low, but the rate due to pollution from vehicles is high. Disease burden due to road injuries is borne disproportionately by young adults, and burden from road injuries declines with age. However, this decline in injuries is offset by an increasing rate of healthy years lost to pollution from vehicles. The health loss among the older population may be due to injuries that happened at a younger age as well as exposure to air pollution over many years. As a result, the prevalence of health loss due to motorized road transport is relatively similar for most age groups.

Table 4 illustrates the transition in the burden from road injuries to diseases linked to ambient air pollution, such as ischemic heart disease, stroke, and COPD, over the life course. Road injuries begin to become prominent after the first year of life for

Figure 12: Rate of healthy years lost to injuries and air pollution from motorized road transport, 2010



both boys and girls. Among males, road injuries are the leading cause of death from age 5 to 29. Although road injuries rank lower for females, they nevertheless are among the top 10 causes of death from age 1 to 44. Among older ages, road injuries decline in rank, but the leading causes of death are replaced by non-communicable diseases, especially ischemic heart disease, stroke, and COPD, that have strong ties to air pollution, to which vehicles are an important contributor.

Road injuries among young adult males are a key hindrance to the overall health of men. Results from GBD 2010 show that remarkable advances have been made in the last four decades in reducing overall mortality rates (Figure 13). Both men and women have been the beneficiaries. However, the advances have been slowest among young adults, especially among males aged 15 to 39. These are the same age groups in which injuries, especially road injuries, are the cause of a considerable proportion of overall deaths.

Figure 13: Global decline in age-specific death rate among males and females, 1980 to 2010

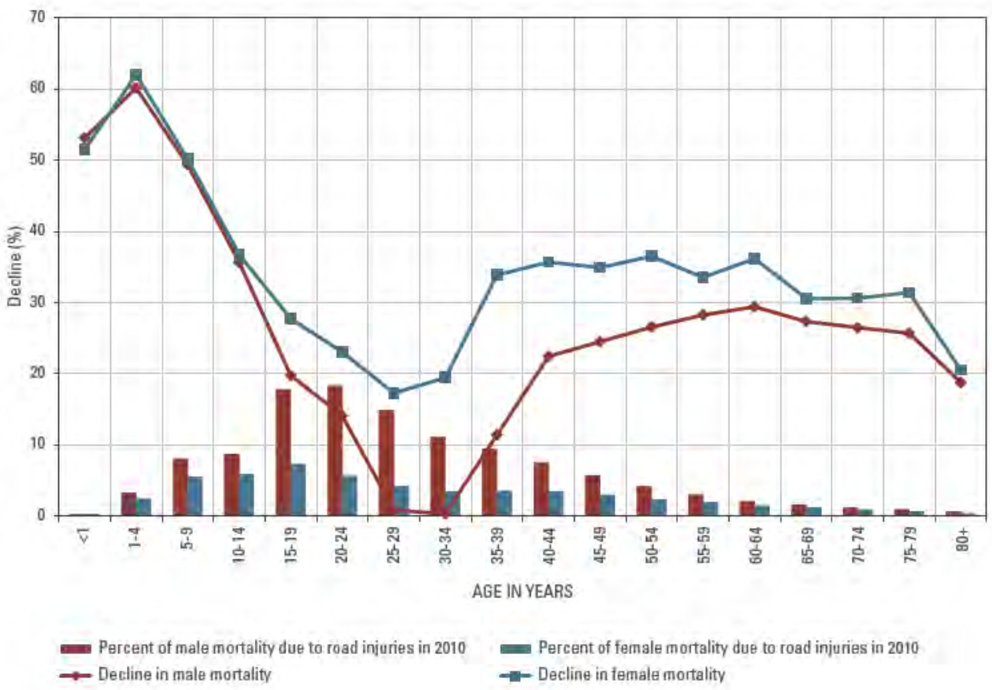


Table 4: Leading causes of death globally by age groups for males and females, 2010

Males

Rank	Under 1 Cause	1-4 years Cause	5-14 years Cause	15-29 years Cause	30-44 years Cause	45-59 years Cause	60-74 years Cause	75+ years Cause
1	Preterm birth complications	Malaria	**ROAD INJURY**	**ROAD INJURY**	HIV/AIDS	Ischemic heart disease	Ischemic heart disease	Ischemic heart disease
2	Lower respiratory infections	Lower respiratory infections	HIV/AIDS	Interpersonal violence	**ROAD INJURY**	Stroke	Stroke	Stroke
3	Neonatal encephalopathy	Diarrheal diseases	Diarrheal diseases	Self-harm	Ischemic heart disease	Cirrhosis	COPD	COPD
4	Neonatal sepsis	Protein-energy malnutrition	Lower respiratory infections	HIV/AIDS	Tuberculosis	Lung cancer	Lung cancer	Lower respiratory infections
5	Diarrheal diseases	HIV/AIDS	Malaria	Tuberculosis	Self-harm	Tuberculosis	Lower respiratory infections	Lung cancer
6	Congenital anomalies	Drowning	Drowning	Drowning	Interpersonal violence	**ROAD INJURY**	Diabetes	Diabetes
7	Malaria	Meningitis	Typhoid fevers	Malaria	Cirrhosis	HIV/AIDS	Tuberculosis	Hypertensive heart disease
8	Meningitis	**ROAD INJURY**	Meningitis	Lower respiratory infections	Stroke	Liver cancer	Cirrhosis	Prostate cancer
9	Protein-energy malnutrition	Measles	Congenital anomalies	Mechanical forces	Lower respiratory infections	COPD	Stomach cancer	Other cardio & circulatory
10	Syphilis	Fire	Forces of nature	Diarrheal diseases	Liver cancer	Self-harm	Liver cancer	Chronic kidney disease

Females

Rank	Under 1 Cause	1-4 years Cause	5-14 years Cause	15-29 years Cause	30-44 years Cause	45-59 years Cause	60-74 years Cause	75+ years Cause
1	Preterm birth complications	Malaria	Diarrheal diseases	HIV/AIDS	HIV/AIDS	Ischemic heart disease	Ischemic heart disease	Ischemic heart disease
2	Lower respiratory infections	Diarrheal diseases	HIV/AIDS	Maternal disorders	Maternal disorders	Stroke	Stroke	Stroke
3	Neonatal encephalopathy	Lower respiratory infections	Malaria	Self-harm	Tuberculosis	Breast cancer	COPD	COPD
4	Neonatal sepsis	Protein-energy malnutrition	Lower respiratory infections	**ROAD INJURY**	Ischemic heart disease	Diabetes	Diabetes	Lower respiratory infections
5	Diarrheal diseases	HIV/AIDS	**ROAD INJURY**	Tuberculosis	Self-harm	HIV/AIDS	Lower respiratory infections	Diabetes
6	Congenital anomalies	Meningitis	Meningitis	Malaria	Stroke	COPD	Lung cancer	Hypertensive heart disease
7	Malaria	Measles	Drowning	Fire	**ROAD INJURY**	Lung cancer	Breast cancer	Alzheimer's disease
8	Protein-energy malnutrition	Congenital anomalies	Typhoid fevers	Diarrheal diseases	Lower respiratory infections	Cirrhosis	Hypertensive heart disease	Other cardio & circulatory
9	Meningitis	Drowning	Congenital anomalies	Lower respiratory infections	Breast cancer	Tuberculosis	Diarrheal diseases	Lung cancer
10	Syphilis	**ROAD INJURY**	Fire	Interpersonal violence	Diarrheal diseases	Cervical cancer	Cirrhosis	Chronic kidney disease

ROAD INJURIES ARE AN IMPORTANT THREAT TO MATERNAL AND CHILD HEALTH

Remarkably, road injuries rank among the top 10 causes of death for children after the first year of life, ranking eighth among boys 1 to 4 years old and 10th among girls 1 to 4 years old, globally (Table 4). Road injuries are the leading cause of death among 1- to 4-year-olds in the high-income countries of North America and the second-leading cause of death in Western Europe, Australasia, and the high-income countries of Asia Pacific. In fact, road injuries are a top-five cause of death for 1- to 4-year-olds in 11 of 21 global regions.

MDG 5 focuses on reducing maternal mortality by giving special priority to pregnancy and childbirth. Although the cause of death ranking of road injuries is lower among women than men, road injuries were among the top 10 causes of death for women in every age group between 5 and 44 in 2010 (Table 4). Road injuries were the fourth- and seventh-leading cause of death for women in the age groups 15 to 29 and 30 to 44, respectively. In the maternal age range of 15 to 49, we have estimated 3.5 million deaths from all causes in 2010. While maternal conditions accounted for 7.3% of these deaths, road injuries accounted for 4.0%.

Road injuries rank prominently as a threat to the health of young women in most regions. For instance, among women 15 to 19 years old, road injuries are the leading cause of death in nine regions, are among the top three causes in 17 regions, and are among the top 10 causes in all global regions with the exception of Oceania. In Western sub-Saharan Africa, road injuries were the third-leading cause of death; they ranked among the top 10 causes in other regions of sub-Saharan Africa.

REGIONAL VARIATION IN DEATH RATES AMONG DIFFERENT TYPES OF ROAD USERS

Figure 14 illustrates that at the global level, occupants of motor vehicles with three or more wheels are at the highest risk, accounting for 36% of all fatalities. Pedestrians account for 35% of global road deaths, and riders of motorized two-wheelers make up another 16%. However, there is dramatic variation in death patterns among road users across regions. In general, car occupants make up higher proportions of total road injury deaths in high-income regions, while pedestrians account for higher proportions in poorer regions. In two of the four sub-Saharan African regions (Eastern and Central sub-Saharan Africa), pedestrian deaths make up over half of all fatalities. In contrast, in North America, vehicle occupants account for almost three-fourths (73%) of all fatalities. However, this general pattern has several exceptions. There are many middle-income regions where car occupants make up a high proportion of total road traffic deaths. Overall, in nine of 21 global regions, more than half of all road deaths are vehicle occupants; six of those regions are low- and middle-income regions, including North Africa and the Middle East, Central Asia, Southern Latin America, and the Caribbean. These results suggest that vastly different road safety strategies will be needed to maximize lives saved in different settings across the globe.

Figure 14: Deaths in road crashes by type of road user and region, 2010

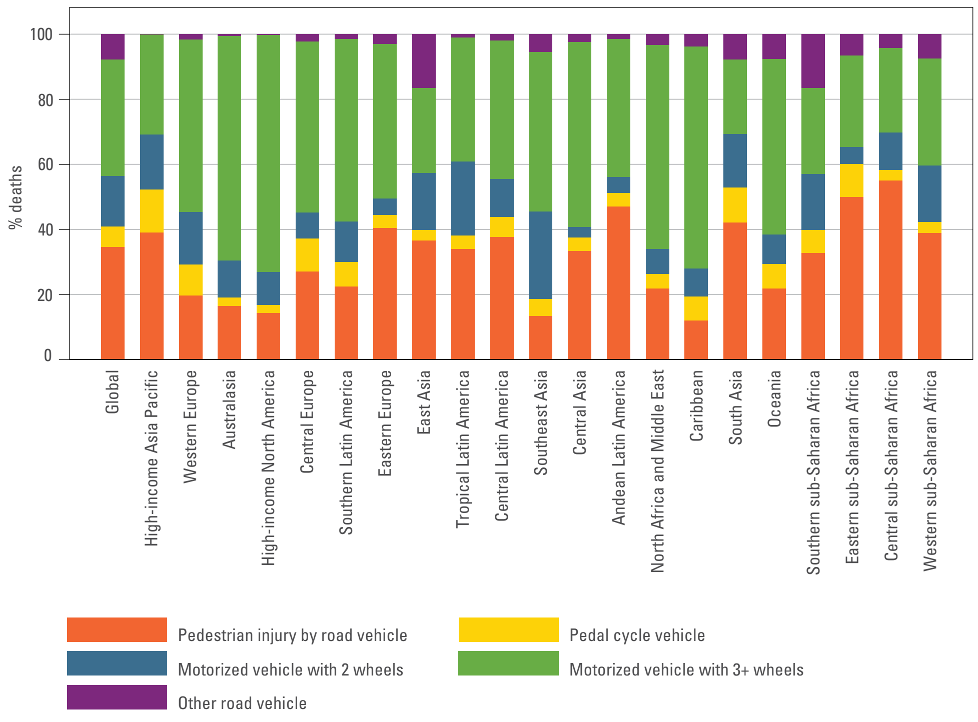
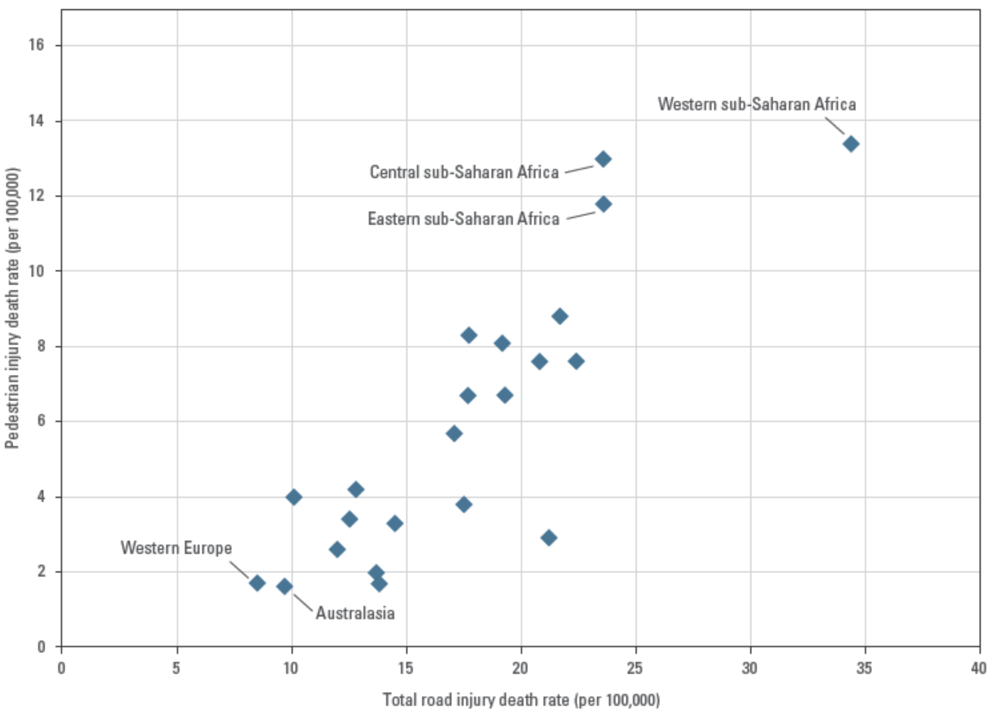


Figure 15 illustrates that regional pedestrian death rates are strongly associated with overall road injury death rates and differ greatly across regions. Rates of death due to pedestrian injury vary by almost an order of magnitude. They are highest in the three sub-Saharan Africa regions and lowest in Western Europe and Australasia. Total road injury death rates in these regions mirror trends in death rates from pedestrian injury.

In addition to being a key part of reducing road injuries, ensuring the safety of pedestrians is essential for reducing emissions from vehicles and increasing physical activity. Promoting active transport by protecting vulnerable road users can reduce the burden of non-communicable diseases, including ischemic heart disease, stroke, lower respiratory infections, COPD, and lung cancer. Research shows that the provision of safety infrastructure for walking and biking is among the most important ways to encourage these active modes of transport.[11] Such infrastructure includes traffic calming measures to reduce vehicle speeds, such as the use of speed bumps, curb extensions, chicanes, and roundabouts, and the provision of separated sidewalks and bicycle lanes to reduce exposure to motor vehicles.[18]

Figure 15: Correlation between regional pedestrian injury death rates and total road injury death rates



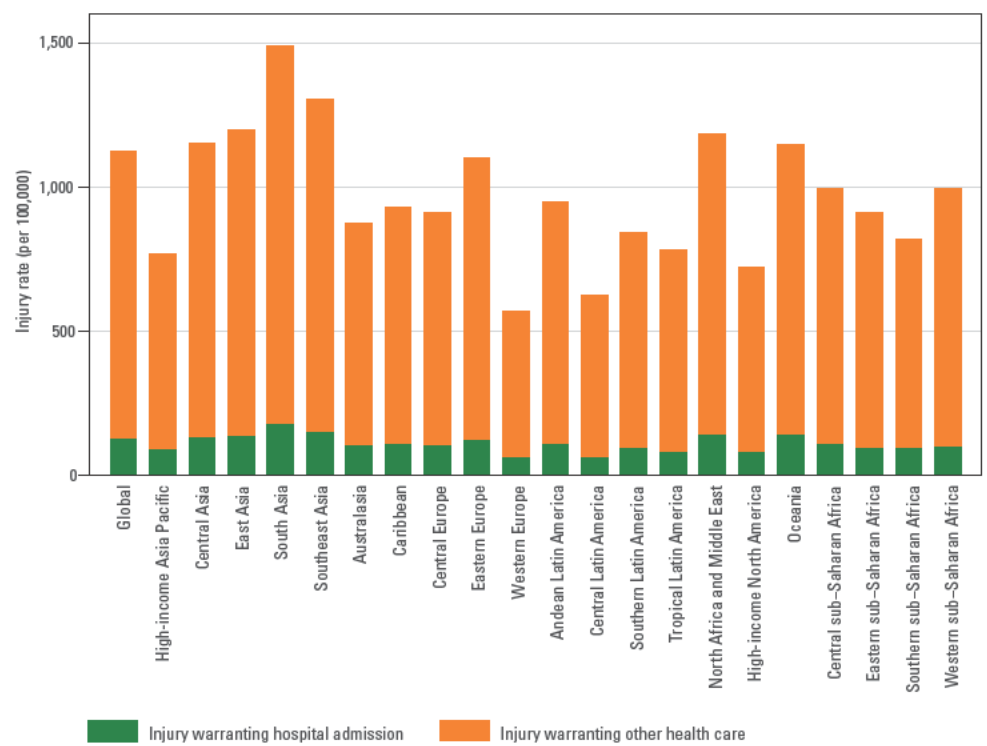
CASES OF DISABLING ROAD INJURIES

Cases of nonfatal road injury are difficult to quantify for several reasons, ranging from the difficulty of measuring injury severity to limited availability of studies from around the world to construct global estimates. GBD 2010 is the first study ever to quantify global cases of nonfatal road injuries. To measure injury severity, we defined two types of injuries: injuries warranting hospital admission (i.e., injuries that would have required at least an overnight hospital stay if adequate access to medical care had been available to the victims), and injuries warranting other health care (i.e., injuries that did not require hospital admission but would have received care by a health care professional had such care been available). Our analysis shows that in 2010, there were 78.2 million road injuries warranting medical care globally. This included 9.2 million road injuries that warranted hospital admission and 69 million road injuries that warranted other medical care.

Figure 16 illustrates that the rate of nonfatal road injuries varies substantially across regions and the pattern differs from that seen in death rates. The highest rate of nonfatal injury cases is in South Asia, where almost 1.5% of the population is injured severely enough to warrant medical care. On the other hand, in Western Europe, nonfatal injury rates are less than half (0.6%) the rate in South Asia.

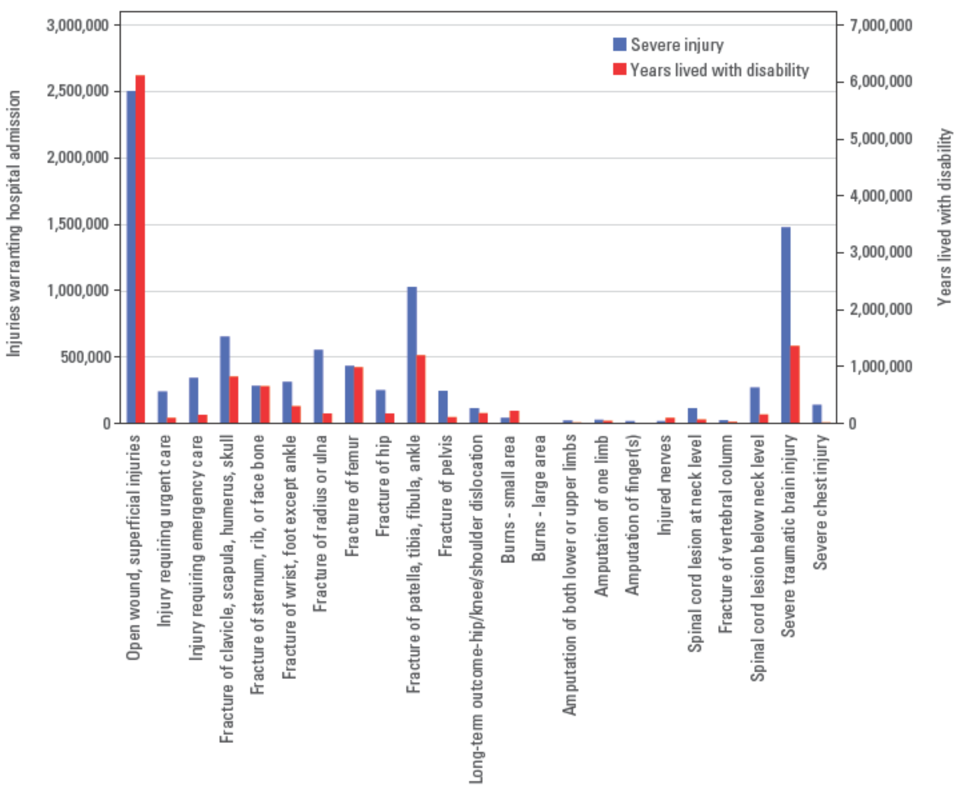
Even though road injuries requiring hospital admission constitute only 11.7% of road injuries that do not result in death, they are responsible for 97% of total years lived with disability from road injury. Figure 17 illustrates the distribution of sequelae associated with injuries requiring hospital admission. Taken together, fractures of various types account for the majority of cases, amounting to 3.8 million nonfatal road injuries. These contribute one-third of the total health loss associated with nonfatal road injuries. Over one-fourth (27%) of the burden of fractures is due to fractures of the patella, tibia, fibula, and ankle. Open wounds and superficial injuries account for over 2.5 million cases and contribute 47% of the health loss. Severe traumatic brain injuries account for over 1.5 million cases and contribute 10% of the health loss of nonfatal road injuries.

Figure 16: Rate of nonfatal road injuries warranting health care, 2010



We estimated years lived with disability due to road injuries by using a large number of household surveys and hospital records from around the world. However, the science of estimating the incidence of injuries and estimating the resulting disabilities is still in its infancy.[19] Improving the epidemiological foundation of such estimates will require sustained research efforts to improve definitions and standardize data-collection methods and new studies to measure the long-term disability outcomes of injuries.

Figure 17: Cases and burden of nonfatal road injuries warranting hospital admission, 2010



CONCLUSION AND POLICY RECOMMENDATIONS

This report presents comprehensive global estimates of the health effects of road injuries. It marks the first attempt to estimate the disease burden attributable to pollution as well as injuries from motorized road transport. Previous estimates of the global burden of road injuries have relied on relatively little local data from most countries. In this report, estimates of road injuries are constructed by analyzing a large number of measurements from even the regions that are considered information-poor. Notably, we incorporate many sources of epidemiological data from sub-Saharan Africa, including data from urban mortuaries, rural health and demographic surveillance sites, and cause-specific mortality measured in national household censuses. Most of these data sources have never been used before to generate national estimates of road injuries.

This report also presents the first global estimates of nonfatal road injuries. We constructed these estimates by combining information derived from more than 100 household surveys, hospital records from 28 countries, and estimates of long-term disability from four follow-up studies. We used a much greater number of data sources than ever before and combined them using a strategy designed to harness the strengths of available information. Despite these advances, there is an urgent need for continued work in this area to improve analytical models for combining available epidemiological data and to improve measurement, especially in quantifying the long-term outcomes from injuries.

Similarly, the Global Burden of Disease due to pollution from vehicles has never been estimated before. It should be noted that our estimates of the health burden due to overall air pollution are much higher than previous estimates. For instance, in our previous comparative risk assessment[20], we estimated that overall air pollution accounted for 0.4% of the Global Burden of Disease, while our current estimates (3.1%) are almost an order of magnitude higher. This is partly because we are able to characterize the population exposure to air pollution more precisely due to the inclusion of populations in rural areas and advances in satellite-based remote sensing and global chemical transport models. In addition, we now have access to a much larger pool of epidemiological studies about diseases caused by air pollution, allowing us to include more health outcomes than before.

Despite the increasing availability of data on exposure to air pollution and robust evidence linking air pollution to diseases, we believe our analysis underestimates the burden of air pollution from transport. This stems primarily from limitations inherent in existing data. For example, the data available on air pollution exposure worldwide underestimate emissions from vehicles in urban areas. Because a large and growing population resides in urban areas, this prevents us from fully assessing many people's exposure to this risk factor. In addition, data limitations prevented us from estimating the number of people around the world who live near busy roads and are therefore exposed to higher levels of air pollution. Residing near heavily trafficked roads is associated with poor health outcomes including asthma in children.

There are three additional reasons why we believe our estimates of the burden of disease from vehicle pollution are too low. First, it is unlikely that the data we use to estimate air pollution exposure globally capture emissions from all types of vehicles. Second, our estimates of the burden of disease from vehicle pollution do not include ozone, which is a pollutant formed in the atmosphere that comes from transport and other sources. Ozone pollution is linked to death and disability from chronic lung diseases such as COPD. Finally, because the relationship between air pollution and mortality is nonlinear, other approaches to the statistical analysis used to estimate the burden of disease from vehicle pollution may produce somewhat larger estimates. More detailed information about these limitations can be found in Annex 1 and the Web appendix.

Currently, these limitations constrain our ability to quantify premature death and disability from vehicle pollution on a global scale. Improved data and disease burden estimates are possible, however, and will be required to guide governments as they design and implement transportation policies designed to reduce the public health burden of road transport. Development of better data warrants financial support from all concerned with this complex and growing problem.

RECOMMENDATIONS

1) Rapidly scale up road safety programs and crash reporting capacity to save lives and promote economic development

Road injuries are a major contributor to the Global Burden of Disease and are vastly underreported. Governments in many low- and middle-income countries report a substantially lower road injury death toll than our estimates. In the poorest countries of sub-Saharan Africa, which have the highest road injury death rates, official government statistics often report less than one-fifth of road injury deaths. Even in the rapidly developing economies of Asia, such as China and India, official statistics often account for less than half of all road injury deaths. At the global level, the sum of countries' official death counts (641,000 deaths) published by the WHO in their 2013 *Global Status Report on Road Safety* is less than half of our global estimate (1.3 million). Unless accounting of road injuries in official statistics reported to WHO is improved, it is likely that road safety will continue to be neglected in national health and development priorities.

A substantial international effort should address how road injury data are collected and the health burden is estimated. Some low- and middle-income countries already have a relatively strong information infrastructure, such as high-quality national vital registration systems, and underreporting is relatively low. In these countries, strengthening existing systems for recording and reporting road injury statistics will enhance the quality of disease burden estimates. Such efforts should include standardization of definitions and methodologies, such as the use of the OECD/IRTAD

protocol as the reporting standard in the World Bank-financed Ibero-American Road Safety Observatory in Latin America, utilizing twinning partnerships between high- and low-income countries' agencies to help develop statistical capacity.

On the other hand, in countries with the highest underreporting, the existing national health surveillance infrastructure is too weak to reliably track road injury mortality. Although developing such should be an ongoing priority, it is a slow process that will take many years. Immediate attention therefore should be given to using all existing data sources to construct statistical estimates of the national burden of road injuries for guiding safety programs. GBD 2010 takes such an approach with an emphasis on developing global and regional models. Such work needs to be extended further at the national level to better utilize the known strengths and biases of local data sources. In addition to generating immediate evidence to guide policy, this approach also helps identify potential country data systems, such as mortuary surveillance, national household surveys, and hospital registries, that can be strengthened and expanded to build reliable information infrastructure.

As acknowledged earlier in the report, the expansion of the road and transit network has long been viewed as a key strategy for driving economic growth and improving the health and well-being of people. However, unmanaged growth without the requisite capacity and oversight from country agency and regulatory bodies can result, in the case of developing countries, in decades of motorized road transit systems that inflict large amounts of harm on their populations, without government capacity to target interventions correctly. While it took high-income countries decades to reduce their road injury death toll, low- and middle-income countries can greatly reduce this timeframe by rapidly investing in a long-term strategy to actively manage safety and mobility performance, the topic of the next section.

2) Promote strong institutional development for multisectoral collaboration in the emerging sustainable development era of safe and clean mobility

Global health is undergoing a rapid transition away from mostly infectious diseases that affect children to non-communicable diseases and injuries that affect adults. This requires adjustment on multiple fronts on the part of different actors ranging from country governments to the private sector to the NGO community. Development agencies will need to create new comprehensive policy frameworks to implement cross-sectoral change in a logical and sequenced manner in client countries and in their own internal global practice areas. This reflects the complexity of an ever-changing, multidimensional environment that demands a clear accounting of emerging health threats to the planet.

For example, the 2004 *World Report on Road Traffic Injury Prevention*, authored jointly by the WHO and the World Bank, focused on creating empowered lead agencies with statutory responsibility to reduce road injuries. This went hand-in-hand with recommendations to ensure adequate resources for these agencies to manage road safety in a multidisciplinary manner across relevant sectors of government.

Unfortunately, attempts by many actors in the internal community to address road safety in low- and middle-income countries still tend to take an “intervention-first” approach, focusing on individual risk factors such as wearing helmets, using seat-belts, preventing drunk driving, and social marketing campaigns.

While these interventions are needed, sustainability of road safety programs requires a government commitment to systematically invest in building transportation systems that promote safe mobility in a holistic manner. Establishing a lead road safety agency, building reliable data systems, and other system-wide investments that encompass vehicle quality, enforcement, safe infrastructure, and road users in the pre-crash, in-crash, and post-crash stages are key. [21]

Therefore, the overarching new science of delivering effective transfer of road safety knowledge means taking weak existing management capacity within a complex system and creating the ability to shift rapidly to a safe system approach focused on getting results.[21] An example is the case of Argentina, which has made road safety a national priority through investment in its National Road Safety Agency, which itself is the recipient of a standalone project loan for road safety from the World Bank, one of the first of its kind. Cooperation across different ministries, in the transport and health sectors in particular, is central to the lending package, which will undertake systematic, measurable, and accountable investment through targeted programs. Such an example can help provide lessons for other low- and middle-income countries striving to replicate an “agency-first” model as advocated in the *World Report* and the 2013 World Bank *Safe System Projects Guidelines*.

Lowering motor vehicle pollution is also important to reducing non-communicable diseases. Further, encouraging walking, biking, and active lifestyles has emerged as a key strategy because of their cardiovascular health benefits. However, as our report indicates, active modes of transport make people highly vulnerable to road injuries. Thus, partnerships between the transport, health, and urban planning sectors are necessary for developing solutions for healthy mobility. Increasingly, one of the key drivers of 21st-century competitiveness will be how countries – particularly urban centers – design their land use patterns to improve the health of their populations. This represents a fundamental switch toward linking transit to health outcomes. This change is currently being discussed in the context of a post-2015 Sustainable Development Goal world, and is particularly important to protect vulnerable generations in low- and middle-income countries.

3) Commit the resources needed to realize the health and economic gains from a safe and clean transport system

Developing transport solutions that deliver health will require financial commitments to support a wide range of strategies. Although the health impacts of road transport compete for attention with other pressing global health concerns, these occur in a development context that is different from that of many diseases and illnesses. As GBD 2010 illustrates, malnutrition, diarrhea, and many infectious diseases occur in settings of extreme poverty where financial resources are severely limited. However, the disease burden associated with road transport is an outcome of economic growth and rapid motorization. An appropriate proportion of this economic gain needs to be assigned to managing the negative impacts of the transport sector.

Addressing the enormous and growing health losses from road transport will require large investments in building and managing transport systems that are safe, clean, and affordable. Although this report does not aim to estimate monetary losses, calculations based on the 2001 WHO Report of the Commission on Macro Economics and Health have shown that such losses are substantial – equivalent to 1% to 3% of gross domestic product per annum and calculated in 2014 for road crashes as high as 4.6% for India and 10.1% for Uganda – potentially exceeding the amount of international development assistance flowing into these countries.[21] In comparison, current investments in road safety remain miniscule.[8] Clearly, there is a strong financial case for increasing investments in safe and clean road transport.

Five decades of experience from high-income regions suggests that growth in transport systems can be managed to reduce injuries and air pollution with appropriate investments. In most high-income countries, road safety has steadily improved since the early 1970s despite increasing vehicle ownership rates and continued expansion of highway infrastructure. As noted elsewhere, the policy history of these countries suggests that they established national road safety agencies with legislative powers and a mandate to manage safety in the transport system. These agencies instituted a long series of interventions that targeted highway infrastructure (e.g., by requiring median barriers, guard rails, traffic calming designs), vehicle safety (e.g., by requiring airbags, seatbelts, child seats, crashworthiness standards, crash avoidance technologies), and road users (e.g., through stronger enforcement of and social marketing campaigns for seat-belt use, helmet use, and prevention of drunk driving). Developing countries can utilize new tools and World Bank *Guidelines* to prioritize short-, medium-, and long-term road safety investment and sequence it in a way that makes sense for sustaining gains.[21]

Similarly, as awareness of the health effects of air pollution grew, high-income countries developed comprehensive policies to reduce motor vehicle emissions. This included a range of regulatory strategies, including emissions control technologies, fuel-composition modifications mandated to meet various air quality objectives, and vehicle inspection programs. For developing countries, reduction technologies such as three-way catalysts and particle traps, the elimination of leaded fuel, and agreement on a globally sustainable level of fuel sulfur content will become critical in the coming years.

4) Systematically account for the health impact of road projects

Successfully addressing concerns that are posed by rapid growth in the road sector in low- and middle-income countries requires improved accounting of health impacts. At present, more effort is invested in estimating the economic rate of return of road projects than in estimating either the social benefits (access to health care, education, markets) or social harms (burden of disease, environmental costs) of transport. For example, to obtain a loan to finance road projects from infrastructure lending agencies, such as multilateral development banks, governments must prove the viability of these loans through careful accounting of the economic returns on investment. To accomplish this, transport planners work in conjunction with transport economists to develop models that can project demand for transport, estimate savings in travel time, monetize savings, identify revenue streams, and estimate rates of return for loans. These analyses are successfully done in complex transportation markets that are shaped by individual behavioral decisions about interrelated choices of residential location, transport modes, trip destinations, and vehicle characteristics, among others.

To fully realize the societal benefit of transport infrastructure, it is important that comparable efforts are made to quantify the full costs and benefits of road projects. We need analytical models of crash causation that can be used to estimate the injuries and deaths that will be caused or avoided by proposed road projects. Importantly, such analysis will require empirical measurement of the risks associated with different types of road infrastructure. Our existing knowledge of causal relationships between road injuries and environmental factors is remarkably weak, especially in low- and middle-income countries where most new road building is currently occurring.

Similarly, analytical models are needed to characterize health impacts of changes in vehicular emissions that accompany road projects. Such analysis requires building spatially refined emission inventories that rely on local driving patterns, fuel types, and vehicle types. In addition, these models need to account for noncombustion sources of particulate matter, such as resuspended road dust, tire wear, and brake wear. These models will need to be validated against actual measurements through field valuation and verification of particulate matter emissions.

Finally, analytical work is needed to characterize the impact of individual transport projects and the broader transport sector on human physical activity and greenhouse gas emissions. In 2010, physical inactivity was the 11th-largest risk factor for years of healthy life lost, accounting for 2.8% of the total disease burden. We were unable to quantify the contribution of motorized transport to physical inactivity due to lack of information. Similarly, vehicular emissions are an important contributor to anthropogenic climate change. However, although the impact of climate change on human health is likely to be large, it acts through complex causal pathways. Our ability to model the diverse effects from greenhouse gases across populations is stymied by the lack of systematic studies in this area.

Improving human health and well-being is ultimately a key goal of all development projects. Health impacts should not be viewed as a potential externality but rather be part of the holistic development objective of transport projects, which aim to support, among other things, healthy, productive lives. This is what we mean with the title of this report, *Transport for Health*.

ANNEX 1: GBD 2010 METHODS

WHAT IS THE GLOBAL BURDEN OF DISEASE 2010 (GBD 2010) STUDY?

In 1991, the World Bank commissioned the first Global Burden of Disease study to develop a comprehensive and comparable assessment of the burden of 107 diseases and injuries and 10 selected risk factors for the world and eight major regions. The findings represented a major improvement in global knowledge of population health metrics and proved to be influential in shaping the global health priorities of international health and development agencies. The study also stimulated numerous national burden of disease analyses that have informed debates on health policy over the last two decades.

GBD 2010, the most recent iteration of the study, is a comprehensive update of the original study and presents estimates for 291 diseases and injuries, 67 risk factors, and 1,160 sequelae (nonfatal health consequences) disaggregated by sex and 20 age groups for 21 regions (Table A1) covering the entire globe. The study is a collaboration of hundreds of researchers around the world, led by the Institute for Health Metrics and Evaluation at the University of Washington and a consortium of several other institutions, including Harvard University, Imperial College London, Johns Hopkins University, University of Queensland, University of Tokyo, and the World Health Organization.

Diseases and injuries result in either premature death or life lived with ill health. GBD aims to quantify the gap between the ideal of a population that lives a full life in full health and reality. GBD uses the following concepts to measure this health burden:

- Years of life lost (YLLs) are the number of years of life lost due to premature death. They are calculated by multiplying the number of deaths at each age by a standard life expectancy at that age.
- Years of life lived with disability (YLDs) are the number of years of life lived with short-term or long-term health loss weighted by the severity of the disabling sequelae of diseases and injuries.
- Disability-adjusted life years (DALYs) are the main summary measure of population health used in GBD to quantify health loss. DALYs provide a metric that allows comparison of health loss across different diseases and injuries. They are calculated as the sum of YLLs and YLDs; thus they are a measure of the number of years of healthy life that are lost due to death and nonfatal illness or impairment.

HOW DID WE CONSTRUCT ESTIMATES OF THE BURDEN OF ROAD TRANSPORT?

This report brings together two streams of work undertaken within GBD 2010: first, a comprehensive effort to improve the evidence base of the estimates of the burden of road injuries using new data sources and improved methods; and second, advances in GBD 2010 in estimating the burden of disease that can be attributed to

Table A1: GBD 2010 countries by region

Andean Latin America	Bolivia, Ecuador, Peru
Australasia	Australia, New Zealand
Caribbean	Antigua and Barbuda, Bahamas, Barbados, Belize, Cuba, Dominica, Dominican Republic, Grenada, Guyana, Haiti, Jamaica, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago
Central Asia	Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Mongolia, Tajikistan, Turkmenistan, Uzbekistan
Central Europe	Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Hungary, Macedonia, Montenegro, Poland, Romania, Serbia, Slovakia, Slovenia
Central Latin America	Colombia, Costa Rica, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama, Venezuela
Central sub-Saharan Africa	Angola, Central African Republic, Congo, Democratic Republic of the Congo, Equatorial Guinea, Gabon
East Asia	China, North Korea, Taiwan
Eastern Europe	Belarus, Estonia, Latvia, Lithuania, Moldova, Russia, Ukraine
Eastern sub-Saharan Africa	Burundi, Comoros, Djibouti, Eritrea, Ethiopia, Kenya, Madagascar, Malawi, Mauritius, Mozambique, Rwanda, Seychelles, Somalia, Sudan, Tanzania, Uganda, Zambia
High-income Asia Pacific	Brunei, Japan, Singapore, South Korea
High-income North America	Canada, United States
North Africa and Middle East	Algeria, Bahrain, Egypt, Iran, Iraq, Jordan, Kuwait, Lebanon, Libya, Morocco, Palestine, Oman, Qatar, Saudi Arabia, Syria, Tunisia, Turkey, United Arab Emirates, Yemen
Oceania	Fiji, Kiribati, Marshall Islands, Micronesia, Papua New Guinea, Samoa, Solomon Islands, Tonga, Vanuatu
South Asia	Afghanistan, Bangladesh, Bhutan, India, Nepal, Pakistan
Southeast Asia	Cambodia, Indonesia, Laos, Malaysia, Maldives, Myanmar, Philippines, Sri Lanka, Thailand, Timor-Leste, Vietnam
Southern Latin America	Argentina, Chile, Uruguay
Southern sub-Saharan Africa	Botswana, Lesotho, Namibia, South Africa, Swaziland, Zimbabwe
Tropical Latin America	Brazil, Paraguay
Western Europe	Andorra, Austria, Belgium, Cyprus, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom
Western sub-Saharan Africa	Benin, Burkina Faso, Cameroon, Cape Verde, Chad, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, São Tomé and Príncipe, Senegal, Sierra Leone, Togo

long-term exposure to air pollution, which we have further partitioned to estimate the contribution from air pollution caused by motorized road transport.

Estimating the global burden of road injuries

The guiding principle of the burden of disease approach is that estimates of population health metrics (such as incidence and prevalence) should be generated after careful analysis of all available data sources and correction for bias. A substantial project-wide effort was made to incorporate data from vital registration and sample registration systems, demographic surveillance systems, and many others. This broad search was coupled with a targeted effort to improve data on road injuries from the most information-poor settings. As a result, a wealth of data from regions such as sub-Saharan Africa was used for the first time in epidemiological research. Key data sources for injuries included the following:

- Vital registration statistics: These are tabulations from national vital registration systems, which usually record causes of death listed on death certificates.
- Verbal autopsy: This is a method of determining cause of death in which a trained interviewer uses a structured questionnaire to collect information about symptoms that preceded an individual's death. Such surveillance is commonly done in regions that do not have reliable vital registration systems.
- Mortuary/burial registers: Medico-legal records from mortuaries and burial permit offices were another important source of data for information-poor regions.
- Household surveys: These were a critical source for estimating the incidence of nonfatal injuries.
- Hospital databases: Large hospital registries were used as a valuable source of information about the sequelae resulting from injuries.
- Prospective studies of disability outcomes: The results from follow-up studies of patients after an injury were used to estimate the duration of disability and the probability that an injury results in permanent disability.

Prior to analysis, these data sources were subjected to systematic harmonization and data cleaning. This includes adjusting for completeness of mortality data sources, mapping across different coding schemes, and reattribution of poorly specified causes.

We estimated mortality from road crashes in 40 age-sex groups for all countries from 1980 to 2010 using Cause of Death Ensemble Modeling (CODEm), which involves developing a large range of plausible statistical models between the cause and known covariates, testing all possible permutations of covariates, and generating ensembles of the component models. The performance of all component models and ensembles is evaluated based on their out-of-sample predictive validity and the best-performing model or ensemble is chosen.

We estimated the burden of nonfatal outcomes of injuries by first constructing estimates of the incidence of the external causes of injuries using household survey data, hospital data, and the injury mortality estimates. We used hospital databases to estimate the incidence of the health outcomes (e.g., fractures, dislocations) that result from road injuries. We estimated the long-term disability from these health outcomes using data collected from studies that have followed patients after they sustained a road injury. Finally, we computed YLDs by applying disability weights. These methods rely on many assumptions and will likely undergo substantial refinements in the years to come. However, they are the only known attempt at large-scale coupling of empirical data to construct global estimates of the burden of nonfatal road injuries.

More details about GBD 2010 data sources and methods can be obtained from the following four publications:

- Lozano RL, et al. Global and regional mortality from 235 causes of death for 20 age groups in 1990 and 2010: a systematic analysis for the Global Burden of Disease Study 2010. *The Lancet.* 2012 Dec 13;380:2095–2128.
- Vos T, et al. Years lived with disability (YLDs) for 1,160 sequelae of 289 diseases and injuries, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010. *The Lancet.* 2012 Dec 13;380:2163–2196.
- Murray CJL, et al. Disability-adjusted life years (DALYs) for 291 diseases and injuries in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010. *The Lancet.* 2012 Dec 13;380:2197–2223.
- Salomon J, et al. Common values in assessing health outcomes from disease and injury: disability weights measurement study for the Global Burden of Disease Study 2010. *The Lancet.* 2012 Dec 13;380:2129–2143.

Estimating the burden of air pollution from motorized road transport

A database of geo-referenced, annual averaged fine particulate matter ($PM_{2.5}$) measurements from surface monitors in 2005 was assembled from national, regional, and local air-quality monitoring reports and published literature. As surface monitor-based measurements of $PM_{2.5}$ do not cover all populations, these data were combined with two other estimates of $PM_{2.5}$: 1) estimates of $PM_{2.5}$ derived from satellite-based observations of aerosol optical depth, a proxy measure for $PM_{2.5}$, combined with information from a global atmospheric chemistry transport model (GEOS Chem); and 2) estimates of $PM_{2.5}$ from a separate global atmospheric chemistry transport model (TM5). Both of these estimates were linked to the geo-referenced surface monitor-based estimates of $PM_{2.5}$ in the database described above, and a regression model was used to relate the average of the satellite-based and chemical transport model estimates of $PM_{2.5}$ with the surface monitoring data. Together, these estimates of $PM_{2.5}$ allowed for the quantification of $PM_{2.5}$ levels at a grid resolution of 10 x 10 square kilometers across the globe for the year 2005. Information on trends in air pollution concentrations and emissions were used to estimate $PM_{2.5}$ levels for 1990 and 2010. Population estimates for each grid cell from the Gridded Population of the World were used to estimate population-weighted average exposure for each GBD region. For more information, see Brauer et al.[15]

To estimate the risk of mortality across the full global range of estimated ambient concentrations of $PM_{2.5}$, exposure-response functions were developed that integrated epidemiologic evidence for the hazardous effects of particulate matter at different concentrations from different sources and environments. Study-level estimates of the relative risk of mortality associated with any or all of ambient $PM_{2.5}$, secondhand smoke, household air pollution, and active smoking were compiled for the following outcomes: ischemic heart disease, stroke, lung cancer, chronic obstructive pulmonary disease, and acute lower respiratory tract infection in children. Several nonlinear functions with up to three parameters for fitting the integrated exposure-response relationship were evaluated and assessed with respect to goodness of fit. These integrated exposure-response curves were used to generate GBD 2010 estimates of the burden of disease attributable to exposure to ambient $PM_{2.5}$. For more details about methods and findings, see Burnett et al.[22]

To estimate the motor-vehicle contribution to $PM_{2.5}$, we used the global air quality source-receptor model, TM5-FASST, developed by the Joint Research Centre of the European Commission.[23] Briefly, this model links emissions of pollutants within a given source region with downwind impacts, using knowledge of meteorology and atmospheric chemistry. TM5-FASST reproduces, for country and regional averages, concentration levels of air pollutants simulated by the full TM5 Chemical Transport Model, which has been fully evaluated in a large number of international comparisons (e.g., the Task Force on Hemispheric Transport of Air Pollution[24]) and is described in more detail in Brauer et al. and references cited therein. The emissions information used to assess the contribution of various source sectors to ambient $PM_{2.5}$ concentrations are those used in the *Global Energy Assessment*[25] and described in detail by Rao et al.[26] Using TM5-FASST, $PM_{2.5}$ concentrations attributable to road transport were calculated for each of 56 global regions along with estimates of $PM_{2.5}$ levels attributable to all anthropogenic emissions sources, which allowed us to estimate the proportional contribution of $PM_{2.5}$ from road transport to the total $PM_{2.5}$ levels for 1990 and 2010 in each of the 21 GBD 2010 regions. The concentrations attributable to road transport were adjusted at the country level to also consider the contributions from "natural" sources such as mineral dust and sea salt by comparing the total anthropogenic source concentrations with the concentrations of $PM_{2.5}$ from all sources, as described in Brauer et al. We then estimated the country-specific burden of disease attributable to $PM_{2.5}$ from road transport by multiplying the country-specific total $PM_{2.5}$-attributable burden by the region-specific (country-specific in some large countries) proportion of ambient $PM_{2.5}$ from road transport.[15]

We have, in all likelihood, underestimated the burden of disease attributable to vehicular emissions. This is the result of the limitations of the available data and methods, which are described below.

Geographic misalignment of exposure data

We applied a regional fraction to both urban and rural areas, which likely underestimates contribution in urban areas, where pollution is higher. For example, the traffic fractions applied to China and India are approximately 2% and 6%, respectively, but in Delhi and Beijing it is estimated to be as high as 20%.[27] Similarly, in the US, we have estimated the fraction of ambient $PM_{2.5}$ attributable to road transport as 15%, while a population-weighted estimate of this contribution derived from state-level emissions information across the US estimates this fraction as 26%.[28]

While this report was being prepared, the International Council for Clean Transportation (ICCT) completed a similar analysis of the mortality attributable to ambient $PM_{2.5}$ from motor vehicles.[14] Overall, results were similar, with the ICCT estimating 230,000 deaths per year in 2005, compared to the 180,000 deaths per year in 2010 that we estimate. The same general regional patterns in mortality attributable to $PM_{2.5}$ from motor vehicles were observed in the two analyses. In addition to the difference in years (2005 and 2010), the ICCT analysis uses a different chemical transport model, the Model for Ozone and Related Tracers, version 4 (MOZART-4). As the ICCT analysis did not use age-stratified exposure-response functions and utilized somewhat different underlying mortality data, the two attributable mortality estimates are not directly comparable. Accordingly, while we cannot fully attribute the 28% lower mortality in our estimate to the spatial misalignment in estimated motor vehicle contributions, this comparison provides a rough estimate of the magnitude of this error and supports our suggestion that the estimates provided here are low.

Both our analysis and that conducted by ICCT used the same database of ambient $PM_{2.5}$ concentrations, however, and therefore allow us to directly compare the fraction of ambient $PM_{2.5}$ attributable to motor vehicles. Consequently, it is clear that the differences in these two estimates are due to differences in the underlying emissions databases and chemical transport models and to the different spatial resolution of the estimated contribution of motor vehicles to ambient $PM_{2.5.}$ While our analysis was conducted at the country level, the ICCT analysis was at 0.4° x 0.5°, approximately 40 x 50 km at the equator.

We also compared the country-level contributions of motor vehicles to ambient $PM_{2.5}$ between the two approaches (Figure A1).

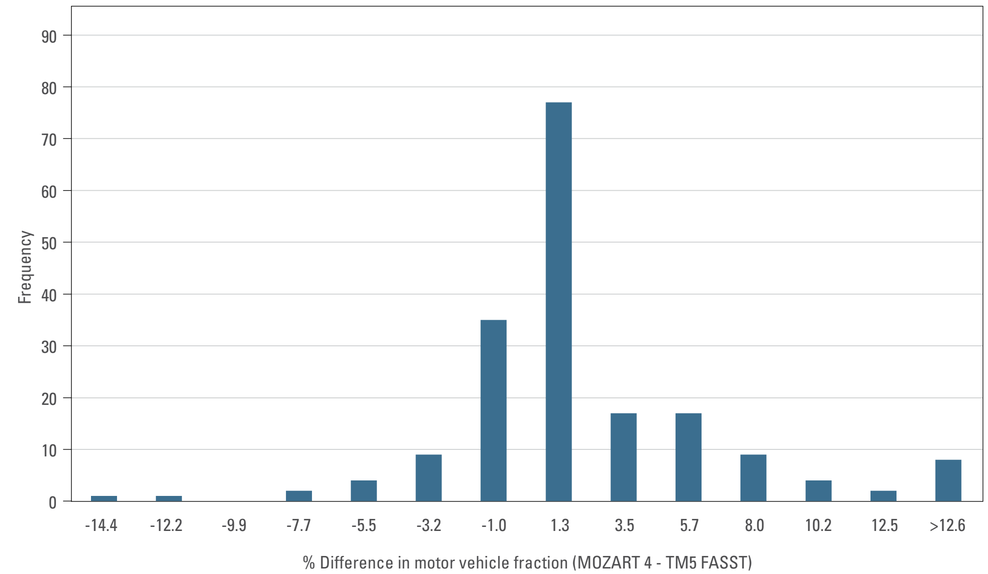
ICCT estimates were systematically higher than those used in our analysis, although absolute differences were rather small. There was reasonable agreement between the two estimates overall (r=0.78), and generally rather small differences (mean absolute difference of 3.0%; SD of differences of 3.6%) in the estimated contributions for specific countries, although large discrepancies were observed in some locations. For example, ICCT estimated that contributions were more than 10% higher in Belgium, Canada, Denmark, Germany, Japan, Luxembourg, Malaysia, Mexico, the Netherlands, Singapore, and Venezuela, while TM5-FASST estimated that contributions were more than 10% higher in Egypt and Malta.

In China (4.9% versus 2.2%) and India (5.6% versus 6.2%), differences between the ICCT study and our analysis were quite small, while in the US (23.5% versus 14.9%), differences were larger.

Limitations of the emissions data

The vehicular contribution to ambient $PM_{2.5}$ is emissions-based, although emissions are processed through a chemical transport model. These estimates therefore only include those transportation sources that are included in currently available emissions inventories.

Figure A1: Country-level differences in estimated fraction of $PM_{2.5}$ attributable to motor vehicles



Limitations of the health data

Although there is considerable evidence regarding the adverse health effects of residential proximity to road traffic, GBD 2010 did not quantify the burden of disease that might be attributable to it.[29,30] As a result, our estimates do not include some adverse effects of traffic-related air pollution, such as increased asthma incidence and severity in children. We have also not included the health impact of motor vehicle contributions to ozone via emission of precursor compounds. GBD 2010 estimated that ozone exposure contributes to the incidence of chronic obstructive pulmonary disease and globally was responsible for 152,000 deaths in 2010. Estimates in the US suggest that mortality attributable to ozone via precursors emitted from road transport is roughly 10% to 15% of that attributable to $PM_{2.5}$ from road transport.[27,30] Further, we do not assess impacts of mobile source "air toxics"[31] such as benzene, 1,3-butadiene, formaldehyde, and acetaldehyde, although these are expected to be much smaller than those attributable to the motor vehicle contributions to $PM_{2.5}$.[32]

Limitations of the statistical model

The estimates reflect the impact of removing road transport given current levels of $PM_{2.5}$ concentrations; however, due to nonlinearities in the integrated exposure-response curves, these numbers are smaller than the burden of road transport absent any other source of $PM_{2.5}$. These issues are discussed in more detail in the Web appendix.

ANNEX 2:
COUNTRY ESTIMATES

	1990		2010											2010					
	Road injury deaths		Road injury deaths									Nonfatal road injuries		Motor vehicle air pollution		Total burden (air pollution + road injuries)			
Country	Deaths count	Rate per 100,000	Official country statistics count	GBD 2010 road deaths count	Uncertainty range 95% CI	Rate per 100,000	Pedestrian %	Bicyclist %	Motorcycle rider %	Vehicle occupant %	Other %	Injuries warranting admission count	Total nonfatal injuries count	Deaths count	Uncertainty range 95% CI	Cause of death rank	YLL rank	YLD rank	DALY rank
Afghanistan	4,590	34	1,501	10,213	(5,054 - 15,093)	32	14	6	12	64	4	36,483	345,765	1,388	(1,130 - 1,705)	10	8	5	8
Albania	332	10	352	395	(259 - 533)	12	16	7	13	51	13	4,149	33,823	136	(112 - 161)	12	11	5	9
Algeria	3,765	15	N.A.	4,283	(3,570 - 5,371)	12	6	9	8	74	2	51,649	432,149	417	(366 - 474)	9	7	7	6
Andorra	5	10	3	6	(3 - 8)	7	19	11	14	55	1	63	519	6	(3 - 10)	10	10	9	9
Angola	6,563	63	4,042	9,408	(2,450 - 31,110)	49	69	2	4	24	1	17,608	184,103	11	(8 - 13)	5	4	5	4
Antigua and Barbuda	3	5	N.A.	5	(4 - 7)	6	14	8	8	69	1	104	837	0	(0 - 1)	11	10	8	10
Argentina	3,389	10	5,094	6,067	(4,484 - 7,015)	15	15	7	14	63	1	39,338	341,421	278	(170 - 436)	9	9	10	8
Armenia	676	19	285	474	(352 - 776)	15	34	4	3	56	3	4,230	35,180	162	(134 - 192)	12	11	9	11
Australia	2,836	17	1,363	2,024	(1,629 - 2,590)	9	18	3	12	67	1	23,097	189,314	18	(11 - 28)	10	9	7	9
Austria	1,411	18	552	723	(622 - 991)	9	18	10	15	56	1	6,272	52,525	393	(311 - 489)	10	10	10	9
Azerbaijan	1,143	16	1,202	882	(585 - 1,510)	10	27	4	3	62	4	13,728	111,534	340	(297 - 383)	12	12	7	12
Bahamas	48	19	N.A.	57	(43 - 72)	17	8	5	12	73	2	397	3,375	1	(0 - 2)	8	5	7	6
Bahrain	128	26	73	256	(185 - 327)	20	3	5	5	87	1	2,162	18,211	10	(7 - 13)	6	3	8	4
Bangladesh	3,432	3	2,872	6,113	(4,148 - 10,330)	4	34	14	11	29	11	298,166	2,304,607	2,667	(2,129 - 3,177)	12	11	6	10
Barbados	30	11	19	31	(23 - 38)	11	14	6	7	72	1	332	2,709	2	(1 - 3)	10	9	7	8
Belarus	2,332	23	1,190	2,117	(1,637 - 2,687)	22	37	6	6	47	3	14,393	123,448	665	(537 - 806)	11	10	11	10
Belgium	1,921	19	840	1,345	(1,139 - 1,720)	12	15	16	18	49	2	7,362	64,902	928	(752 - 1,120)	10	10	9	9
Belize	19	10	41	59	(42 - 71)	19	10	11	11	64	2	337	2,911	1	(0 - 1)	8	5	8	5
Benin	982	21	816	1,726	(1,245 - 2,155)	19	36	5	16	39	4	10,624	91,918	22	(18 - 27)	6	6	8	7
Bhutan	75	14	79	87	(53 - 147)	12	39	10	11	36	3	1,482	11,794	12	(9 - 16)	10	6	7	7
Bolivia	1,476	22	1,681	1,989	(1,310 - 2,571)	20	45	5	4	45	2	11,183	97,324	23	(17 - 30)	8	6	9	7
Bosnia and Herzegovina	45	1	336	65	(34 - 132)	2	29	11	7	49	4	4,893	37,699	187	(156 - 221)	13	13	7	13
Botswana	155	11	385	283	(191 - 484)	14	36	7	14	38	5	1,962	18,242	0	(0 - 0)	8	4	9	4
Brazil	31,443	21	36,499	43,985	(35,301 - 52,857)	23	34	4	23	38	1	166,013	1,538,102	618	(426 - 852)	9	6	12	7
Brunei	40	16	46	50	(37 - 58)	12	17	13	12	58	0	356	3,076	1	(0 - 2)	8	7	9	7
Bulgaria	1,219	14	775	913	(739 - 1,092)	12	19	6	7	64	4	7,818	65,719	844	(726 - 978)	12	11	6	11
Burkina Faso	2,844	30	966	5,585	(4,271 - 7,113)	34	34	3	14	33	15	14,308	144,032	54	(41 - 70)	8	5	8	4
Burundi	2,097	37	357	2,534	(812 - 5,044)	30	35	16	12	25	12	9,588	89,842	17	(12 - 24)	8	7	9	6
Cambodia	875	9	1,816	2,394	(1,414 - 3,298)	17	10	6	23	52	10	21,924	183,274	129	(110 - 150)	10	7	7	8
Cameroon	4,051	33	1,353	6,951	(4,682 - 9,920)	35	41	4	13	37	4	20,934	205,855	52	(44 - 62)	5	4	8	4
Canada	4,191	15	2,227	2,962	(2,559 - 3,909)	9	17	5	10	68	1	33,251	275,144	607	(474 - 758)	10	9	10	10
Cape Verde	45	13	63	80	(36 - 177)	16	44	7	10	35	4	646	5,490	1	(1 - 1)	9	5	9	8
Central African Republic	916	31	145	1,911	(899 - 3,835)	43	47	4	15	26	9	4,357	44,557	12	(10 - 15)	5	6	5	6
Chad	954	16	3,226	2,765	(2,144 - 3,536)	24	38	4	16	36	7	11,096	102,518	23	(17 - 31)	10	9	4	9

	1990		2010											2010					
	Road injury deaths		Road injury deaths									Nonfatal road injuries		Motor vehicle air pollution		Total burden (air pollution + road injuries)			
Country	Deaths count	Rate per 100,000	Official country statistics count	GBD 2010 road deaths count	Uncertainty range 95% CI	Rate per 100,000	Pedestrian %	Bicyclist %	Motorcycle rider %	Vehicle occupant %	Other %	Injuries warranting admission count	Total nonfatal injuries count	Deaths count	Uncertainty range 95% CI	Cause of death rank	YLL rank	YLD rank	DALY rank
Chile	1,587	12	2,071	2,204	(1,573 - 2,572)	13	47	7	7	37	2	17,104	144,068	220	(159 - 287)	9	8	9	7
China	155,521	14	70,134	282,576	(205,235 - 414,850)	21	37	3	17	26	16	1,903,239	16,300,000	27,379	(23,028 - 31,278)	10	6	6	7
Colombia	6,260	19	5,502	7,503	(5,997 - 9,241)	16	41	7	24	27	1	30,559	281,963	105	(73 - 145)	9	6	11	6
Comoros	143	33	14	213	(122 - 411)	29	49	18	5	24	4	851	7,871	0	(0 - 0)	5	6	8	6
Congo	1,005	42	269	1,916	(633 - 5,519)	47	65	2	5	27	1	3,236	35,686	15	(12 - 18)	6	4	10	4
Costa Rica	429	14	700	753	(625 - 913)	16	36	9	17	36	2	4,876	41,535	24	(16 - 34)	9	5	12	5
Côte d'Ivoire	3,383	27	699	6,536	(4,232 - 8,893)	33	37	4	17	39	4	19,363	188,795	68	(57 - 84)	8	6	10	6
Croatia	1,019	23	426	537	(443 - 669)	12	20	10	15	53	2	3,799	32,727	267	(207 - 335)	10	10	6	10
Cuba	2,247	21	809	1,162	(995 - 1,578)	10	32	17	12	35	5	13,751	112,686	83	(53 - 116)	12	9	7	8
Cyprus	167	26	60	111	(93 - 140)	15	17	4	21	56	2	1,076	9,006	26	(20 - 33)	9	9	7	8
Czech Republic	1,532	15	802	988	(795 - 1,229)	9	21	12	10	56	1	13,665	110,901	663	(552 - 776)	10	10	5	10
Democratic Republic of the Congo	6,497	18	332	7,733	(5,107 - 11,060)	12	35	5	23	28	8	82,668	678,838	136	(110 - 170)	15	12	7	12
Denmark	763	15	255	476	(394 - 603)	9	18	13	13	55	1	4,028	33,958	183	(135 - 236)	10	10	9	9
Djibouti	303	54	N.A.	345	(167 - 723)	39	65	8	3	22	2	993	9,634	1	(1 - 2)	4	2	11	2
Dominica	10	15	8	9	(7 - 11)	13	11	5	11	72	1	87	708	0	(0 - 0)	10	8	8	7
Dominican Republic	1,185	16	2,470	2,231	(1,730 - 2,581)	22	4	1	6	89	1	9,040	84,034	55	(41 - 72)	8	5	6	6
Ecuador	2,366	23	3,222	3,498	(2,798 - 4,157)	24	56	5	7	31	1	13,732	126,386	23	(16 - 32)	7	4	8	3
Egypt	7,025	12	9,602	11,708	(9,030 - 13,959)	14	30	3	2	64	1	116,416	964,142	11,315	(9,876 - 12,579)	8	7	7	7
El Salvador	1,375	26	1,017	1,589	(1,333 - 2,116)	26	10	14	14	58	3	5,344	50,112	15	(7 - 26)	8	5	12	6
Equatorial Guinea	178	47	53	524	(109 - 1,855)	75	68	2	3	26	1	560	6,796	1	(1 - 2)	4	3	7	3
Eritrea	682	22	N.A.	1,202	(898 - 1,673)	23	41	14	7	31	8	5,966	54,463	9	(7 - 11)	7	6	8	7
Estonia	383	25	78	126	(100 - 182)	9	21	9	4	57	8	1,417	11,820	26	(14 - 41)	12	11	11	10
Ethiopia	15,103	31	2,506	21,520	(16,689 - 27,821)	26	47	11	4	30	9	65,191	642,113	118	(96 - 143)	6	4	7	4
Federated States of Micronesia	11	11	2	14	(9 - 23)	12	19	8	7	58	7	163	1,340	0	(0 - 0)	10	10	10	10
Fiji	45	6	52	63	(53 - 78)	7	17	9	6	61	7	1,344	10,737	0	(0 - 0)	13	12	10	11
Finland	660	13	272	387	(326 - 529)	7	12	12	11	63	2	5,092	41,515	44	(25 - 69)	12	9	8	10
France	10,009	18	3,992	5,523	(4,699 - 7,626)	9	11	8	21	58	1	46,255	388,852	3,529	(2,808 - 4,280)	10	8	8	8
Gabon	586	63	327	1,267	(340 - 3,485)	84	68	2	5	25	1	1,172	14,868	2	(2 - 3)	4	2	9	2
Gambia	223	23	N.A.	387	(283 - 519)	22	37	4	15	38	6	2,016	17,906	4	(3 - 5)	7	5	7	6
Georgia	1,206	22	685	515	(378 - 795)	12	9	4	4	81	2	5,320	43,693	228	(181 - 279)	12	11	8	12
Germany	11,771	15	3,648	5,469	(4,689 - 7,584)	7	17	12	15	55	1	61,846	507,966	7,359	(6,118 - 8,729)	9	11	7	11
Ghana	2,053	14	1,986	4,844	(3,267 - 6,097)	20	38	5	7	46	4	32,905	281,393	72	(61 - 84)	7	5	8	6
Greece	2,179	21	1,451	1,773	(1,498 - 2,242)	16	15	8	25	41	11	12,006	103,222	742	(559 - 980)	11	9	7	9
Grenada	8	8	N.A.	13	(9 - 16)	12	8	7	7	76	2	126	1,042	1	(0 - 1)	11	8	8	9
Guatemala	590	7	958	944	(722 - 1,200)	7	37	5	8	45	4	17,381	137,969	44	(36 - 54)	14	13	9	12
Guinea	1,019	18	503	1,869	(1,409 - 2,305)	19	33	5	17	39	6	12,295	105,831	33	(26 - 41)	9	8	8	9
Guinea-Bissau	309	30	134	443	(288 - 600)	29	30	4	22	38	6	186	15,686	4	(3 - 6)	8	6	9	8

	1990		2010											2010					
	Road injury deaths		Road injury deaths									Nonfatal road injuries		Motor vehicle air pollution		Total burden (air pollution + road injuries)			
Country	Deaths count	Rate per 100,000	Official country statistics count	GBD 2010 road deaths count	Uncertainty range 95% CI	Rate per 100,000	Pedestrian %	Bicyclist %	Motorcycle rider %	Vehicle occupant %	Other %	Injuries warranting admission count	Total nonfatal injuries count	Deaths count	Uncertainty range 95% CI	Cause of death rank	YLL rank	YLD rank	DALY rank
Guyana	68	9	112	127	(72 - 171)	17	10	10	11	66	3	846	7,203	4	(2 - 6)	9	8	7	9
Haiti	1,168	16	N.A.	1,395	(988 - 1,745)	14	7	9	10	65	8	11,270	94,986	62	(46 - 86)	14	13	7	12
Honduras	654	13	1,217	1,231	(982 - 1,542)	16	36	7	11	43	4	6,920	60,980	27	(18 - 37)	11	8	11	8
Hungary	2,194	21	740	1,246	(998 - 1,579)	12	28	18	9	44	1	13,285	109,725	816	(688 - 957)	12	11	7	11
Iceland	27	10	8	16	(12 - 19)	5	7	8	10	69	7	253	2,035	2	(1 - 3)	9	8	7	9
India	145,378	17	130,037	273,835	(176,843 - 440,771)	22	44	11	17	21	8	2,197,047	18,500,000	38,804	(32,697 - 44,928)	10	9	8	9
Indonesia	43,407	24	31,234	65,335	(53,625 - 80,627)	27	12	6	19	57	6	360,187	3,170,472	1,374	(1,167 - 1,606)	7	5	6	6
Iran	15,399	28	23,249	27,486	(19,719 - 34,419)	37	28	5	12	48	7	173,153	1,413,027	2,602	(2,265 - 2,951)	8	3	6	4
Iraq	1,638	9	5,708	2,593	(2,027 - 3,652)	8	27	7	9	54	3	43,833	349,096	931	(803 - 1,055)	10	10	7	10
Ireland	461	13	212	292	(238 - 412)	6	19	6	9	64	1	3,449	28,547	112	(75 - 154)	11	9	9	9
Israel	573	12	352	729	(578 - 858)	10	38	4	7	51	1	5,362	45,641	304	(248 - 376)	9	8	8	7
Italy	11,212	20	4,237	6,832	(5,829 - 9,084)	11	27	11	16	46	1	40,682	356,709	5,895	(4,731 - 7,104)	10	10	8	8
Jamaica	42	2	319	85	(36 - 122)	3	16	6	16	59	2	3,366	26,529	17	(12 - 22)	13	13	7	9
Japan	14,299	12	5,772	10,017	(8,284 - 14,084)	8	37	18	14	31	0	118,924	974,382	8,280	(6,524 - 10,200)	10	10	9	10
Jordan	543	16	670	728	(593 - 882)	12	24	6	5	63	2	8,715	71,435	185	(156 - 213)	9	7	8	7
Kazakhstan	3,768	23	3,379	3,965	(3,167 - 5,133)	25	26	4	4	64	2	19,011	170,027	283	(243 - 322)	10	10	8	10
Kenya	3,648	16	2,966	7,820	(5,183 - 13,628)	19	51	12	4	29	3	48,022	427,257	15	(10 - 21)	7	4	7	5
Kiribati	10	14	6	15	(11 - 19)	16	14	8	7	62	9	135	1,130	0	(0 - 0)	9	9	10	9
Kuwait	311	15	374	493	(415 - 595)	18	12	12	12	61	2	4,276	36,137	40	(34 - 45)	9	4	7	6
Kyrgyzstan	1,045	24	850	1,161	(900 - 1,394)	22	26	6	7	57	4	7,089	61,481	102	(87 - 118)	11	10	8	7
Laos	555	13	767	1,068	(670 - 1,539)	17	11	4	25	53	7	7,668	65,649	68	(55 - 82)	11	9	6	9
Latvia	882	33	218	344	(269 - 511)	15	37	8	5	48	2	4,830	39,225	84	(57 - 116)	11	10	11	9
Lebanon	492	17	533	516	(369 - 715)	12	17	6	4	71	1	6,348	51,495	245	(203 - 291)	9	9	8	8
Lesotho	76	5	362	232	(106 - 405)	11	26	8	18	37	11	2,362	19,535	7	(5 - 11)	15	14	10	16
Liberia	428	20	78	561	(199 - 983)	14	23	5	29	35	9	5,091	42,338	8	(6 - 12)	10	11	9	12
Libya	811	19	N.A.	1,322	(985 - 1,775)	21	17	5	5	72	1	9,136	76,161	83	(72 - 97)	9	6	9	7
Lithuania	1,085	29	299	613	(510 - 857)	18	33	10	6	49	2	4,914	41,634	130	(98 - 168)	10	10	11	9
Luxembourg	73	19	32	48	(36 - 60)	10	9	3	10	70	8	372	3,153	30	(19 - 43)	10	9	9	9
Macedonia	144	8	452	133	(96 - 157)	6	6	3	4	83	4	2,720	21,354	128	(104 - 153)	12	12	5	11
Madagascar	2,891	26	422	3,405	(2,631 - 4,846)	16	48	11	5	30	6	25,756	217,814	14	(9 - 20)	8	7	8	9
Malawi	2,722	29	976	4,867	(3,293 - 6,560)	32	43	12	7	32	6	16,259	154,318	3	(2 - 5)	7	6	11	6
Malaysia	2,638	15	6,872	4,106	(3,124 - 4,968)	14	4	4	21	69	1	52,427	422,519	405	(339 - 475)	9	8	9	7
Maldives	30	14	6	29	(22 - 38)	9	9	13	17	55	6	535	4,267	2	(0 - 4)	7	5	5	7
Mali	1,813	21	739	3,133	(2,379 - 3,924)	20	35	4	17	38	5	14,787	131,881	33	(26 - 44)	8	5	7	6
Malta	15	4	15	16	(12 - 19)	4	14	8	18	53	7	330	2,615	39	(22 - 58)	10	10	9	9
Marshall Islands	6	12	4	7	(5 - 10)	11	18	8	7	61	6	91	742	0	(0 - 0)	9	9	10	8
Mauritania	514	26	163	1,016	(743 - 1,383)	29	35	5	15	40	5	3,090	30,463	5	(4 - 6)	6	5	8	6
Mauritius	107	10	158	123	(79 - 151)	9	8	10	13	63	6	1,841	14,819	1	(0 - 3)	10	9	9	9
Mexico	15,954	19	17,301	20,096	(16,217 - 24,578)	18	41	4	7	46	2	55,622	558,214	2,179	(1,892 - 2,478)	9	7	11	7
Moldova	1,069	24	452	534	(447 - 745)	15	29	7	10	45	9	5,660	46,667	261	(215 - 309)	12	10	10	10
Mongolia	462	21	477	661	(456 - 908)	24	21	4	5	66	4	3,668	32,991	26	(23 - 30)	10	8	9	8

	1990		2010											2010					
	Road injury deaths		Road injury deaths									Nonfatal road injuries		Motor vehicle air pollution		Total burden (air pollution + road injuries)			
Country	Deaths count	Rate per 100,000	Official country statistics count	GBD 2010 road deaths count	Uncertainty range 95% CI	Rate per 100,000	Pedestrian %	Bicyclist %	Motorcycle rider %	Vehicle occupant %	Other %	Injuries warranting admission count	Total nonfatal injuries count	Deaths count	Uncertainty range 95% CI	Cause of death rank	YLL rank	YLD rank	DALY rank
Montenegro	70	12	95	82	(66 - 96)	13	48	7	11	33	2	768	6,389	31	(26 - 36)	10	10	6	10
Morocco	2,210	9	3,778	2,857	(2,421 - 3,872)	9	7	7	6	77	2	42,311	339,187	454	(394 - 522)	9	8	9	9
Mozambique	2,264	17	2,549	7,154	(5,493 - 11,166)	31	41	11	8	30	10	26,996	238,575	3	(2 - 5)	6	4	8	4
Myanmar	4,528	12	2,464	9,277	(5,037 - 13,985)	19	9	6	23	53	9	56,886	490,076	548	(422 - 703)	9	9	8	6
Namibia	111	8	292	222	(157 - 385)	10	32	9	11	42	6	2,107	18,961	0	(0 - 1)	12	11	9	12
Nepal	2,598	14	1,689	3,293	(2,493 - 4,197)	11	28	13	15	26	19	57,934	461,572	675	(570 - 800)	11	9	8	11
Netherlands	1,780	12	640	1,068	(898 - 1,493)	6	12	28	14	46	1	12,579	102,940	1,092	(865 - 1,323)	10	10	8	10
New Zealand	743	22	375	454	(390 - 562)	10	11	3	9	76	1	4,654	38,567	3	(2 - 5)	11	9	8	8
Nicaragua	512	12	742	639	(525 - 798)	11	22	10	13	50	4	6,810	56,293	12	(7 - 18)	9	9	11	9
Niger	1,496	19	703	2,078	(1,412 - 2,821)	13	30	5	19	39	7	18,891	156,679	46	(35 - 61)	14	13	5	13
Nigeria	32,606	33	5,279	74,548	(55,477 - 91,154)	47	41	3	18	30	8	154,369	1,608,482	297	(241 - 362)	3	2	8	2
North Korea	3,518	17	N.A.	3,728	(1,602 - 6,331)	15	15	6	12	26	42	40,189	329,849	725	(593 - 867)	11	9	9	10
Norway	514	12	208	279	(235 - 378)	6	13	6	13	67	1	3,629	29,595	15	(9 - 25)	11	10	10	11
Oman	857	46	820	1,090	(856 - 1,331)	40	68	2	2	28	0	3,717	36,799	41	(36 - 46)	3	1	7	1
Pakistan	8,867	8	5,192	16,573	(12,746 - 22,510)	10	39	13	13	28	7	331,613	2,651,023	4,496	(3,855 - 5,238)	12	10	7	12
Palestine	286	14	N.A.	440	(321 - 560)	11	15	6	5	73	2	5,630	46,594	132	(108 - 155)	8	6	7	6
Panama	439	18	422	591	(501 - 774)	17	42	6	4	46	2	3,343	29,132	8	(5 - 13)	10	6	12	7
Papua New Guinea	475	11	269	871	(545 - 1,197)	13	23	7	10	52	7	9,780	79,442	1	(0 - 1)	12	11	8	13
Paraguay	500	12	1,206	1,247	(823 - 1,469)	19	41	3	28	27	2	6,362	55,947	8	(3 - 15)	9	7	10	8
Peru	2,682	12	2,514	3,973	(3,103 - 4,649)	14	41	4	3	51	1	35,026	291,197	69	(50 - 90)	9	4	7	5
Philippines	4,317	7	6,739	8,396	(6,464 - 10,535)	9	21	5	19	50	5	110,309	900,551	554	(416 - 714)	10	12	9	14
Poland	7,513	20	3,907	5,681	(4,590 - 7,152)	15	34	10	5	50	0	46,151	391,422	1,814	(1,537 - 2,117)	11	11	6	11
Portugal	2,853	29	937	1,327	(1,097 - 1,940)	12	25	9	12	49	5	4,914	46,631	593	(443 - 768)	11	9	9	8
Qatar	80	17	228	306	(212 - 380)	17	7	12	14	64	3	3,564	29,191	7	(6 - 8)	3	1	8	2
Romania	4,159	18	2,377	2,906	(2,389 - 3,687)	14	22	9	8	56	5	12,279	112,734	1,581	(1,353 - 1,831)	12	11	7	11
Russia	40,747	28	26,567	33,379	(27,469 - 40,921)	24	42	3	5	48	2	179,432	1,569,191	6,572	(5,439 - 7,787)	10	10	10	10
Rwanda	2,885	41	438	2,492	(1,431 - 5,488)	23	53	13	5	23	6	12,724	111,807	16	(12 - 20)	7	6	7	6
Saint Lucia	26	19	14	25	(20 - 33)	14	10	6	6	75	2	211	1,791	1	(0 - 1)	10	8	8	8
Saint Vincent and the Grenadines	8	7	5	11	(8 - 13)	10	18	10	9	61	2	135	1,095	1	(0 - 1)	11	9	8	9
Samoa	16	10	55	15	(11 - 21)	8	18	9	5	60	7	272	2,153	0	(0 - 0)	11	10	8	11
São Tomé and Príncipe	12	10	33	15	(10 - 24)	9	38	4	14	40	4	220	1,775	0	(0 - 0)	10	7	10	11
Saudi Arabia	5,757	36	6,596	9,128	(7,304 - 10,400)	34	5	1	1	93	0	42,258	342,789	333	(285 - 376)	5	2	8	4
Senegal	392	5	277	645	(307 - 1,406)	5	48	5	16	26	5	14,528	114,598	12	(10 - 16)	15	16	7	15
Serbia	1,176	12	660	988	(769 - 1,141)	10	24	11	12	52	1	12,272	100,090	564	(475 - 654)	10	10	6	10
Seychelles	8	12	13	12	(8 - 18)	15	16	6	17	61	1	123	1,008	0	(0 - 0)	9	9	8	9
Sierra Leone	951	24	357	1,095	(627 - 1,505)	19	29	5	24	36	6	7,063	61,334	14	(11 - 18)	10	9	10	9
Singapore	256	9	193	164	(123 - 212)	4	23	9	40	28	1	3,574	28,787	44	(23 - 64)	11	9	7	9
Slovakia	971	18	515	618	(527 - 801)	11	29	11	7	51	1	5,796	48,554	356	(298 - 415)	10	10	6	10

	1990		2010											2010					
	Road injury deaths		Road injury deaths									Nonfatal road injuries		Motor vehicle air pollution		Total burden (air pollution + road injuries)			
Country	Deaths count	Rate per 100,000	Official country statistics count	GBD 2010 road deaths count	Uncertainty range 95% CI	Rate per 100,000	Pedestrian %	Bicyclist %	Motorcycle rider %	Vehicle occupant %	Other %	Injuries warranting admission count	Total nonfatal injuries count	Deaths count	Uncertainty range 95% CI	Cause of death rank	YLL rank	YLD rank	DALY rank
Slovenia	487	24	138	220	(183 - 297)	11	16	9	16	58	1	3,023	24,560	107	(85 - 132)	10	10	5	9
Solomon Islands	32	10	12	62	(44 - 84)	11	14	8	9	59	10	765	6,272	0	(0 - 0)	10	8	9	10
Somalia	1,898	28	N.A.	2,083	(1,509 - 3,255)	22	43	10	7	29	12	10,805	95,810	14	(11 - 18)	8	9	7	9
South Africa	2,597	7	14,804	4,479	(3,339 - 5,571)	9	50	5	7	36	1	51,312	422,129	231	(180 - 291)	10	10	9	11
South Korea	12,262	28	5,505	7,839	(6,365 - 9,651)	16	43	7	20	30	0	42,262	374,837	2,126	(1,673 - 2,586)	9	9	9	9
Spain	7,949	20	2,478	3,950	(3,403 - 5,439)	9	23	4	14	58	1	9,698	102,160	1,848	(1,487 - 2,253)	10	10	9	9
Sri Lanka	1,294	7	2,483	2,650	(1,832 - 4,226)	13	14	8	13	60	5	27,914	228,517	217	(168 - 271)	10	9	8	10
Sudan	5,511	21	3,582	10,278	(7,877 - 13,730)	24	65	7	3	22	3	27,318	273,830	43	(34 - 54)	5	4	9	5
Suriname	63	15	87	80	(55 - 97)	15	10	7	18	64	1	615	5,117	1	(1 - 2)	9	7	7	6
Swaziland	53	6	216	218	(127 - 346)	18	33	7	14	40	5	906	9,055	2	(1 - 3)	10	10	9	10
Sweden	1,011	12	266	512	(413 - 750)	6	14	9	13	63	1	7,134	57,704	159	(110 - 221)	11	9	8	10
Switzerland	1,120	17	327	594	(488 - 793)	8	28	12	11	47	2	2,691	24,535	444	(344 - 551)	10	10	7	9
Syria	825	7	2,118	1,100	(768 - 1,660)	5	18	6	5	68	3	24,325	194,113	970	(857 - 1,111)	9	9	7	10
Taiwan	5,330	26	N.A.	4,156	(3,234 - 5,562)	18	14	11	34	20	22	38,323	320,120	444	(363 - 537)	8	7	7	7
Tajikistan	803	15	442	619	(468 - 873)	9	20	5	4	66	5	9,690	78,354	97	(82 - 110)	15	12	6	14
Tanzania	4,857	19	3,582	9,404	(6,482 - 14,042)	21	53	7	5	29	6	51,035	464,028	12	(8 - 18)	7	5	8	6
Thailand	12,337	22	13,365	19,867	(14,779 - 24,943)	29	18	3	35	43	0	56,372	542,010	1,521	(1,276 - 1,828)	11	5	8	5
Timor-Leste	65	9	99	90	(49 - 134)	8	10	6	21	56	8	1,726	13,741	1	(1 - 2)	10	9	8	10
Togo	835	23	742	1,401	(966 - 1,733)	23	28	5	20	38	9	6,958	62,337	16	(13 - 20)	6	6	9	7
Tonga	10	11	6	12	(8 - 16)	11	20	8	4	59	8	148	1,207	0	(0 - 0)	11	11	9	10
Trinidad and Tobago	158	13	200	230	(170 - 295)	17	21	6	6	65	1	1,571	13,337	3	(1 - 5)	9	8	7	7
Tunisia	2,038	25	1,208	2,719	(1,880 - 3,317)	26	30	3	14	52	1	12,578	113,041	214	(181 - 255)	9	5	8	6
Turkey	8,022	15	5,253	5,810	(4,839 - 8,418)	8	19	3	8	68	3	63,339	520,623	2,402	(2,141 - 2,701)	9	9	8	10
Turkmenistan	704	19	N.A.	704	(487 - 1,118)	14	23	4	4	67	3	7,197	59,607	66	(55 - 75)	10	11	8	10
Uganda	3,185	18	2,954	7,365	(5,368 - 10,509)	22	54	10	7	24	5	37,368	332,414	30	(23 - 40)	5	4	9	5
Ukraine	12,059	23	6,116	8,007	(6,323 - 9,784)	18	37	7	5	47	5	49,729	431,242	4,272	(3,589 - 5,058)	11	10	9	10
United Arab Emirates	527	29	826	1,838	(1,128 - 2,654)	25	12	5	7	75	1	11,495	103,262	53	(45 - 62)	4	2	6	3
United Kingdom	5,526	10	1,905	3,710	(3,169 - 4,822)	6	24	5	16	54	1	45,987	376,369	3,384	(2,730 - 4,053)	12	10	9	11
United States	49,643	20	32,885	44,001	(36,199 - 53,473)	14	14	2	10	73	0	247,223	2,195,212	15,374	(12,643 - 18,263)	10	9	11	9
Uruguay	420	14	556	428	(332 - 514)	13	10	11	18	57	3	2,974	25,493	52	(26 - 84)	10	9	11	8
Uzbekistan	3,566	17	2,731	4,683	(3,598 - 6,555)	17	50	3	1	43	2	39,414	334,218	513	(448 - 582)	11	11	8	9
Vanuatu	19	13	4	35	(23 - 54)	14	16	8	7	61	8	332	2,776	0	(0 - 0)	9	8	9	8
Venezuela	4,696	24	7,714	7,616	(6,017 - 10,598)	26	33	8	12	45	2	25,149	240,924	150	(118 - 186)	8	5	11	5
Vietnam	9,146	14	11,859	16,371	(12,460 - 19,166)	19	13	7	58	15	7	249,726	2,034,092	607	(485 - 728)	8	5	6	6
Yemen	1,860	16	3,843	3,520	(2,003 - 5,220)	15	16	5	8	68	3	32,778	272,129	581	(486 - 710)	11	8	6	9
Zambia	2,276	29	1,348	2,798	(2,077 - 3,955)	21	53	8	5	30	4	14,883	131,637	4	(3 - 5)	9	6	9	6
Zimbabwe	1,453	14	1,777	3,527	(1,375 - 5,853)	28	11	10	31	11	38	10,477	96,577	2	(1 - 4)	10	8	9	8

Note: Official country statistics are the country-reported data presented in the 2013 WHO Global Status Report on Road Safety *after adjustment to 30-day definition. Countries for which official data were not available are marked N.A.*

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