Transportation Research Part A 46 (2012) 588–601

Contents lists available at SciVerse ScienceDirect

Transportation Research Part A

journal homepage: www.elsevier.com/locate/tra

Assessing the energy and greenhouse gas emissions mitigation effectiveness of potential US modal freight policies

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ARTICLE INFO

Article history:
Received 29 April 2011
Received in revised form 14 November 2011
Accepted 29 November 2011

Keywords:
Freight movement policy
Energy and emissions
Modal choice
Supply chain
Input–output analysis

ABSTRACT

This paper estimates the total embodied energy and emissions modal freight requirements across the supply chain for each of over 400 sectors using Bureau of Transportation Statistics Commodity Flow Survey data and Bureau of Economic Analysis economic input–output tables for 2002. Across all sectors, direct domestic truck and rail transportation are similar in magnitude for embodied freight transportation of goods and services in terms of ton-km. However, the sectors differ significantly in energy consumption, greenhouse gas emissions, and costs per ton-km. Recent pressure to reduce energy consumption and emissions has motivated a search for more efficient freight mode choices. One solution would be to shift freight transportation away from modes that require more energy and emit more (e.g., truck) to modes that consume and emit less (e.g., rail and water).

Our results show there are no individual sectors for which targeting changes would significantly decrease the total freight transportation energy and emissions, therefore we have also looked at the prospect of policies encouraging many sectors to shift modes. There are four scenarios analyzed: (1) shifting all truck to rail, shifting top 20% sector mode choice, (2) based on their emissions, (3) based on a multi-attribute analysis, and (4) increasing truck efficiency (e.g., mpg). Increasing truck efficiency by 10% results in similar energy and emissions reductions (approximately 7% for energy and 6% for emissions) as targeting the top 20% of sectors when selected based on emissions, whereas selecting the top 20% based on availability to shift from truck results in slightly less reductions of energy and emissions. Implementing policies to encourage higher efficiency in freight trucks may be a sufficient short term goal while efforts to reduce truck freight transportation through sectoral policies are implemented in the long term.

1. Introduction

The transportation sector, including freight and passenger movement, is responsible for a large portion of US annual energy and emissions; approximately 30% of US energy and 33% of US carbon dioxide (CO_2) emissions. With energy consumption and emissions becoming a national issue, knowing the embodied freight transportation for each product is useful for considering how to reduce energy and emissions (Smith et al., 2005). Transportation also represents billions of dollars per year in investment by local, state, and federal agencies (CBO, 2007). Freight transportation, a portion of total US transportation energy and emissions (approximately 30%), is embodied in the supply chain of all goods and services (EIA, 1999; FHWA, 2005). For example, when manufacturing an automobile, glass is shipped to the windshield manufacturer, windshields are shipped to the automobile manufacturer, and the final product of the vehicle is shipped to the sales lots. The freight transportation with different segment lengths, volumes, weights, and modes is embodied in the final vehicle product.

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0965-8564/$ - see front matter
doi:10.1016/j.tra.2011.11.010

The ton-km of each transportation segment is summed and defined as the embodied freight transportation. In work by Nealer et al. (2011), the embodied transportation in ton-km was modeled for 2002. In this paper we builds on the embodied transportation results, and add the energy and emissions associated with the freight transportation embodied in final goods and services for 2002. Although there is significant international freight transportation as well, in this work we focus on domestic mitigation options and policies, therefore international modes were excluded.

The tradeoffs between various performance metrics, such as time, cost, energy, and emissions are important. With concerns growing about the sustainability and the external costs embodied in transportation, one potential option is to use efficient modes of transportation (e.g., rail and water) more often than the less efficient modes (e.g., truck and air) (Forkenbrock, 1999; Corbett and Winebrake, 2007; Tsamboulas et al., 2007). Few mode choice decisions are made based on reducing energy and emissions only, but cost and time are cited as two of the most important factors (Cullinane, 2005). In this paper we measure energy use, greenhouse gas (GHG) emissions, and cost associated with embodied freight transportation for 428 sectors of the 2002 US economy. The data are old, however, we assume the average transportation requirements do not change much over time for time. We use each of these metrics to validate the model, and we analyze energy and emissions through various reduction scenarios. The scenarios we chose to analyze reflect a range of effects and we determine the feasibility of shifting mode preference away from truck freight transportation. Although time cannot be calculated at a national level, it is an important issue that we qualitatively discuss.

Other studies suggest shifting away from truck can reduce energy and emissions and various states are taking action by enacting policies to reduce truck transportation (Ecola et al., 2009). The American Association of State Highway and Transportation Officials estimates if 10% of intercity freight transported by truck were shifted to rail it would save 2.5 million tons of CO_2 per year (AASHTO, 2003). However, this reduction is less than 1% of the total US CO_2 emissions per year and the study lacks identification of specific sectors and their ability to shift (AASHTO, 2003). These studies also cite various uncertainties, such as current infrastructure capacity constraints, time-sensitive products, and significant monetary investments. Specific state governments are also interested in reducing their highway transportation, such as, Connecticut's investments in rail and water service and increasing weight limits on the roads to encourage more tons per kilometer of travel (Lyons et al., 2003). Oregon and Vermont are also investing in air, rail, and water infrastructure (VTrans, 2008; Oregon DT, 2008). We identify specific sectors capable of changing their mode choices, and the supply chain effect those choices have on the entire transportation industry. Also, we assess the total (direct and supply chain) energy and emissions of mode shift policies.

Similar to past work by Weber et al. (2008) that estimated energy and emissions embodied in the manufacturing and transportation of products and services, we use input–output analysis (IOA) to estimate "total embodied ton-km" for domestic freight modes across the supply chain of product. The IOA model previously developed estimates direct and indirect freight transportation for individual economic sectors, and is further disaggregated into which modes of transportation are required for each sector's final products (Nealer et al., 2011). We define direct transportation as the final delivery of the purchased good to a final consumer. Indirect transportation we define as the transportation required in the upstream supply chain. Lastly, total, or embodied, transportation is the amount of transportation required to produce a final product or service, and is the sum of direct and indirect transportation for a single product or service. The total transportation we calculate includes both line haul and intercity transportation. The energy, emissions, and cost associated with direct, indirect, or embodied freight transportation can be calculated using energy, emissions, and cost per ton-km factors. Further modeling history can be found in Section 2.1.

In this paper we analyze sector specific mode choice shifts, and examine whether large-scale reductions can be achieved. There are four scenarios we analyze: (1) shifting all truck transportation to rail, determining the top 20% sector's mode choices and shifting truck transportation, (2) based on their emissions, (3) based on a multi-attribute analysis, and (4) independent of mode choice shifts increasing truck efficiency. We first discuss the IOA model results and the current energy use and emissions to deliver products based on total embodied transportation in ton-km previously estimated by Nealer et al. (2011). Then we quantify and validate the expected supply chain results of the scenarios above in terms of energy and emissions for each sector and uncertainties associated with the model as well as the energy and emissions factors. Uncertainties include rail and water capacity to assume more transportation, variation in energy and emissions factors, and data imperfections.

2. Methodology

2.1. Model development

Previous work that quantifies the direct transportation and the energy and emissions associated with transportation (Chapman, 2007; Corbett and Winebrake, 2007; Vanek and Morlok, 1998), but few studies quantify the total transportation embodied in products and services (Facanha and Horvath, 2006). It is valuable to calculate the direct implications of each sector's mode choices, but misses the indirect transportation of a product which is often a large contributor to total transportation. In order to estimate the total effects of the transportation sector it is important to understand the interactions of the US economy and how transportation is utilized (Leontief and Strout, 1963; Matthews et al., 2001; Williams and Tagami, 2003; Wilson, 1970). We estimate the total impacts using two different methods: input–output analysis (IOA), an economic framework for modeling sectoral interactions, and life-cycle assessment (LCA), an engineering framework for estimating the