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Emissions allocation in transportation routes

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ABSTRACT

This article studies the allocation of CO_2 emissions to a specific shipment in routing transportation. The authors show that this problem differs from a cost allocation problem specifically because the concavity condition does not hold necessarily in the CO_2 allocation problem. This implies that a traditional cost allocation method cannot be straightforwardly translated into a CO_2 allocation problem, and thus, new methods need to be developed. This study proposes four allocation mechanisms that are extensions from the literature and the common practice in industries. In doing so, the authors introduce the concept of carbon efficiency to assess if a particular allocation rule drives companies to carbon emissions reduction. They present analytical properties that show that the current practice of allocating CO_2 emissions based on the greenhouse gas protocol, fails to be sensitive to drive companies to the sustainable practice of placing consolidated orders. The authors also conduct an experimental analysis using data of a logistics service provider that operates in Europe. Using the results of the experiments, they show that simple allocation methods can lead to a fair and carbon efficient allocation. In addition, the study provides insights by conducting a sensitivity analysis, and it shows that the CO_2 allocations are not substantially susceptible to shipment size estimation errors.

1. Introduction

Transportation is one of the main contributors of carbon dioxide (CO_2) (Intergovernmental Panel on Climate Change, 2007), and predictions indicate increases in the next 20 years (European Commission, 2011). Road transportation accounts for a large share of freight transport emissions. In the European Union (EU), for instance, road transport accounts for more than 65% of EU transport-related greenhouse gases (GHG) and over 20% of the EU's total emissions of CO_2 (EU Transport GHG, 2007). In the United States, road transport accounts for approximately 30% of GHG and it is the fastest-growing major source of CO_2 emissions (Environmental Protection Agency, 2011). These figures drive a significant amount of companies, including Logistics Service Providers (LSPs), to implement sustainable practices into their business models. For example, the Carbon Disclosure Project (2011), a not-for-profit foundation, reported that large LSPs in the US and Europe (e.g. FedEx, UPS, Kuehne Nagel, TNT, etc.) have disclosed their CO_2 emissions and publicly committed to a self-imposed reduction target.

As a first step toward emissions reductions, companies require to estimate actual emissions. The most common approach to estimate emissions is the Greenhouse Gas Protocol (GHG, 2011). The protocol distinguishes emissions in three scopes. Scope 1 includes all emissions by assets owned by the reporting company. Scope 2 refers to the indirect emissions caused by the production of electricity that these assets consume. Finally, Scope 3 includes other indirect emissions not covered in Scope 1 and 2, such as transport-related activities in vehicles not owned or controlled by the reporting entity.

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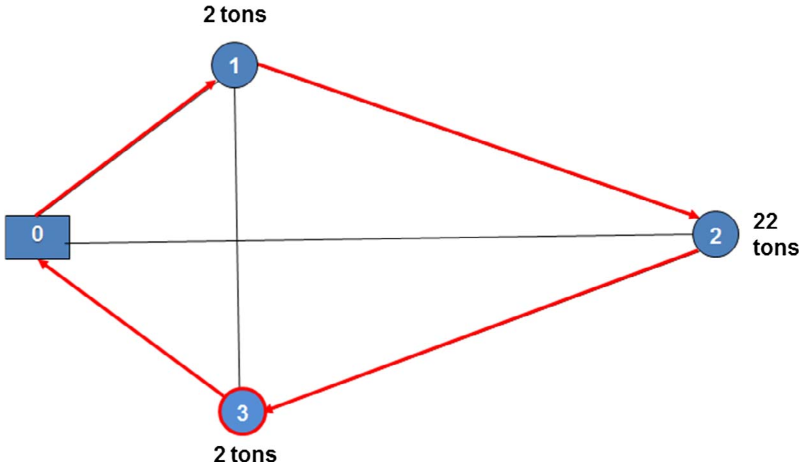

Fig. 1. Example of a transportation route.

While emissions estimations can be certainly calculated, a key challenge is to properly assign the emissions to the right entity. This problem is common in transportation. For example, consider a LSP that serves three customers in a single route in a single vehicle. The vehicle carries 26 tons of demand when it leaves the depot, and after delivering to three customers with demand (tons) 2, 22 and 2, respectively, then the vehicle goes back to the depot. Fig. 1 shows the transportation route 0-1-2-3-0.

For this example, the LSP faces the task of allocating the transportation CO_2 emissions to each customer it serves. Consider the emissions allocation for customer 3. What is the amount of emissions that customer 3 is responsible for? Should the LSP consider the traveled distance before delivering to customer 3 (i.e. 0-1-2-3) or just the distance from the depot (i.e. 0-3). Should the LSP consider the entire load carried before delivering to customer 3 (i.e. 26 tons) or just customer three's demand (i.e. 2 tons). These differences in distance-demand drive to different estimations in CO_2 emissions, and thus, different allocations.

In order to correctly assign the CO_2 emissions to each company/customer, LSPs require implementing mechanisms to allocate those emissions in a fair way. This allocation may play an important role by helping companies to study the impact of their logistics decisions (order frequency, lot size, etc.) and in correctly account for the proper amount of CO_2 emissions into their GHG inventory report. In addition, any carbon emissions allocation rule should ideally be fair, rational (understandable) and drive companies to achieve CO_2 emissions reductions in their logistics operations.

The allocation of CO_2 emissions to customers' shipments is far from trivial. First, we need to determine the amount of CO_2 emitted on each trip, which proves to be a time-consuming task when trip-level fuel consumption data is unavailable. Second, because different stakeholders might have different interests, the applied allocation method has to be carefully motivated. Typically, LSPs use the GHG protocol (2011) to estimate the road transportation CO_2 emissions, based on estimates for emissions per ton-mile obtained from different databases (e.g., Department for Environment, Food and Rural Affairs (2012) and Environmental Protection Agency (2011), etc.). This factor is then multiplied by the total units transported (e.g. tons) and distance traveled (e.g. miles) to obtain the total CO_2 emissions of that trip. Once these emissions are estimated, the usual practice consists in allocating those emissions to each customer using the distance from the depot to the customer location, and the order size. Although this approach is easy to understand, we will show that it does not provide sufficient details on the operations (e.g., shipments, load utilization, empty return, etc.) and thus, it does not drive companies to reduce their CO_2 emissions.

Although recent studies explore the allocation of CO_2 emissions, the area is still scarce. Cadarso et al. (2010) present an allocation of CO_2 emissions for international freight transport, where they determine the proportion of pollutions linked to the fragmentation of production across different countries using the offshoring broad and narrow measures (imported intermediate inputs from all sectors or only from the own sector, respectively) from the input–output tables. Kellner and Otto (2012) study the CO_2 emissions allocation in freight transport by studying a simplified network, i.e. 3 destinations and 1 depot. The article presents a comparison of different allocation rules under a set of criteria. Zhu et al. (2014) study emission allocation in maritime logistics, and the study presents a framework that is tested with different created scenarios. Kellner (2016) study the CO_2 emissions allocation for road freight transport, by studying specific tours in transportation. The study argues that distance is the most useful unit to conduct allocation of emissions.

Although interesting insights are shown in these studies, to the best of our knowledge no article has been published dealing with more complex delivery operations, two or more depots, pickup and delivery activities and empty returns. In addition, all the studies have dealt with a set of created scenarios, and no case study with a real company has been analyzed.

Even though the allocation of CO_2 emissions in routing transportation has not been fully studied before, related methods can be found in the cost allocation literature. A cost allocation problem is understood as a cooperative game such that for a group of participants interested in collaborating in a specific project, the objective is to assign the total costs/benefits to each of the participants. A cost allocation problem is seen as a cooperative game because the participants are interested in the collaboration, i.e. the cost of the project if they collaborate is smaller than or equal to the cost of the project they would perform separately, i.e. sub-additivity property (Fiestras-Janeiro et al., 2011).