Transportation Global Environmental Impact

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This paper addresses the role of highway transportation and its contribution to greenhouse gases. It outlines cleaner fuel options and discusses pavement construction and maintenance impacts on the environment. In addition, it considers carbon tax to encourage industry and governmental associations to promote green technology and low-carbon footprint products.

Sustainable development is defined as the ability to "meet the needs of the present without compromising the ability of future generations to meet their own needs".[1] A critical element of sustainability is protecting the environment from various pollutants.

Greenhouse gas (GHG) emissions have been reported to prevent heat from escaping the earth's atmosphere and therefore contribute to increasing temperatures on the planet.[2] If the emission of GHG continues at the current rate, our planet's climate will change, which will have long-term adverse effects on humans and the environment.[3]

Transportation sources constitute a substantial percentage of GHG emissions, but—more significantly—this percentage has been increasing steadily in the past two decades. In 2010, transportation sources contributed approximately 27 percent of the total GHG emissions in the United States. Transportation is the fastest-growing source of U.S. GHG emissions, accounting for 45 percent of the net increase in total U.S. emissions from 1990 to 2010.[4]

The primary greenhouse gases in the Earth's atmosphere are water vapor, carbon dioxide (CO_2), methane, nitrous oxide, and ozone. Since the Industrial Revolution, the burning of fossil fuels has contributed to an exponential and alarming increase of carbon dioxide in the atmosphere, from 280 parts per million (ppm) to 397 ppm.[5]

Background

In 2010, total vehicle registration in the world exceeded 1 billion motor vehicles; this number is expected to reach 2 billion by 2020.[6] Figure 1 shows the trends of vehicle registration in the world from 1970 to 2010, and Figure 2 shows the changing rates of car ownership in the United States. In 2010, global vehicle ownership was 148 vehicles in operation per 1,000 inhabitants; in 2009 this value was only 58 vehicles per 1,000 inhabitants in China but has more than doubled in the previous five years.[6] The automobile is at the center of many unsustainable trends, such as air pollution due to tailpipe emissions, oil dependence, traffic fatalities and injuries, and traffic congestion.

CO_2 emissions per capita vary substantially between nations. World Bank records for CO_2 emissions in metric tons per capita in 2009 include: Brazil 1.9, China 5.8, Egypt 2.7, France 5.6, Germany 9.0, India 1.6, Japan 8.6, Italy 6.7, United Kingdom 7.7, and United States 17.3.[8] The transportation sector contribution to CO_2 emissions varies among nations; for example, it contributes 30 percent of CO_2 emissions in the United States but only 20 percent in Germany.[9] In Sweden, fuel consumption has been steadily decreasing in the past decade; this decline was mainly attributed to the technological and market change as well as the shift toward diesel and flex-fuel ethanol vehicles. This shift, in turn, led to a 13 percent decrease in fuel consumption between 2007 and 2010.[10]

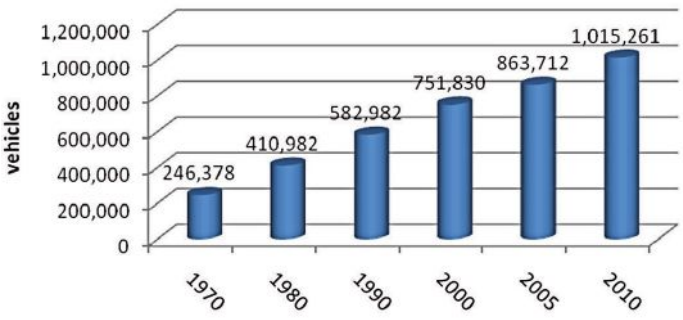

Figure 1. Total World Vehicle Registration[7]

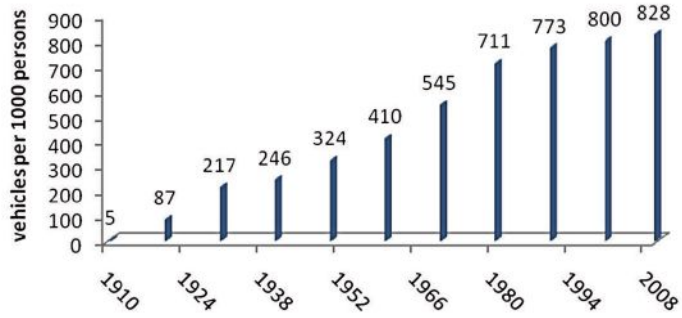

Figure 2. Vehicle Ownership Rates in the USA[7]

The continuous annual increase in the number of registered motor vehicles and operations worldwide significantly contributes to air pollution, particularly GHG emissions. The average annual passenger-car emission rates for various air pollutants are given in Table 1, which shows that the average CO_2 emission is 11,450 pounds per vehicle per year, which adds up to an estimated total global CO_2 emissions of 11,450 billion pounds per year (for 1 billion vehicles).

Table 1. Passenger-car emissions summary[11]

Component	Average emission rate (lb/100 miles)	Average annual pollution emitted (lb)
Hydrocarbons	0.6	77.2
Carbon Monoxide	4.6	575.8
NOx	0.3	38.2
Carbon Dioxide	91.3	11450

Options for Reducing Motor Vehicle Emissions

General

Emission levels are usually reduced by using high-standard vehicle exhaust systems or/and cleaner fuels (natural gas, biogas, electric, fuel cell, solar, etc.). An alternative-fuel vehicle is one that runs on a fuel other than "traditional" petroleum fuels or on any technology powering an engine that does not involve solely petroleum. A combination of factors, including environmental concerns and high oil prices, accelerated the development of cleaner alternative fuels. This movement has become a high priority for many governments and vehicle manufacturers worldwide.

Solar- and fuel-cell-powered vehicles have virtually no pollution emissions; however, they are very impractical for substantial trips, and solar energy is only obtained during daytime and under mostly clear skies. A fuel-cell vehicle or fuel-cell-electric vehicle is a type of hydrogen vehicle, which uses a fuel cell to produce electricity to power the motor. Electric vehicles—particularly trams, trolley buses, light rail, and rapid rail—have minimal pollution emissions in their locations of usage, but if the method of electric generation is through coal or petroleum fuel, then they too could significantly contribute to GHG and global warming. Electric cars and those that run on natural gas and biofuel are currently in commercial use, but there are limitations on distance between refuelings and some alternative fuels are still less economical than petroleum fuel. Hybrid cars are also becoming a viable option, but the initial investment cost for the vehicle remains higher than that of regular petroleum vehicles. Despite the current limitations of these technologies, all have potential. Their main disadvantage is that they are not economical compared with traditional petroleum-fuel vehicles in terms of purchase and running costs; however, due to the increase in petroleum prices and continuous advancement in new technologies, the potential for economic feasibility for the various alternative fuel options is becoming more realistic, and government policies that offer incentives for cleaner-fuel vehicles help them to become more competitive in the marketplace.

Bio-alcohol/Ethanol

Both ethanol and methanol have been used as automotive fuels. Methanol is the simplest alcohol and, when produced from wood, is considered as renewable energy. Due to its high octane ratio, methanol is mostly known for its use in car races; however, it is toxic and highly corrosive. Therefore, when methanol is used for road vehicles, it is usually limited to about 3 percent.[12] Ethanol has attracted more attention because it is considered a renewable source of energy that is easily obtained from sugar or starch in crops. Support for ethanol comes from the fact that it is a biomass fuel, which addresses climate change and GHG emissions.[13] However, it should be noted that producing biofuels from food crops is detrimental to biodiversity and worldwide production of the essential crops that meet the basic needs of poor nations. Biofuel production from food crops is expected to increase 170 percent by 2020.[14]

The U.S. Environmental Protection Agency (EPA) tests for all 2006 E85 (a blend of 85 percent ethanol and 15 percent gasoline) models found that the average fuel economy for E85 vehicles was 25.56 percent lower than unleaded gasoline.[15] E85 flex-fuel vehicles (FFV) run on a blend of 15 percent gasoline, with 85 percent

anhydrous ethanol. In August 2008, the United States average spread between the price of E85 and gasoline was 16.9 percent in favor of E85.[15] However, when the price advantage of an E85 FFV is compared with its lower fuel consumption (miles/gallon), such vehicles are less economical than traditional gasoline vehicles. The significant breakthrough is that cleaner-fuel vehicles are becoming competitive with traditional petroleum-fuel vehicles: about 3 percent of vehicles in the United States are FFV. Sweden has taken a leading role in ethanol flex-fuel usage; in 2008, 25 percent of all new cars sold in Sweden were FFV.[16] Because FFV are reaching economical competition and becoming more prevalent on roadways, research in this area is expected to accelerate in the coming years.

Carbon Tax

In contrast to the current practice in North America, which applies taxes to fuel and uses the revenue to finance highways and public transportation–related services, carbon taxes refer to fuel consumption's environmental costs[17] and are based on the carbon content of fossil fuels; in other words, carbon taxes tax CO_2 emissions. Therefore, carbon taxes indirectly encourage GHG reduction and energy conservation. In addition, if the revenues from carbon taxes are returned to residents and businesses, then the carbon tax will not significantly increase government income. Thus, carbon tax would be considered to be revenue neutral—or a so-called "tax shift"—which is usually employed to help governments achieve strategic policy objectives.[17] Because a carbon tax encourages consumers to apply various energy conservation strategies to minimize the cost associated with carbon tax, it can actually be more effective than strategies that mainly promote one solution, such as the development of fuel-efficient vehicles or vehicles that use alternative fuels.[18] It should be noted that increasing vehicle fuel efficiency without increasing fuel prices can increase vehicle travel distances, which consequently increases such traffic-related problems as congestion. On the other hand, carbon taxes result in an increase of vehicle fuel economy and a decrease in travel distances,[18] both of which result in lower overall vehicle emissions.

Environmental Protection Methods for Road Construction and Maintenance

The United States spends approximately $100 billion on roadway construction per year. This level of activity suggests significant implications for GHG emissions from construction activities. Energy usage per lane mile of pavement construction typically ranges from 3 to 7 terajoules (TJ), which is the equivalent of the yearly energy consumption of 41 U.S. households.[19]

Concerns about GHG emissions from road construction continue to grow, particularly because more than 94 percent of U.S. highways are paved with asphalt concrete. To address environmental concerns, a new group of technologies has been developed to produce asphalt pavement. Notable among such technologies is warm mix asphalt (WMA), which allows producers to lower the temperatures—by up to 50 to 100 degrees Fahrenheit—at which the material is mixed and placed on the road.[20] Reducing production temperature results in reduced fuel consumption and GHG emissions, and improves job-site conditions for workers.

In an attempt to reduce the carbon footprint of pavements, departments of transportation (DOTs) are allowing high percentages of reclaimed asphalt pavement (RAP) and recycled asphalt shingles (RAS) to be used in pavement construction.[21] RAP is the term given to removed and reprocessed pavement materials that contain asphalt and aggregates. RAS refers to manufacturers' shingle scraps or tear-offs from roofs. In the United States, about 100 million tons of RAP and 11 million tons of RAS are produced annually.[22] RAP generally contains between 3 to 7 percent asphalt by weight, and RAS are composed of 30 to 35 percent asphalt cement.[22] Therefore, this amount of recycling contains more than 6 million tons of asphalt binder that can be used in paving mixtures to replace virgin binder. It has been shown that using recycled materials instead of conventional virgin materials in highway construction (for example, the Baraboo Bypass, Wisconsin, USA) led to significant reduction in potential global warming.[23] Reductions in CO_2 were mainly due to the reduction of material production. It has been reported that asphalt concrete material production accounts for about 60 to 80 percent of energy usage and 60 to 90 percent of CO_2 emissions during highway construction.[23]

Conclusion

There is no single solution to effectively reduce transportation's contribution to GHG. Stakeholders and policymakers should employ a holistic approach; collective measures should include, using cleaner-fuel vehicles, implementing a carbon tax to encourage industries and consumers to use low-carbon-footprint vehicles, and employing green road technology in pavement construction and maintenance in order to reduce CO_2 emissions and energy consumption. Public awareness of these collective measures is also important, but it is not sufficient; local, national, and international policies and regulations are essential to effectively protect the environment.

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References

1 United Nations, Department of Economic and Social Affairs. *United Nations Report of the World Commission on Environment and Development: Our Common Future*. New York, NY: United Nations, 1987.

2 Karl, T.R. and K.E. Trenberth. "Modern Global Climate Change." *Science*, Vol. 302, No. 5651 (2003): 1719–1723. DOI: 10.1126/science.1090228.

3 McMichael, A.J., D.H. Campbell-Lendrum, C.F. Corvalan, K.L. Ebi, A.K. Githeko, J.D. Scherage, and A. Woodward. *Climate Change and Human Health: Risks and Responses*. Geneva, Switzerland: World Health Organization, 2003.

4 U.S. Environmental Protection Agency (EPA), Office of Transportation and Air Quality. *U.S. Transportation Sector Greenhouse Gas Emissions 1990–2010*. EPA-420-F-12-063 (December 2012).

5 Earth System Research Laboratory. "Trends in Atmospheric Carbon Dioxide." http://www.esrl.noaa.gov/gmd/ccgg/trends.

6 Sousanis, J. "World Vehicle Population Tops 1 Billion Units." *Ward Auto-World*. http://wardsauto.com/ar/world_vehicle_population_110815.

7 Davis, S., S. Diegel, and R. Boundy. *Transportation Energy Data Book: Edition 30*. ORNL-6986. Oak Ridge, TN: Oak Ridge National Laboratory, 2011.

8 World Bank. "CO_2 Emissions in Metric Tons per Capita." http://data.worldbank.org/indicator/EN.ATM.CO2E.PC\.

9 Buehler, R. "Determinants of Automobile Use Comparison of Germany and the United States." *Transportation Research Record* 2139 (2009): 161–171.

10 Sprei, F. and S. Karlsson. "Shifting Fuels, Downsizing or Both? The Swedish example." *Transportation Research Part D*, No. 18 (2013): 62–69.

11 U.S. Environmental Protection Agency (EPA). "Emission Facts: Average Annual Emissions and Fuel Consumption for Passenger Cars and Light Trucks." EPA420-F-00-013, Air and Radiation EPA420-F-00-013, April 2000.

12 European Commission. *Final Report: Impact of the Use of Biofuels on Oil Refining and Fuels Specifications*. 2010.

13 "Ethanol Fuel, Journey to Forever." http://journeytoforever.org/ethanol.html#ethintro.

14 *Annual Review of Ecology, Evolution, and Systematics, Vol. 41 (2010): 351–377. DOI: 10.1146/annurev-ecolsys-102209-144720.*

15 Goettemoeller, J. and A. Goettemoeller. *Sustainable Ethanol: Biofuels, Bio-refineries, Cellulosic Biomass, Flex-Fuel Vehicles, and Sustainable Farming for Energy Independence*. Maryville, MO: Prairie Oak Publishing, 2007.

16 Christiansen, R. "Sweden's Drive for E85." *Ethanol Producer Magazine* (June 2009). http://www.ethanolproducer.com/articles/5737/swedens-drive-for-e85.

17 Litman, T. "Evaluating Carbon Taxes as an Energy Conservation and Emission Reduction Strategy." *Transportation Research Record* 2139 (2009): 125–132.

18 Litman, T. "Efficient Vehicles versus Efficient Transportation: Comparing Transportation Energy Conservation Strategies." *Transport Policy*, Vol. 12, No. 2. (2005): 121–129.

19 Muench, S. "Roadway Construction Sustainability Impacts Review of Life-Cycle Assessments." *Transportation Research Record* 2151 (2010): 36–45.

20 Hurley, C. and B. Prowell. "Evaluation of Potential Processes for Use in Warm Mix Asphalt." *Journal of the Association of Asphalt Paving Technologists*, Vol. 75 (2006): 41–90.

21 Copeland, A., J. D'Angelo, R. Dongre, S. Ramaiah, and G. Sholar. "Field Evaluation of a High Reclaimed Asphalt Pavement/Warm Mix Asphalt Project in Florida, 10-3792." 89th Transportation Research Board Annual Meeting, January 10–14, 2010.

22 Sengoz, B. and A. Topal. "Use of Asphalt Roofing Shingle Waste in HMA." *Journal of Construction and Building Materials*, Vol.19, No. 5 (2005): 337–346.

23 Lee, J., T. Edil, C. Benson, and J. Tinjum. "Evaluation of Variables Affecting Sustainable Highway Design with BE2ST-in-Highways System." *Transportation Research Record* 2233 (2011): 178–186.

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