Environmental Life-cycle Assessment of Infrastructure Systems

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Infrastructure costs a modern society a substantial fraction of its national product, but we cannot function without it, thus the benefits are large, too, perhaps unquantifiably large. Infrastructure is everywhere, and we tend to notice it only when something goes wrong, when the tap goes dry, when a bridge collapses, when phone lines go silent. Few of us stop every day to marvel what infrastructure makes possible. In fact, I am not even sure we have the right concept of infrastructure. To most people, the word includes only the transportation infrastructure and the utilities, when it should mean more, at least the telecommunications system and the internet, but perhaps also the energy economy and the health care system.

Society has traditionally worried about the technical, economic, safety and quality performance of infrastructure. Lately we have started to become interested in the environmental performance as well. Because infrastructure is everywhere, the environmental burdens are correspondingly large. Just how large depends on where one draws the boundaries around the infrastructure. We worry about greenhouse gas emissions, toxic discharges, water use and pollution, waste generation, human and ecological health impacts, and many other impacts. It should always be kept in mind that infrastructure is expensive, but the benefits are enormous, too.

ENVIRONMENTAL MODELING OF INFRASTRUCTURE

In one word: difficult. Many decision-makers have heard about environmental life-cycle assessment (LCA) by now. It is an approach that has the potential to be very useful for infrastructure assessment. By design, it has to quantify all the resource inputs and environmental outputs of a product, process or service not just at the point of manufacturing or generation, but through the entire underlying supply chain. Unfortunately, few of us practice LCA. Rarely has it been applied yet that we know of.

LCA was conceptualized to change practices throughout the entire economy, to protect human and ecological health, to preseve resources, and to allow for sustainable development without regretful decisions. We need to start applying LCA to infrastructure decisions. Not only should the billions of dollars be invested more effictively into infrastructure, they should be invested to enhance environmental quality. While this makes sense and there is general consensus among all societal stakeholders that this should be done, essential questions remain to be answered by LCA and other forms of environmentally informed decision making. Here are some significant questions that we do not have definitive answers for:

Should roadways be built to follow natural topography or utilize cuts, fills and tunnels?
Does centralized or decentralized waste water treatment have a lower energy need?
Is high-speed rail more environmentally efficient than flying or driving?
Should we build concrete or steel bridge designs?
What are the life-cycle environmental emissions of the U.S. telecommunications system?
Should we build water reservoirs on a hill or on flatland?
Is solar electricity more environmentally friendly than wind electricity?

These are just some of the infrastructure decisions we ponder every day. The environmental implications of answering the above questions correctly are profound. Yet for many of these types of questions we do not even know the sign of the results, e.g., that one alternative is more environmentally friendly than another, let alone have robust answers about the absolute numbers, or differences between choices. We are many years away from knowing the answers with certainty.

In all modeling, abstraction of reality is necessary in order to make the problem understandable, solvable and manageable Environmental modeling of infrastructure starts with modeling the complex systems that are behind transportation, energy, water, waste water, municipal and industrial waste management, telecommunications, and other services. Modeling of infrastructure is doubly difficult as most are networks that have substantial geographical and temporal dimensions. For example, the electric power sytems in the United States is more than 100 years old and reaches every corner of this vast country. While most of these systems are within the geographical boundaries of a country, they connect with international systems and have supply chains that span the globe. For example, the civilian air transportation system of the United States is closely connected to international civil aviation. Most of the aircraft owned by U.S. airlines were assembled here, but many critical components were sourced from other countries. Mapping these supply chains is difficult.

Many products and processes, therefore many economic sectors are involved with the life cycle (planning and design, construction, operation, maintenance, end of life) of infrastructure systems. Analyzing the thousands of products is difficult enough, but assessing services is even more so because descriptions, process models and data are scarce. The technologies employed are far from uniform across the United States, let alone internationally. There are variations in all life-cycle phases, and modeling them all is a daunting task.

LIFE-CYCLE ASSESSMENT OF PASSENGER TRANSPORTATION MODES

The following example illustrates the complexities and current challenges of environmental assessment, especially LCA. In a recent paper (Chester and Horvath, 2009), we explored the total energy, greenhouse gas (GHG), SO_2, NO_x, and CO burden of several passenger transportation modes, some specific to the San Francisco Bay Area: sedan, SUV, pickup truck, city bus, the Bay Area Rapid Transit (BART) (considered a subway), commuter rail (Caltrain), light rail (MUNI), and for comparison, small, midsize and large aircraft, as well as the Boston Green Line light rail, the oldest line of the Boston subway, and the most heavily traveled light-rail line in the United States. The results are presented in Figure 1.

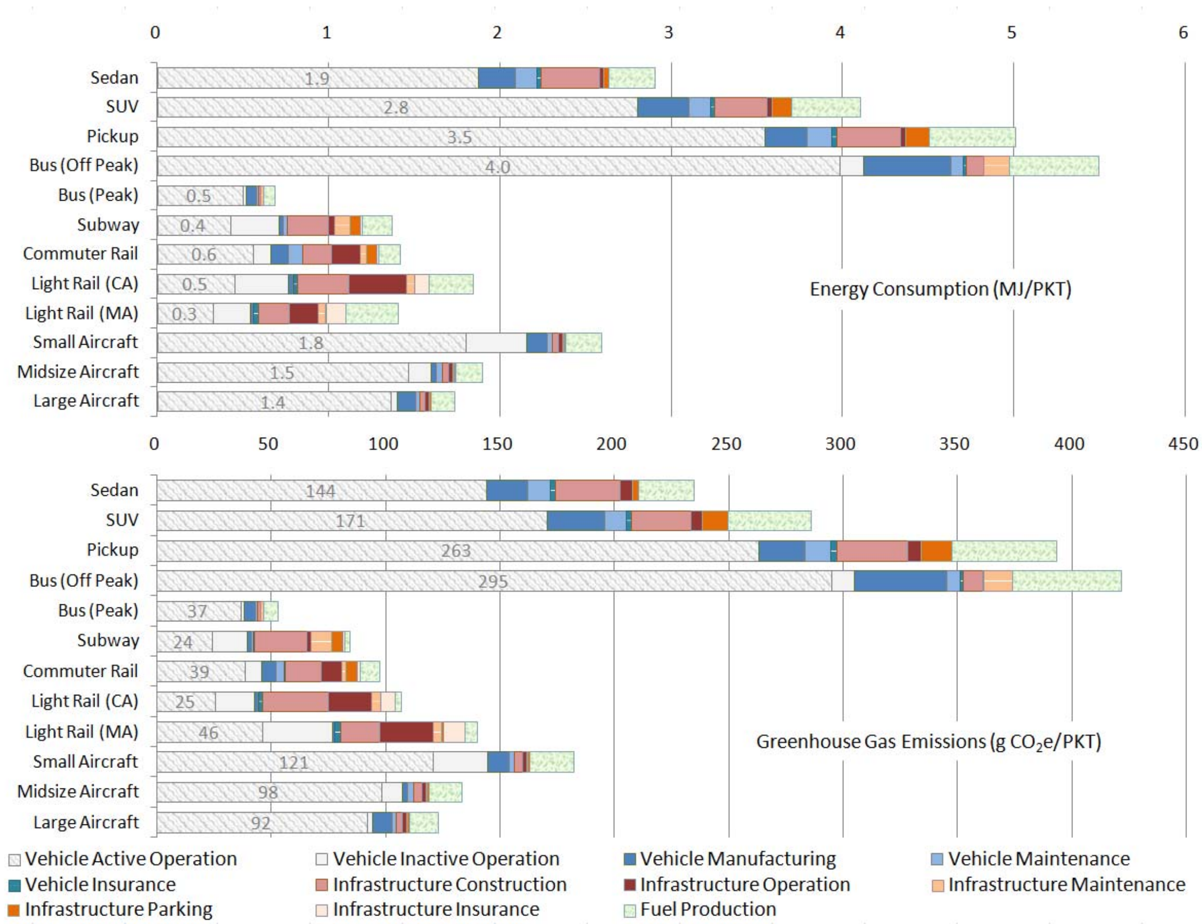

Figure 1. Energy use and greenhouse gas emissions per PKT for various passenger transportation modes. Source: (Chester and Horvath, 2009). Permission needs to be obtained to reprint.

This analysis looked at not just the tailpipe emissions, which is a typical measure of vehicles' emissions, but also included the provision of vehicles, the transportation infrastructure, and fuels, i.e., all the life-cycle phases of vehicles, the physical infrastructure that makes travel possible (roads, rails, stations, airports, etc.), as well as the stages prior to the combustion of fuels or generation of electricity.

Altogether 79 components associated with these transportation modes have been analyzed (representing about 200 different calculations), representing a great variety of technologies, products, processes and services in the Bay Area, California, and Boston, as well as nationwide and worldwide, wherever the supply chains behind these components reach. As well, it was challenging to assess the environmental performance of these systems because the data were not just numerous to collect, but spanned many decades, and were generally difficult to obtain. For example, components of many of these systems were built decades ago, and some are shared with freight transportation modes.

As the analysis highlighted, the contribution of the physical infrastructure and the fuel provision is significant. For example, these components add 63% to onroad, 155% to rail, and 31% to air transport's total burden over the tailpipe greenhouse gas emissions, as expressed by passenger kilometers. Usage rates of these transportation modes also make a big difference in their total environmental burden.

CONCLUSIONS

Environmental assessment of infrastructure has appeared in the scientific literature decades ago. LCA studies are more recent, started about 15 years ago. In order to answer even the most burning infrastructure questions, we will need many more studies, especially adopted by practitioners.

ACKNOWLEDGMENTS

This material is based upon research supported by the UC Berkeley center for Future Urban Transport.

REFERENCE

Chester, M.V., and A. Horvath. 2009. Environmental assessment of passenger transportation should include infrastructure and supply chains. Environmental Research Letters 4: 024008 (8pp), doi: 10.1088/1748-9326/4/2/024008.