CONF-9708105--1

ENERGY AND ENVIRONMENTAL CONSEQUENCES OF TRANSPORTATION: INDICATORS OF SUSTAINABILITY

David L. Greene
Center for Transportation Analysis
Oak Ridge National Laboratory

July 1997

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
managed by
LOCKHEED MARTIN ENERGY RESEARCH CORP.
for the
U. S. DEPARTMENT OF ENERGY
under contract DE-AC05-96OR22464

ENERGY AND ENVIRONMENTAL CONSEQUENCES OF TRANSPORTATION: INDICATORS OF SUSTAINABILITY

by

Dr. David L. Greene
Oak Ridge National Laboratory, P. O. Box 2008,
Bldg. 3156, MS-6073, Oak Ridge, Tennessee, U.S.A.

1. INTRODUCTION

The rapid motorization of world transportation systems puts growing emphasis on controlling transportation's direct and indirect impacts on the global environment, in other words, on achieving sustainability in transport. In 1950, the world contained 70 million motor vehicles, of which 70% were in the United States. Today the world's motor vehicle fleet exceeds 600 million, of which less than one-third are in the U.S. Outside of the U.S., motor vehicle stocks are growing twice as fast (Davis & McFarlin, 1996, tables 1.1 & 1.2). With this explosive growth of motorized transport comes a compelling need to control its concomitant pollution, greenhouse gas emissions, and fossil fuel consumption. Large-scale indicators of transportation's performance with respect to sustainability are therefore becoming increasingly important for monitoring trends and evaluating the effectiveness of policies at national and international scales.

A recent survey by the Bureau of Transportation Statistics (U.S. DOT/BTS, 1996) of data on transportation's environmental consequences in the U.S., found that reasonable indicators exist for energy use and for certain of transportation's environmental impacts. Statistics on air pollutant emissions, greenhouse gas emissions, and energy use are adequate for developing rigorous indicators of at least emissions and energy use. Much less is known about noise generation, water and groundwater pollution, solid waste, land-use and habitat impacts.

2. SUSTAINABILITY AND TECHNOLOGICAL CHANGE

Measuring transportation's performance with respect to sustainability requires a working definition of the term. Though there remains substantial argument over the precise definition of sustainability, it is nonetheless one of the most important concepts to arise this century. The World Commission on Environment and Development has produced the most widely cited definition.

> "...sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs." (WCED, 1987)

Daly (1991) has defined sustainable development by three basic conditions: (1) rates of use of renewable resources do not exceed their rates of regeneration, (2) rates of use of non-renewable resources do not exceed the rate at which sustainable renewable substitutes are developed, and (3) rates of pollution emission do not exceed the assimilative capacity of the environment. Perhaps the most interesting feature of Daly's definition is its emphasis on rates. Pearce and Warford (1996) have introduced the critical role of technology in the sustainabilty issue, by noting that the "environmental coefficient" linking economic activity to its environmental impact can be reduced dramatically by technological change.

There are therefore three fundamental elements to the sustainability equation. First, the level of output, or activity; second, the "environmental coefficient" translating the level of output into emissions; third the resulting environmental damage (or environmental quality). Clearly, the third is the most difficult for which to develop indicators, since the impacts of transportation's emissions or resource consumption depend on other factors, among which are the emissions of other economic sectors.

Daly's definition also reminds us that sustainability is not only a question of environmental impacts, but of the consumption of exhaustible resources, as well. Once again, technology enters the equation, since not only the substitutability of renewable alternative resources but the productivity of exhaustible resources and their extent depend on technology. Noting that the WCED's definition of sustainability only requires that the resources available to future generations not be *decreased*, one can see that if technology can expand the scope of resources (through, e.g., enhanced oil recovery) and improve their productivity (e.g., by increasing energy efficiency) at sufficient rates, then sustainability can be achieved even without necessarily switching to renewable substitutes. Viewed in this way, the problem of sustainability becomes one of insuring the appropriate rate and direction of technological change so that neither environmental resources, nor renewable resources, nor exhaustible resources are diminished. Of course, even this definition of sustainability is not full satisfactory since it overlooks human and capital stocks and completely ignores questions of social justice.

3. MEANINGFUL INDICATORS OF SUSTAINABILITY

The U.S. Environmental Protection Agency (U.S. EPA, 1996) divides environmental indicators into four categories:

Root cause indicators - describing underlying factors influencing activity levels;
Activity indicators - describing the quantity and type of transportation occurring;
Output indicators - quantifying the amount of pollution (or resource use); and
Outcome indicators - measuring the health, ecological, and economic impacts.

Relationships between root causes and activity levels, and between outputs and outcomes are generally highly complex and are not easily given simple mathematical representations, even at a gross scale. In addition, data on outcomes are scarce and rarely comprehensive. Therefore, we focus initially on indicators of the level of transport activity and emissions because these can provide valuable insights on the "environmental coefficient" that links economic output to environmental damage. The structure of the resulting sustainability equation,

$$DAMAGE = (ACTIVITY) \times (EMISSION\ RATE) \times (DAMAGE\ RATE) \quad (1)$$

suggests a very simple mathematical formulation. Activity levels at time t (A_t) may be divided into types, i, and multiplied by respective emissions rates (e) and damage rates (d), then summed over all activity types to obtain total damage, D. This simple formulation allows one to focus on the rates, or environmental coefficients, as distinct from the level of activity, or economic output.

$$D_t = \sum_{i=1}^{N} A_{it} \cdot e_{it} \cdot d_{it} \quad (2)$$

Any time-varying quantity with the structure of D_t may be precisely mathematically analyzed into its component parts by means of the Divisia method (see, e.g., Greene and Fan, 1994, appendix

A). Thus, changes in D_t over time can be precisely attributed to changes in, (1) levels of activity, (2) the distribution of activity across types, (3) changes in emissions rates, and (4) changes in damage rates, both from year-to-year and cumulatively.

Of course, equation (1) is too simplistic to tell the whole story. Knowing the quantity of damage from air pollution or the quantity of petroleum resources consumed does not reveal whether those levels of damage are sustainable. Nonetheless, it does inform about whether things are getting better or worse and, to some extent, why. It also focusses attention on the critical technological question identified by Pearce and Warford (1996): Is technological change reducing the environmental coefficient fast enough to outpace development?

4. TRANSPORTATION'S ENVIRONMENTAL AND ENERGY CONSEQUENCES

Modern transportation systems produce a variety of significant environmental impacts that threaten their sustainability. The most significant are:

Urban, Regional, and Global Air Pollution
Surface Water and Groundwater Pollution
Land-Use and Habitat Impacts
Solid Waste from Vehicles and Infrastructure
Noise Pollution
Energy Resource Consumption
Greenhouse Gas Emissions promoting Global Climate Change

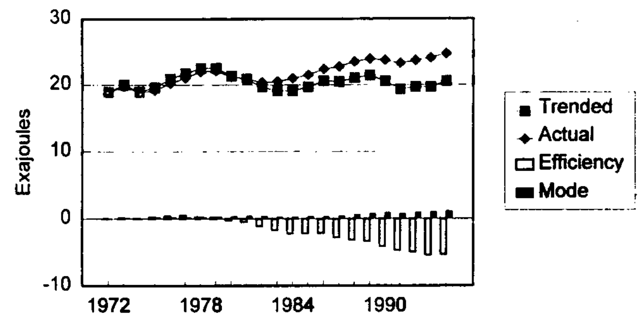
It is not possible to treat each in this brief note, but several recent studies have quantified the full costs of all these components (e.g., ECMT, 1994; Delucchi, 1997), and the 1996 *Transportation Statistics Annual Report* comprehensively reviews available information on the environmental impacts of the U.S. transportation system. In general, estimates of damage rates per unit of emission are scarce and, when available, tend to be controversial. For the U.S., data on water pollution, land use and habitat impacts, and noise pollution are generally not available at a national scale. The importance of these environmental impacts is well documented, but considerable work remains to be done to develop adequate statistical series.

The Divisia method has been applied to trends in air pollutant and greenhouse gas emissions, as well as energy use, decomposing them into changes due to: (1) the growth of activity, (2) the rate of emissions per unit of activity, and (3) the distribution of activity among various categories. Results of the Divisia analysis for transportation energy use, emissions of hydrocarbons, carbon monoxide, and oxides of nitrogen for the period 1970-1995 show that despite a doubling of transportation activity, the U.S. has been able to hold NO_X emissions from transportation nearly constant, and reduce HC and CO emissions, but that energy use and carbon dioxide emissions have continued to increase. In the figures below, the curves labeled "trended" assume no change in the "environmental coefficient" or in the distribution of activity across modes. The difference between the actual emissions and the trended curve is divided into that due to changes in rates versus changes in the modal distribution of activity, shown by paired bars that sum to the distance between the two curves. Clearly the effect of technological change, as reflected in rates, predominates. Had there been no changes in environmental coefficients, the doubling of U.S. transportation activity from 1970 to 1995 would have resulted in 4-5 times as much HC emissions, three times the CO pollution and twice as much NO_X. The U.S. transportation system would be consuming 20% more energy and consequently generating 20% more CO_2 emissions.

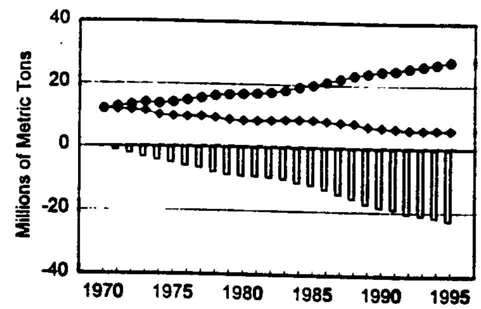
SUMMARY

Monitoring the progress of transportation in achieving sustainability will be a complex undertaking requiring accurate and meaningful measures of all four types of indicators. At present, significant areas of transportation's environmental effects are not well understood, and measures of environmental damage are incomplete and controversial. Where reasonable measures of emissions are available, there is sufficient activity data to use Divisia analysis to measure progress in reducing the environmental coefficients of transportation and determine whether technological progress is keeping pace with growth.

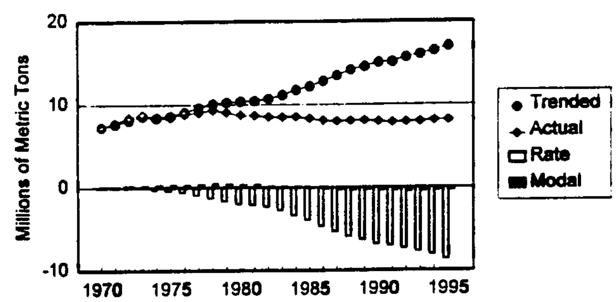
Transportation Energy Use and CO2 Emissions in the United States: 1972-1994



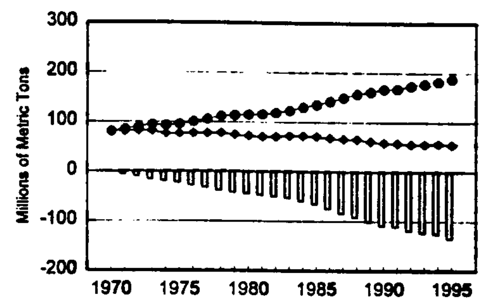
HC Emissions from Transportation in the United States: 1970-1995



NOx Emissions from Transportation in the United States: 1970-1995



CO Emissions from Transportation in the United States: 1970-1995



BIBLIOGRAPHY

Daly, H.E. (1991). *Steady State Economics*, Island Press, Washington, DC.

Davis, S.C. and D.N. McFarlin. (1996). *Transportation Energy Data Book: Edition 16*, ORNL-6898, Oak Ridge National Laboratory, Oak Ridge, Tennessee, July.

Delucchi, M.A. (1997). "The Annualized Social Cost of Motor-Vehicle Use in the United States, based on 1990-1991 Data," a series of 20 reports, UCD-ITS-RR-96-3 (1 to 20), Institute of Transportation Studies, University of California, Davis.

European Conference of Ministers of Transport (ECMT). (1994). *Internalizing the Social Costs of Transport*, Organisation for Economic Cooperation and Development, Paris.

Greene, D.L. and Y. Fan. (1994). *Transportation Energy Efficiency Trends, 1972-1992*, ORNL-6828, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Pearce, D.W. and J.J. Warford. (1996). *World Without End*, published for the International Bank for Reconstruction by Oxford University Press, Oxford.

U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation. (1996). *Indicators of the Environmental Impacts of Transportation*, Final Report, Washington, DC, June.

U.S. Department of Transportation, Bureau of Transportation Statistics. (1996). *Transportation Statistics Annual Report 1996*, Part II: Transportation and the Environment, Washington, DC.

World Commission on Environment and Development. (1987). *Our Common Future*. Brundtland Report, Oxford University Press, Oxford.

(18) DOE, XF
(19) UC-900, DOE

DOE